

Geologic Map of the Long Beach 30' x 60' Quadrangle, California

Version 2.0

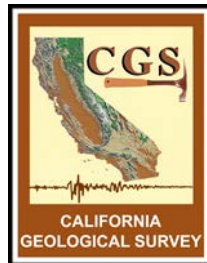
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Introduction

The Long Beach 30' x 60' quadrangle covers an area of approximately 5,300 km² of onshore and offshore southern California. The onshore portion of the quadrangle comprises about one-third of the area extending about 45 km in an east-west direction and about 40 km in a north-south direction. The onshore portion covers southern Los Angeles County and the northwestern corner of Orange County, a large part of the Los Angeles metropolitan area, second largest metropolitan area in the United States. Onshore areas include the Palos Verdes Peninsula, and part of the Los Angeles basin. Major cities in the area include Long Beach and southern parts of Los Angeles. Other cities include Whittier in the northeast corner of the map, Anaheim and Huntington Beach in the east and Torrance, Inglewood, and Redondo Beach to the west. The area also includes Los Angeles International Airport in the north and the ports of Los Angeles and Long Beach to the south. The offshore, Inner Continental Borderland, includes Santa Monica and San Pedro bays, Santa Monica and Redondo canyons, and parts of Santa Monica and San Pedro basins. Overall relief in the quadrangle ranges from 900 meters below sea level in the offshore Santa Monica and San Pedro basins to over 400 meters above sea level at San Pedro Hill and Workman Hill in the Palos Verdes Hills and Puente Hills, respectively. Residents and visitors to the area may be subject to potential hazards from earthquakes, debris flows and other types of landslides in the upland areas, floods, wildfires, subsidence from ground water and petroleum withdrawal, and swelling soils; and coastal areas are exposed to flooding and erosion by storm and tsunami waves. This geologic map is intended to illustrate the distribution of the rocks and surficial deposits of the area and their structural and stratigraphic relations to one another. It provides a regional geologic framework as an aid to better evaluations of the potential for hazard from active earth processes. As a digital product it includes some areas mapped in greater detail than others; however, it is not sufficiently detailed to serve as a basis for site-specific evaluations.

Sources of geologic mapping

The geologic map of the Long Beach 30' x 60' quadrangle has been through several iterations. The first, an analog compilation of the onshore area (Greenwood and Saucedo, 1993), was prepared under the USGS cooperative geologic mapping program - COGEOGMAP, the predecessor to STATEMAP. This version was never published or formally released. In 1997, when digital technology became the norm for geologic mapping projects, STATEMAP funds were obtained to transfer the analog Long Beach 30' x 60' geologic map into digital format (Bezore and others, 1997). During a meeting of the California Geologic Mapping Advisory Committee, where current and future mapping projects are discussed, it was recommended that geologic maps of the coastal 30' x 60' quadrangles should incorporate offshore geology. In 2002-2003 STATEMAP funds were used to compile version 1.0 of the digital geologic map of the Long Beach 30' x 60' quadrangle (Saucedo and others, 2003). This revision included the incorporation of offshore geology based in part on the mapping of Vedder and others (1986) and new interpretations of available imagery and geophysical data (Greene and Kennedy, 2003). In addition, updates and revisions to the Quaternary geology were made using studies by the California Geological Survey's Seismic Hazard Zonation Program in their evaluations for liquefaction hazards in the area.

This compilation, version 2.0 of the digital geologic map of the Long Beach 30' x 60' quadrangle, represents an update of the map by Saucedo and others (2003). It was prepared by the Department of Conservation, California Geological Survey (CGS) in cooperation with the Moss Landing

Marine Laboratories Center for Habitat Studies and was supported in part by the U.S. Geological Survey (USGS) National Cooperative Geologic Mapping Program, STATEMAP Award No. 02HQAG0018.

The map has been compiled from a number of scientific studies throughout the quadrangle, and represents the work of many geologists. The listing of sources of geologic mapping below includes geologic maps used in this compilation and reports describing the liquefaction zoning and earthquake-induced landslide zoning for each quadrangle. Although the Seismic Hazard Zone Reports referenced below are focused on the details of delineation of the hazard zones, virtually all reports resulted in revised mapping of some geologic units. Revised mapping of younger Quaternary units, including the contact between late Quaternary alluvium and bedrock, was a focus of the seismic hazard zoning effort because these contacts can define the boundaries of Liquefaction Hazard Zones. Quaternary units are designated using the terminology of Matti and Cossette (2007).

In version 2.0, modifications were made to provide continuity with the adjacent map compilations of the Los Angeles 30' x 60' quadrangle to the north (Campbell and others, 2014), and the Santa Ana 30' x 60' quadrangle to the east (Morton and Miller, 2006). Changes were made primarily to Quaternary units which included removal of the grain-size, sub-unit designations and their respective contacts shown on previous versions of this map. Also, new interpretations and additional detail were added to offshore Santa Monica Bay, west of the Palos Verdes Peninsula, and the San Pedro Shelf area. Landslides depicted in this version, were taken primarily from inventories prepared by the Seismic Hazard Zonation Program, with additional data taken from the source geologic maps. Due to the scale of this map, most small landslides and all landslides considered "questionable" in the original landslide inventories are not shown. CGS landslide inventory maps, and related 1:24,000-scale maps, show a more complete depiction of landslides. Landslides that are too small to show on 1:24,000-scale maps can be hazardous and damaging, so no regional map should be used to evaluate the landslide hazard to a particular location or parcel.

The major sources of mapping are listed below by the 7.5-minute quadrangles shown in Figure 1. Sources are underlined if they are a major source of geologic unit boundaries shown on this compilation. Seismic Hazard Zone (SHZ) Reports for each quadrangle are also listed, along with any landslide inventory maps that resulted from the Seismic Hazard Zonation Program, which are published as part of the CGS Landslide Inventory Map Series (LSIM).

Inglewood: California Division of Mines and Geology, 1986a; Castle, 1960a; Poland and others, 1959; Tinsley, unpublished; Weber and others, 1982.
SHZ Reports: Pridmore, 1998a; Silva, and Irvine, 1998a.

Long Beach: Bezore and others, 1997; California Division of Mines and Geology, 1986b; McNeilan and others, 1996; Poland, Piper, and others, 1956; Poland, 1959; Randell, and others, 1983; Tinsley, unpublished.
SHZ Reports: Greenwood, 1998a; McMillan and Haydon, 1998a.

Los Alamitos: Bryant, 1988; California Department of Water Resources, 1961; California Division of Mines and Geology, 1986c; Foster, 1996; Morton, and Miller, 1981.
SHZ Reports: Greenwood, 1998b.

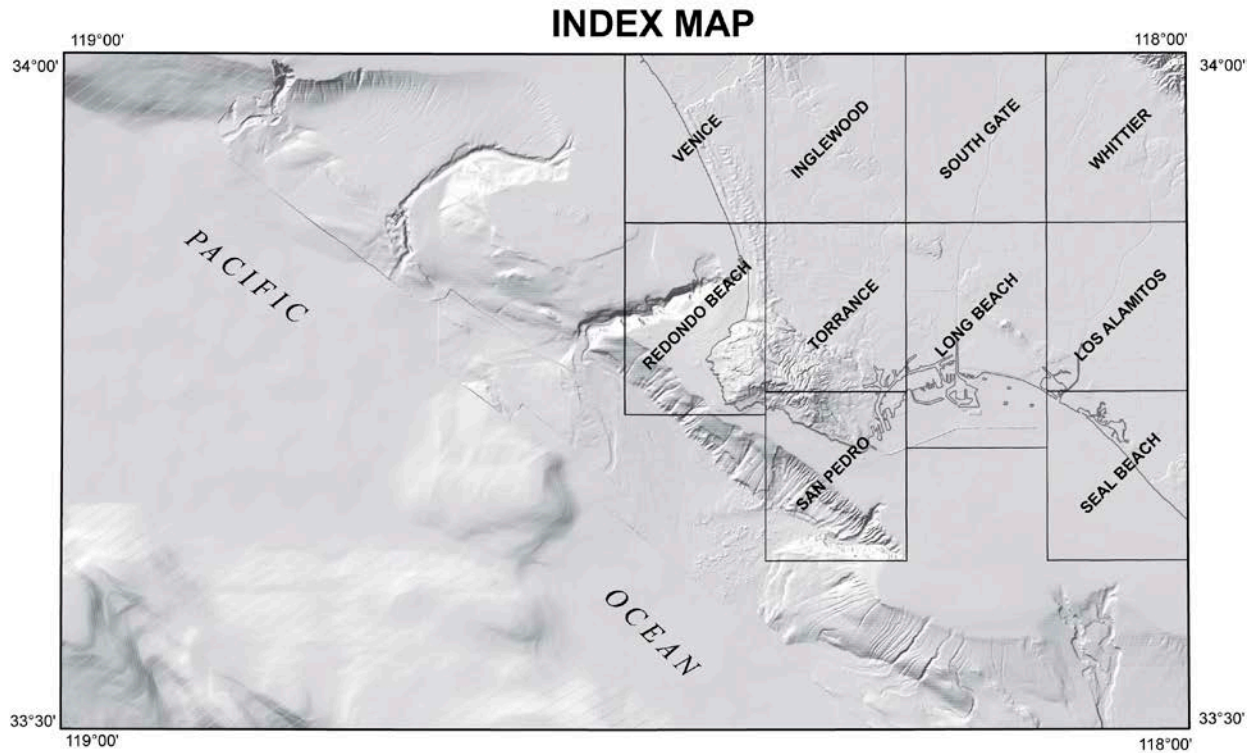


Figure 1. Index map of 7.5 minute quadrangles within the Long Beach 30'x60' quadrangle. DEM from U.S. Geological Survey

Redondo Beach: Bezore, 1997; Bezore and others, 1997; Cleveland, 1976; Tinsley, unpublished; Woodring and others, 1946.

SHZ Reports: Greenwood, 1998c; McMillan and Haydon, 1998b; LSIM Series: Haydon, 2007.

San Pedro: Bezore, 1997; Bezore and others, 1997; Bryant, 1987; Clarke and Kennedy, 1998; Cleveland, 1976; Darrow and Fisher, 1983; Goodman and others, 2015; McNeilan and others, 1996; Tinsley, unpublished; Woodring and others, 1946.

SHZ Reports: Greenwood, 1998d; McMillan and Haydon, 1998c; LSIM Series: Haydon, 2007.

Seal Beach: Bryant, 1988; California Division of Mines and Geology, 1986d; Foster, 1996; Poland, 1959.
SHZ Reports: Greenwood, 1998e; McMillan, 1998.

South Gate: Tinsley, unpublished.

SHZ Reports: Pridmore, 1998b.

Torrance: Bezore, 1997; Bezore and others, 1997; California Division of Mines and Geology, 1986e; Clarke and Kennedy, 1998; Cleveland, 1976; Freeman and others, 1985; Goodman and others, 2015; Poland and others, 1959; Stephenson and others 1995; Tinsley, unpublished; Woodring and others, 1946.

SHZ Reports: Greenwood, 1998f; McMillan and Haydon, 1998d; LSIM Series: Haydon, 2007.

Venice: Castle, 1960a,b; Eckis, 1934; Poland and others, 1959; Tinsley, unpublished; Weber and others, 1982.

SHZ Reports: Wills and others, 1998; Silva and Irvine, 1998b.

Whittier: Saucedo, 1999, Yerkes, 1960.

SHZ Reports: Pridmore, 1998c; Perez and others, 1998.

Offshore area: Greene and Kennedy, 2003; Vedder and others, 1986.

Geologic Summary

The Long Beach 30' x 60' quadrangle lies within the northwestern Peninsular Ranges geomorphic province which includes part of the Inner Continental Borderland of southern California, between 33°30' and 34° N. latitude and 118° and 119° W. longitude. Bounded on the north by the east-west trending mountain ranges and valleys of the Transverse Ranges, and on the east by the low-lying basin of the Colorado Desert, the Peninsular Ranges of southern California form a general northwest-trending geomorphic province that occupies the southwestern corner of California and extends southeastward to form the Baja California peninsula (Fig. 2). In general, the topography of the Peninsular Ranges is comparable to the Coast Ranges, but the geology is more like the Sierra Nevada, with granitic rock intruding the older metamorphic rocks. The Los Angeles basin and the southern Channel Islands (Santa Catalina, Santa Barbara, San Clemente, and San Nicolas islands), together with the adjacent continental shelf, are included in this province (California Geological Survey, 2002).

In general, the Peninsular Ranges province includes rocks that range in age from Quaternary to Paleozoic. Basement rocks include Jurassic and Cretaceous igneous rocks of the Peninsular Ranges batholith that intrude Triassic and Jurassic metasedimentary sequences. The western margin of the province contains large areas of Jurassic and Cretaceous prebatholithic and synbatholithic volcanic, metavolcanic, and metasedimentary rocks. Thick sequences of post-batholithic sedimentary and volcanic rocks of Upper Cretaceous and Tertiary age flank the older rocks on the west. The youngest deposits are marine, lagoonal, and fluvial sediments of Quaternary age that crop out discontinuously over the entire province. Dramatic series of emergent marine, wave-cut terraces and their overlying paralic sediments are common along the coastal margin of the province. These terraces, coupled with isotopic data, provide clear evidence of regional uplift during the past million years (Kennedy and Tan, 2007).

The geologic history of the Long Beach 30' x 60' quadrangle reflects the complex and diverse tectonic evolution of the California continental margin from a convergent margin to a transform boundary. Western North America was the site of a convergent margin during the Mesozoic and early Cenozoic when the Farallon Plate was actively being subducted eastward beneath the western edge of the North American Plate. Sometime during late Oligocene (~28 Ma) a portion of the East Pacific Rise collided with the subduction zone causing an interaction between the Pacific Plate and the North American Plate initiating development of the San Andreas transform fault system. Olson (2007) provides a comprehensive summary of the tectonic and stratigraphic evolution of the Los Angeles/Inner Borderland region of southern California relative to the Palos Verdes Peninsula.

Onshore Geology

Onshore, the sediment filled Los Angeles basin underlies the central part of the Long Beach 30' x 60' quadrangle and extends north and east and south onto the adjacent 30 x 60-minute quadrangles. The Los Angeles basin, along with the Ventura and San Fernando basins to the north, were the sites of very thick accumulations of marine sediments in late Miocene and Pliocene time. Sediments extend to a depth of more than 9,000 meters in the deepest part of the Los Angeles basin, close to where the Los Angeles and Rio Hondo rivers merge, near the city of South Gate (Yerkes and others, 1965). At present, the basin is an alluviated coastal plain bound on the north by the Santa Monica Mountains and the Elysian Park, Repetto, and Puente hills, and on the east and southeast by the Santa Ana Mountains and San Joaquin Hills. This lowland slopes gently to the south and west toward the Pacific Ocean but is interrupted by a series of elongated low hills and mesas to the south, and west and by the Palos Verdes Peninsula at the coast (Yerkes and others, 1965).

In the northeast corner of the quadrangle, the Puente Hills form part of the northern boundary of the Los Angeles basin. Here Miocene and Pliocene marine sediments of the Puente and Fernando formations have been complexly folded, faulted, and uplifted to form the present landscape. The Whittier fault passes through this portion of the quadrangle along the southwest side of the hills. Quaternary alluvial fan and valley deposits overlie the Tertiary strata and extend in a southwest direction.

Onshore, the most prominent topographic feature is the Palos Verdes Peninsula separating the Los Angeles basin from the offshore San Pedro Basin (Sorlein and others, 2013). The peninsula has undergone compressional deformation and has been described structurally as a doubly plunging anticlinorium. The Palos Verdes Peninsula is underlain primarily by middle Miocene to Pliocene sedimentary and volcanic rocks that are deposited unconformably on a metamorphic basement of pre-Late Cretaceous age Catalina Schist. The Catalina Schist, exposed only in a small area on the north slope of the peninsula, forms the core of the anticlinorium and consists of variety of schists (quartz-sericite, quartz-talc, and quartz-glaucophane schists) (Woodring and others, 1946; Yerkes and others, 1965). Unconformably overlying the schist is a thick sequence of marine sediments assigned to the Monterey Formation. Here the Monterey Formation is divided into three members based on lithology. From oldest to youngest they are the middle Miocene Altamira Shale (which underlies most of the peninsula), the upper Miocene Valmonte Diatomite, and the upper Miocene/lower Pliocene(?) Malaga Mudstone (Woodring and others, 1946). Although largely sedimentary, volcanic tuff and basalt are also found within the Monterey Formation. Altered olivine basalts in the Palos Verdes Hills underlie or are interbedded with the base of the Monterey Formation (Woodring and others, 1946). The basalts thin and wedge out on the northeast side of the peninsula between the Catalina Schist and the base of the Monterey Formation (McCulloh and others, 2002). Although they have not been dated radiometrically, an age of 15.5 Ma has been estimated for the basalts based on paleontological evidence (McCulloh and others, 2002). In addition, a K/Ar age of 14.9 ± 1.1 Ma was obtained from plagioclase in the Portuguese Tuff Bed of the Altamira Shale (Turner, 1970; recalculated by Stanley and others, 2000).

The Monterey Formation, in the Palos Verdes Peninsula, was deposited in a tectonically active basin within the California Inner Continental Borderland from middle Miocene to early Pliocene (Conrad and Ehlig, 1983). Lower Pliocene rocks in the Palos Verdes Peninsula unconformably overlie the Monterey Formation. These rocks, originally mapped as Repetto by Woodring and others, (1946) are included in the lower member of the Fernando Formation in this compilation. Upper Pliocene rocks, however, are absent in the peninsula likely a result of uplift, erosion and non-deposition between early

and late Pliocene (Henry, 1987). Unconformably overlying the Miocene and Pliocene deposits on the northeast side of the peninsula are Pleistocene deposits of the San Pedro Formation and Pleistocene to Holocene alluvial deposits that record the transition from marine to a nonmarine depositional environment.

As regional uplift continued, along with Pleistocene sea level fluctuations, the peninsula emerged from the sea leaving behind a series of marine terraces around what could be considered an island (Woodring and others, 1946). A series of 13 emergent marine terraces were identified with elevations ranging from near sea level to about 370 meters above sea level (Woodring and others, 1946). Ward and Valensise (1994) estimate an average rate of uplift for the peninsula at 0.40 to 0.72 mm/yr using the current elevation, age and depth of deposition of the lower Pliocene deposits (“Repetto Formation”). Terrace deposits found at an elevation of 40 to 50 meters and correlated with oxygen isotope stage 5e (125 ka) suggest an uplift rate of 0.3 to 0.4 mm/yr (Ward and Valensise, 1994). Landslides are a well known hazard in the Palos Verdes Peninsula. Most notable is the Portuguese Bend landslide complex on the southwest side of the peninsula. Wave erosion of seaward dipping beds at the base of the seacliffs, coupled with weak bentonitic clay beds in the Monterey Formation, provided the setting for major landsliding in the late Pleistocene and historically within the Palos Verdes Peninsula (Olson, 2007).

The geology of the Palos Verdes Peninsula reflects the complex tectonic evolution of the Los Angeles Basin – Inner Continental Borderland. Research continues in an effort to better understand the geologic history, structure, and tectonics of this region and how they relate to potential geologic hazards that might affect the entire Los Angeles area.

Offshore Geology

The offshore surficial geology of the Long Beach Quadrangle is composed predominantly of Quaternary sedimentary deposits. However, locally exposures of Mesozoic metamorphic rocks and Tertiary sedimentary and volcanic rocks have been mapped on the flat wave eroded shelves, on the slopes, and in submarine canyons and gullies.

Mesozoic Rocks

The oldest rocks mapped offshore are found at the base of the Santa Cruz-Santa Catalina Ridge in the SW corner of the Long Beach Quadrangle, as well as along the bedrock high in San Pedro Basin. Here, metamorphic rock exposures of pre-late Cretaceous age are mapped by Vedder and others (1986), which are locally covered with unconsolidated Quaternary sediment.

Tertiary Rocks

Tertiary rocks consisting primarily of Miocene sedimentary and volcanic rocks and Pliocene sedimentary rocks are mapped offshore. Undivided Miocene plutonic and hypabyssal rocks are mapped along the base of the Santa Cruz-Santa Catalina Ridge by Vedder and others (1986). Miocene sedimentary rocks are locally exposed on the San Pedro shelf, in the vicinity of the San Pedro Shelf segment of the Palos Verdes Cabrillo fault zones, and in the heads of submarine gullies at the southern edge of the shelf.

Undivided Miocene sedimentary and volcanic rocks locally crop out on the slope west of the San Pedro shelf, along the central Palos Verdes Peninsula slope, on the flat bedrock high in southern Santa Monica Bay, and on the Santa Monica Mountains slope in northern Santa Monica Bay. These rocks are

found exposed in the walls of lower Redondo Canyon, in the middle part of the Santa Monica Canyon, as well as in the head of Dume Canyon. They are also exposed as small isolated local outcrops on the distal shelf offshore of the Palos Verdes Peninsula.

Pliocene sedimentary rocks are locally exposed on the seafloor along the eastern side of the San Pedro Shelf segment of the Palos Verdes fault zone, along the slope south of the San Pedro shelf, and along the central and northern Palos Verdes Peninsula slope. Locally, Pliocene sedimentary rocks are mapped in the upper walls of the lower Redondo Canyon and the upper part of Dume Canyon.

Pliocene to Pleistocene marine terrace deposits are mapped in the nearshore areas of the western and northern Palos Verdes Peninsula shelf and in the vicinity of the northern head of Redondo Canyon on the southern Santa Monica Bay shelf. In addition, a bedrock exposure of these terrace deposits is mapped on the bedrock high in San Pedro Basin.

Quaternary Sedimentary Deposits

Undivided Pleistocene deposits are mainly restricted to the mid and nearshore areas of the San Pedro Shelf and Santa Monica Bay. A lens-shaped deposit extends out onto the shelf from San Pedro Point where it is generally restricted between the Palos Verdes and Cabrillo fault zones. To the north, in the NW corner of the quadrangle, these deposits have also been mapped along the Santa Monica Mountains slope.

Quaternary (Pleistocene & Holocene) landslide and submarine fan deposits have been mapped and are primarily concentrated within the central part of the Long Beach Quadrangle. A major landslide scar (rockfall) is located on the steep and heavily gullied slope offshore of southern Palos Verdes Peninsula, while a landslide deposit (of debris flow and block glides) is located on the gentle slope of the San Pedro Basin at the toe and west of the scarp. Many smaller landslides have been mapped along the Palos Verdes Peninsula slope north of the rockfall, the lower slope west and east of the rockfall, offshore of the San Pedro shelf, and on the southern part of the Redondo Canyon fan. In addition, many small landslides are mapped in the submarine canyons and gullies, especially in the lower and headward parts of Redondo Canyon and in the middle part of the Santa Monica Canyon. An extensive Quaternary submarine fan is mapped at the mouth of Redondo Canyon. These deposits appear to abut the northern fault controlled bedrock high scarp mapped in San Pedro Basin, which forces the sediments to spread either to the north or south. The active fan channel appears to be directing the modern day sediments to the north.

Holocene marine sedimentary deposits are the predominant surficial substrate type found in the offshore Long Beach Quadrangle. These deposits range from unconsolidated shelf, flank (slope), basin, ridge, and canyon sediments to gully and canyon fill, and overbank deposits. These are clastic and organic marine deposits that cover Tertiary bedrock and fill depressions, gullies and canyons.

Faults

The area within the Long Beach 30' x 60' quadrangle remains tectonically and seismically active and includes parts of several major, northwest-trending, oblique, right-lateral, strike-slip, fault zones that characterize the Pacific-North American plate boundary. From east to west they include the Whittier fault along the northeastern corner of the quadrangle, the Newport-Inglewood-Rose Canyon fault zone (source of the March 1933, Mw 6.4, Long Beach earthquake), the Palos Verdes fault zone, the Cabrillo fault, the San Pedro Basin fault zone, and the Santa Cruz-Santa Catalina Ridge and San Clemente fault zones in the

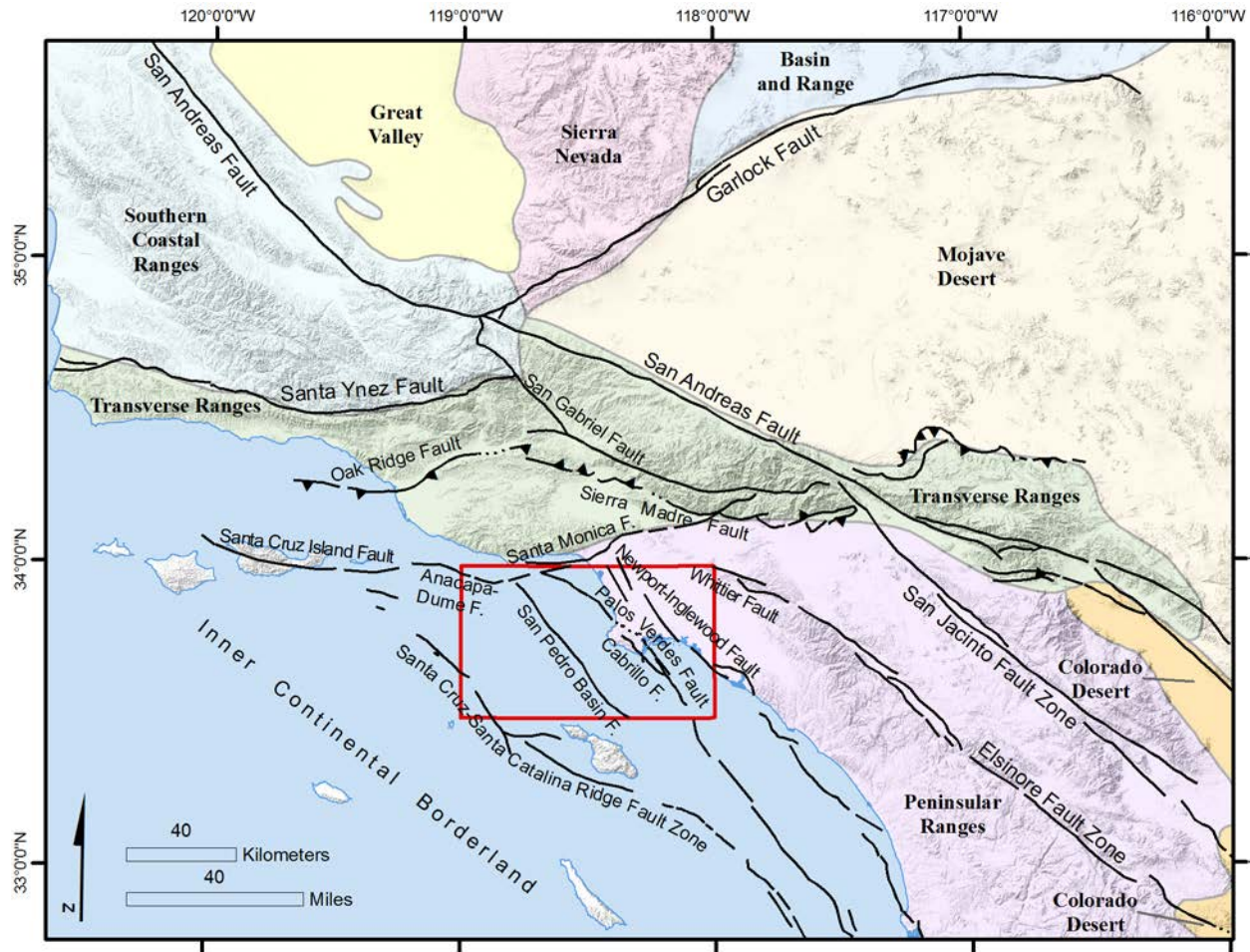


Figure 2. Area of the Long Beach 30' x 60' quadrangle in reference to geomorphic provinces and major faults of southern California.

southwestern corner of the map (Fig. 2). The Newport-Inglewood-Rose Canyon fault zone, and the offshore Palos Verdes and San Pedro basin fault zones, as well as other northwesterly trending faults in the Peninsular Ranges Province, appear to be truncated by an east-west zone of interconnected faults which includes the Anacapa-Dume fault along the northwestern edge of the quadrangle and the Santa Monica fault a few kilometers to the north of the northern boundary of the quadrangle. The Anacapa-Dume fault is also considered to be the southern boundary of Transverse Range structures west of Santa Monica.

In addition to the numerous seismic hazards in the area, the rapid uplift of relatively weak sedimentary rocks in the upland areas has led to an abundance of landslides in the western and offshore parts of the quadrangle. Tsunami hazard zones also exist along the coastal margin.

Onshore Faults

Whittier Fault

The Whittier fault is a prominent structural feature in the eastern Los Angeles basin. It is considered the northernmost section of the Elsinore fault zone, a major right-lateral shear system, parallel

to the southern San Andreas fault, that accommodates about 5 mm/yr of the Pacific-North American plate boundary slip. Only a short segment extends along the southwest side of the Puente Hills in the northeast corner of the quadrangle. The Whittier fault is considered to be active based on evidence for Holocene surface displacement in the Whittier Quadrangle and to the northwest and southeast. (Treiman, 1991; Treiman and Lundberg, 1998a).

Newport-Inglewood-Rose Canyon Fault Zone (North and South Los Angeles Basin Sections)

The Newport-Inglewood-Rose Canyon fault zone traverses the quadrangle. The Newport-Inglewood fault zone consists of a series of northwest-trending, generally right-lateral strike-slip faults. Individual faults at or near the surface within the zone form short, discontinuous, generally left-stepping en echelon patterns. Associated northwest to west-trending, right-stepping anticlinal folds and numerous short subsidiary normal and reverse faults form what has been termed the Newport-Inglewood structural zone (Barrows, 1974 in Bryant, 1988). Aligned hills and mesas within the structural zone include Bolsa Chica Mesa, Signal Hill, Dominguez Hills, Rosecrans Hills, and the Baldwin Hills (Barrows, 1974). This fault zone is a major structural element within the Peninsular Ranges separating contrasting Mesozoic basement terrane-Catalina Schist on the west and metasediments, intrusives and volcanics to the east (Yerkes and others, 1965). A Holocene to late Pleistocene age has been determined for traces within the quadrangle with a slip rate of about 1.0 mm/yr (Treiman and Lundberg, 1999a,b).

Palos Verdes Fault Zone (Palos Verdes Hills Section)

The Palos Verdes fault zone is mapped both offshore and onshore in the quadrangle and consists of three sections, from north to south they are; the Santa Monica Basin, Palos Verdes Hills, and the San Pedro Shelf sections (Treiman and Lundberg, 1998b). The Palos Verdes fault zone is approximately 73 km in total length. The southern San Pedro Shelf section trends northwesterly across the upper slope and shelf for a distance of roughly 30 km where it connects to the onshore Palos Verdes Hills section. Here the fault heads in a more westerly direction for about 12 km through the peninsula where it connects with the Santa Monica Basin section. This section, the most northerly segment, continues on trend for an additional 32 km where it is truncated by the Anacapa-Dume fault.

The Palos Verdes Hills section trends northwesterly through the peninsula and is largely concealed by landslides, colluvium, and slopewash, with its location inferred from topographic and geomorphic features along the northeast margin of the Palos Verdes Hills (Treiman and Lundberg, 1998b). Goodman and others (2015) estimate the Palos Verdes fault zone to be about 2,000 meters wide and consisting of three principal strands, collectively defining a steep asymmetric flower structure. The dip and style of faulting changes progressively to the northeast (Goodman and others, 2015). In general the fault is a southwest-dipping, high-angle dextral oblique fault with a reverse component that forms the southwestern boundary of the Los Angeles basin with the Palos Verdes uplift (Treiman and Lundberg, 1998b). Holocene activity is recognized for the southern offshore San Pedro Shelf section while late Quaternary (<15 ka) and possible Holocene activity is estimated for the Palos Verdes Hills section. A slip-rate of between 1.0 and 5.0 mm/yr is suggested for this section (Treiman and Lundberg, 1998b).

Cabrillo Fault

The Cabrillo fault includes an onshore and offshore segment that extends about 21 km in total length. The fault is considered to be a splay of the San Pedro Shelf section of the Palos Verdes fault zone that takes on a more westerly trend extending from mid-shelf onto the Palos Verdes Peninsula. Offshore the fault location is based on geophysical imaging of a “zone of disruption” up to 500 m wide (Treiman and Lundberg, 1998c,d). The onshore fault segment is about 10 km in length and trends northwesterly across the Palos Verdes Hills. Here the fault trace is not well defined and is based on discontinuous exposures and geomorphic features mapped by various workers (Woodring and others, 1946; Cleveland, 1976; Bryant and Raub, 1986). The fault exhibits normal, east side down displacement with a probable dextral component (Treiman and Lundberg, 1998c). Holocene activity is recognized for the offshore segment while late Quaternary (<130 ka) activity is reported for the onshore segment with a suggested slip-rate of between 0.2 and 1.0 mm/yr (Treiman and Lundberg, 1998c,d).

Offshore Faults

Three major NW-SE trending fault zones are mapped in the offshore of the Long Beach Quadrangle; the Palos Verdes, San Pedro Basin, and Santa Cruz-Santa Catalina Ridge fault zones. With the exception of the Santa Cruz-Santa Catalina Ridge fault zone, these fault zones extend from the south and end south of, or are terminated in the north by splays of the Malibu Coast fault zone. A fourth fault zone, unnamed faults at the base of the Palos Verdes Peninsula slope, has also been mapped solely within the quadrangle. These fault zones are briefly described below from south to north:

Palos Verdes Fault Zone

The Palos Verdes fault zone is mapped both offshore and onshore and consists of three segments, all of which cut strata of Holocene age offshore; the San Pedro Shelf segment, Palos Verdes Hills segment, and the Santa Monica Basin segment. Offshore the San Pedro shelf segment is mapped as an approximately located fault zone, which trends NW-SE (generally N30°W) from the south across the upper slope and across the shelf for a distance of approximately 33 km where it connects to the onshore Palos Verdes Hills segment. Two primary strands in the south and multiple en echelon strands in the north characterize the San Pedro Shelf segment. An inferred horse-tail splay of the San Pedro Shelf segment of the Palos Verdes Hills fault zone extends from near the middle part of the fault zone located at mid-shelf, and which extends in a more westerly direction (~N50°W) as the well-located Cabrillo fault zone that similarly to the San Pedro Shelf segment extends onshore into the Palos Verdes Peninsula. Offshore these fault zones bound a subtle flat outcrop of undivided Miocene sedimentary bedrock locally covered by Pleistocene sedimentary deposits. To the east of the San Pedro Shelf segment several well-located faults trending parallel to the segment are mapped along the San Pedro Shelf flank (southern slope) within the San Pedro canyon/gully complex and cut strata of Holocene age. Further to the east on the shelf, several approximately located short en echelon faults, one of which cuts Holocene strata, are mapped, and represent the northern extension of the THUMES-Huntington Beach fault zone.

In Santa Monica Bay, the Santa Monica Basin segment of the Palos Verdes fault zone is mapped as a NW-SE (~N60°W) trending fault that extends approximately 37 km from its onshore connection to the Palos Verdes Hills segment at the southern bight of the Bay to the Santa Monica Mountain slope in the north. The northern end of this segment abuts or is truncated by the offshore splays of the Malibu Coast fault zone. In central Santa Monica Bay, this segment of the Palos Verdes fault zone crosses the

Santa Monica Canyon where it appears to control the right-lateral channel axis offset at the head of the gully. East of the Santa Monica Basin segment of the Palos Verdes fault zone a series of parallel to sub-parallel approximately located normal faults lie to the NE, and are sub-parallel to the trend of the Palos Verdes fault zone. To the SW of this series of faults, an extensive outcrop of undivided Miocene sedimentary bedrock is found bounded by the Santa Monica Basin segment of the Palos Verdes fault zone, which cuts Pleistocene strata, and another shorter but parallel fault along the SW margin of the outcrop.

In southern Santa Monica Bay, in the vicinity of Redondo Canyon, two faults in close proximity to the Palos Verdes fault zone appear to influence the canyon's morphology and cut strata of Holocene age. Near the head of the canyon, west of, and parallel to the Santa Monica Bay segment of the Palos Verdes fault zone a short (~6.5 km long) well-located fault crosscuts the canyon where a distinct canyon axis meander exists. The other fault is obliquely oriented to the first fault having a general E-W trend, and extends from deep in the Santa Monica Bay bite near shore across the shelf and into the lower part of Redondo Canyon where it appears to control the orientation of the canyon axis. Along the northern margin of the Santa Monica Bay, at the base of the Santa Monica Mountains, a curvilinear fault zone extends westward from the shelf where it is mapped as cutting strata of Holocene age and truncates the Palos Verdes fault zone. This fault zone continues obliquely across the slope, and across the Dume Canyon where it appears to control a major axial meander. This fault zone is part of the Malibu Coast fault zone that extends from onshore forming the northern margin of the Santa Monica Bay, and extends out into the northern part of the Santa Monica Basin where it cuts strata of Pleistocene age.

A possible splay of the Palos Verdes fault zone is mapped at the base of Palos Verdes Peninsula slope, along the inflection point between the relative steep slope to the east and the more gently sloping to flat lying San Pedro Basin to the west. Here, between the shelf break and the fault, the slope is characterized by a dense concentration of gullies, a major rockfall, and other landslides. This fault is oriented parallel to the Santa Monica Basin segment of the Palos Verdes fault zone and appears to obliquely splay from the San Pedro Shelf segment of the fault zone along the southern San Pedro shelf where it controls the orientation of a more E-W trending gully.

San Pedro Basin Fault Zone

The San Pedro Basin fault zone is mapped as an approximately located structure consisting of several en echelon fault strands that trend NW-SE (~N40°W) and cuts strata of Pleistocene age. This structure extends from the southern edge of the mapped area within the San Pedro Basin offshore (west) of the San Pedro shelf to the southern margin of the Santa Monica Basin where it appears to merge at the intersection of the Santa Monica Canyon with the inferred most southerly splay of the Palos Verdes fault zone mapped at the base of the Palos Verdes Peninsula slope. This fault zone steps to the right and continues northward as one fault trace to where it terminates near the Santa Monica Mountain fault zone in the vicinity of Dume Canyon. This fault zone truncates a Miocene volcanic rock high in San Pedro Basin that constricts the westward propagation of sediments debouching from the mouth of Redondo Canyon. Near the intersection of the San Pedro Basin fault zone and the inferred southern splay of the Palos Verdes fault zone several short generally E-W oriented faults have been mapped. These faults are approximately located and cut strata of Pleistocene age within the Santa Monica Basin.

Santa Cruz-Santa Catalina Ridge Fault Zone

Further offshore, and restricted to the SW corner of the map sheet, the Santa Cruz-Santa Catalina Ridge fault zone as mapped by Vedder and others (1986) is composed of two sets of NW-SE ($\sim N40^{\circ}W$ and $\sim N25^{\circ}W$) trending faults. These faults generally displace Tertiary undifferentiated sedimentary and volcanic rocks and one cuts strata of Holocene age.

Description of map units

The arrangement of geologic units on the map sheet illustrates the relative correlation of map units between the onshore and offshore areas. The map area covers the northwestern part of the Peninsular Ranges physiographic province and the adjacent offshore area which includes rocks commonly associated with the Inner Continental Borderland of southern California. The majority of the units on this map have been adopted from the source maps used in compilation.

Map labels are abbreviations that indicate age and origin of surficial deposits, or age and formally recognized names of formations and members. Where stratigraphic assignment is tentative, a query (?) is added to the label in the database. Where informal subunits are represented by subscripted numbers, numbers increase with decreasing age (i.e., of subunits 1-3, 3 is the youngest and 1 is the oldest). Quaternary deposits are found throughout the map area and are commonly associated with distinctive geomorphic features such as fans, flood plains and terraces.

Onshore Units

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.
- Qa **Alluvium (late Holocene)**—Active and recently active alluvial deposits along canyon floors. Consists of unconsolidated sandy, silty, or clay-bearing alluvium.
- Qw **Wash deposits (late Holocene)**—Unconsolidated deposits of silt, sand, and gravel in active and recently active washes; artificially channelized in part.
- Qb **Beach deposits (late Holocene)**—Unconsolidated beach deposits consisting of well-sorted, fine- to coarse-grained sand. Locally may include talus.
- Qe **Eolian deposits (late Holocene)**—Unconsolidated deposits of very well sorted, fine- to medium-grained sand. Gradational into older eolian deposits.
- Qpe **Paralic estuarine deposits (late Holocene)**—Unconsolidated deposits of loose to moderately dense fine-grained sand, silt, and clay.

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 alluvium, undivided (Holocene and late Pleistocene)**—Poorly consolidated, poorly sorted, permeable flood-plain deposits consisting of soft clay, silt and loose to moderately dense sand and silty sand.

- Qya₃ **Young alluvium, Unit 3 (Holocene and late Pleistocene)**—Poorly consolidated, poorly sorted, permeable flood-plain deposits consisting of soft clay, silt and loose to moderately dense sand and silty sand.
- Qya₂ **Young alluvium, Unit 2 (Holocene and late Pleistocene)**—Poorly consolidated, poorly sorted, permeable flood-plain deposits consisting of soft clay, silt and loose to moderately dense sand and silty sand.
- Qya₁ **Young alluvium, Unit 1 (Holocene and late Pleistocene)**—Poorly consolidated, poorly sorted, permeable flood-plain deposits consisting of soft clay, silt and loose to moderately dense sand and silty sand.
- Qyf **Young alluvial fan deposits, undivided (Holocene and late Pleistocene)**—Poorly consolidated and poorly sorted clay, sand, gravel and cobble alluvial fan and valley deposits.
- Qyf₂ **Young alluvial fan deposits, unit 2 (Holocene and late Pleistocene)**—Four distinct, gently sloping fan-shaped deposits overlying unit 1. Composed of poorly to moderately consolidated and poorly sorted clay, silty clay and sand.
- Qyf₁ **Young alluvial fan deposits, unit 1 (Holocene and late Pleistocene)**—Gently sloping, slightly dissected alluvial fan deposits apron northeast of the Palos Verdes uplands. Composed of poorly to moderately consolidated and poorly sorted silty clay and sand.
- Qye **Young eolian deposits (Holocene and late Pleistocene)**—Unconsolidated eolian deposits consisting of fine- and medium-grained sand.
- Qype **Young paralic estuarine deposits (Holocene and late Pleistocene)**—Unconsolidated deposits of fine-grained sand and clay.
- Qls **Landslide deposits (Holocene and Pleistocene)**—Only selected landslide deposits shown on this map as described below. Deposits represent rock detritus from bedrock and surficial materials, broken in varying degrees from relatively coherent large blocks to disaggregated small fragments, deposited by landslide processes. Most mapped landslides include scarp area as well as slide deposit. In some areas the scarp is shown separately with pattern. Most deposits are Holocene, some dissected landslides may be as old as late Pleistocene. Many Pleistocene age landslides were reactivated in part or entirely during late Holocene. For this map, only landslides described as definite or probable and larger than 50,000 square meters are shown to preserve the clarity of the underlying bedrock geology. Selected historically active landslides between 10,000 and 50,000 square meters are shown, but no landslides smaller than 10,000 square meters are shown on this map. Exceptions to these rules include small or questionable landslides surrounded by larger probable or definite landslides.

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 alluvium, 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. Includes stream terrace deposits in the Torrance quadrangle.

- Qof Old alluvial fan deposits, undivided (late to middle Pleistocene)**—Moderately to well consolidated, moderately sorted sand, clay, and silt.
- Qoe Old eolian deposits (late to middle Pleistocene)**—Poorly consolidated eolian deposits of dense to very dense, well-sorted, fine- to coarse-grained sand and silty sand.
- Qom Old shallow marine deposits on wave-cut surface (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. Locally may include older alluvium.

Very Old Surficial Deposits

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 alluvium, 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. Includes reddish-brown, well-cemented and resistant silty sands, locally pebbly and gravelly in the Baldwin Hills.
- Qvof Very old alluvial fan deposits, undivided (middle to early Pleistocene)**—Consists of well-dissected, well-indurated, reddish-brown sand and gravel deposits on alluvial fans.

Sedimentary and Volcanic Bedrock Units

Qlh La Habra Formation (late Pleistocene)—Siltstone, thick-bedded friable sandstone, pebbly sandstone, and pebble-cobble conglomerate; locally abundant clasts of platy white siltstone.

San Pedro Formation (early Pleistocene)—Consisting of:

- Qsp San Pedro Formation, undivided**—Poorly consolidated fine- to coarse-grained sand and silty sand interbedded with thin beds and lenses of gravel. Marine. Also includes fluvial sand and gravel with local beds of clayey-silt in the Baldwin Hills.
- Qspt Timms Point Silt Member**—Dense sandy silt and silty sand.
- Qspl Lomita Marl Member**—Marl and calcareous sand and gravel.
- QTi Inglewood Formation (late Pliocene to early Pleistocene)**—Well bedded siltstone with interlayered beds of very fine-grained sandstone; locally abundant calcareous and limonitic con-cretions. Marine.

Fernando Formation (Pliocene and Pleistocene)—Consisting of:

- QTfu Upper Member**—Massive friable silty and pebbly sandstone interbedded with thin beds of siltstone, massive pebble conglomerate at base; locally abundant angular chips of platy white siltstone. Locally contains limy concretions.

- QTfl Lower Member**—Massive silty sandstone with interbedded pebbly sandstone and conglomerate.
- QTflc** Basal conglomerate contains locally abundant angular chips of platy white siltstone. **QTflc** – conglomerate and sandstone interbedded with **QTfl**. Includes rocks mapped as Repetto in the Torrance quadrangle by Woodring and others, 1946.

Puente Formation (upper Miocene)—Consisting of:

- Tpnsc Sycamore Canyon Member**—Sandstone with interbedded pebble-cobble conglomerate and sandy siltstone. **Tpnsc** – pebble-cobble conglomerate and pebbly sandstone interbedded with **Tpnsc**.
- Tpny Yorba Member**—Platy diatomaceous siltstone with interbeds of sand-stone, limestone and marl.
- Tpnsq Soquel Member**—Thick-bedded to massive graded sandstone and siltstone; local lenses of pebble-cobble conglomerate in upper part.
- Tpnlv La Vida Member**—Laminated to platy siltstone with interbedded pebbly sandstone; limestone and altered tuff beds in lower portion.

Monterey Formation (middle and upper Miocene to Pliocene(?))—Consisting of:

- Tmm Malaga Mudstone Member**—Radiolarian mudstone and diatomite.
- Tmvd Valmonte Diatomite Member**—Diatomaceous shale, mudstone, and diatomite with beds and lenses of hard, resistant silicified limestone and shale and resistant zones of chert.
- Tmv Volcanic rocks within the Monterey Formation* (middle Miocene)**—Consists of basalt, andesite, volcanic breccia, and tuff breccia; mainly or completely intrusive.
- Tma Altamira Shale Member**—Siliceous shale, silty and sandy shale, cherty shale, chert, siltstone, bituminous shale, diatomaceous shale, diatomite, phosphatic shale, tuffaceous shale, limestone, sandstone, conglomerate, breccia, and silicified limestone and shale.

Metamorphic Bedrock Units

- mcs Catalina Schist (pre- late Cretaceous)**—Consists of quartz-chlorite schist, quartz-sericite schist, and quartz-glaucophane schist.

Offshore Units

- Qms Unconsolidated shelf sediment (late Holocene)**—Deposits of unconsolidated sand and silt on the shelf.
- Qmfl Unconsolidated flank sediment (late Holocene)**—Deposits of mud on the slope.
- Qmb Unconsolidated basin sediment (late Holocene)**—Deposits of mud on the basin floor.
- Qmr Unconsolidated ridge sediment (late Holocene)**—Deposits of mud on the ridge.
- Qmc Unconsolidated canyon sediment (late Holocene)**—Deposits of mud on the canyon walls.
- Qgf Gully fill (late Holocene)**—Deposits of mud in gullies.
- Qcf Canyon fill deposits (late Holocene)** —Unconsolidated deposits of mixed gravel, sand, and mud on the canyon floor.

- Qol Overbank levee deposits (Holocene and Pleistocene)**—Deposits of mud and sand.
- Qmf Fan deposits (Holocene and Pleistocene)**—Deposits of gravel, sand, and mud at base of slope at mouths of submarine canyons and gullies.
- Qls Landslide deposits (Holocene and Pleistocene)**—Highly fragmented to largely coherent landslide deposits. Unconsolidated to moderately well-consolidated. Most mapped landslides include scarp area as well as slide deposit. In some areas the scarp is shown separately with pattern. Many Pleistocene age landslides were reactivated in part or entirely during late Holocene. In the offshore region preponderance of landslides found in submarine canyons.
- Qps Pleistocene sedimentary deposits, undivided (Pleistocene)**—Deposits of mostly unconsolidated sand in nearshore areas of continental shelf.
- QTmt Plio-Pleistocene terrace deposits (Pliocene and Pleistocene)**—Deposits of unconsolidated gravel and sand on low-stand erosional platforms.
- Tps Pliocene sedimentary rocks, undivided* (Pliocene)**—Sandstone and silt-stone, heavily gullied where mapped on the slope.
- Tmu Tertiary sedimentary and volcanic rocks, undivided* (Tertiary)**—Sandstone, mudstone, and volcanic rocks found on the outer banks.
- Tmp Miocene plutonic and hypabyssal rocks, undivided* (Miocene)**—Plutonic and hypabyssal rocks found on the outer banks.
- Tmms Miocene sedimentary rocks, undivided* (middle and upper Miocene)**—Predominantly diatomaceous mudstones of the Monterey Formation. **Tmmv** – volcanic rocks mostly within the Monterey Formation.
- ms Metamorphic rocks of pre- Late Cretaceous age* (Jurassic - Cretaceous)**—Mainly rocks of the Franciscan Complex.

* Q/ = Map unit overlain by more than 3 meters of unconsolidated Quaternary sediment.

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