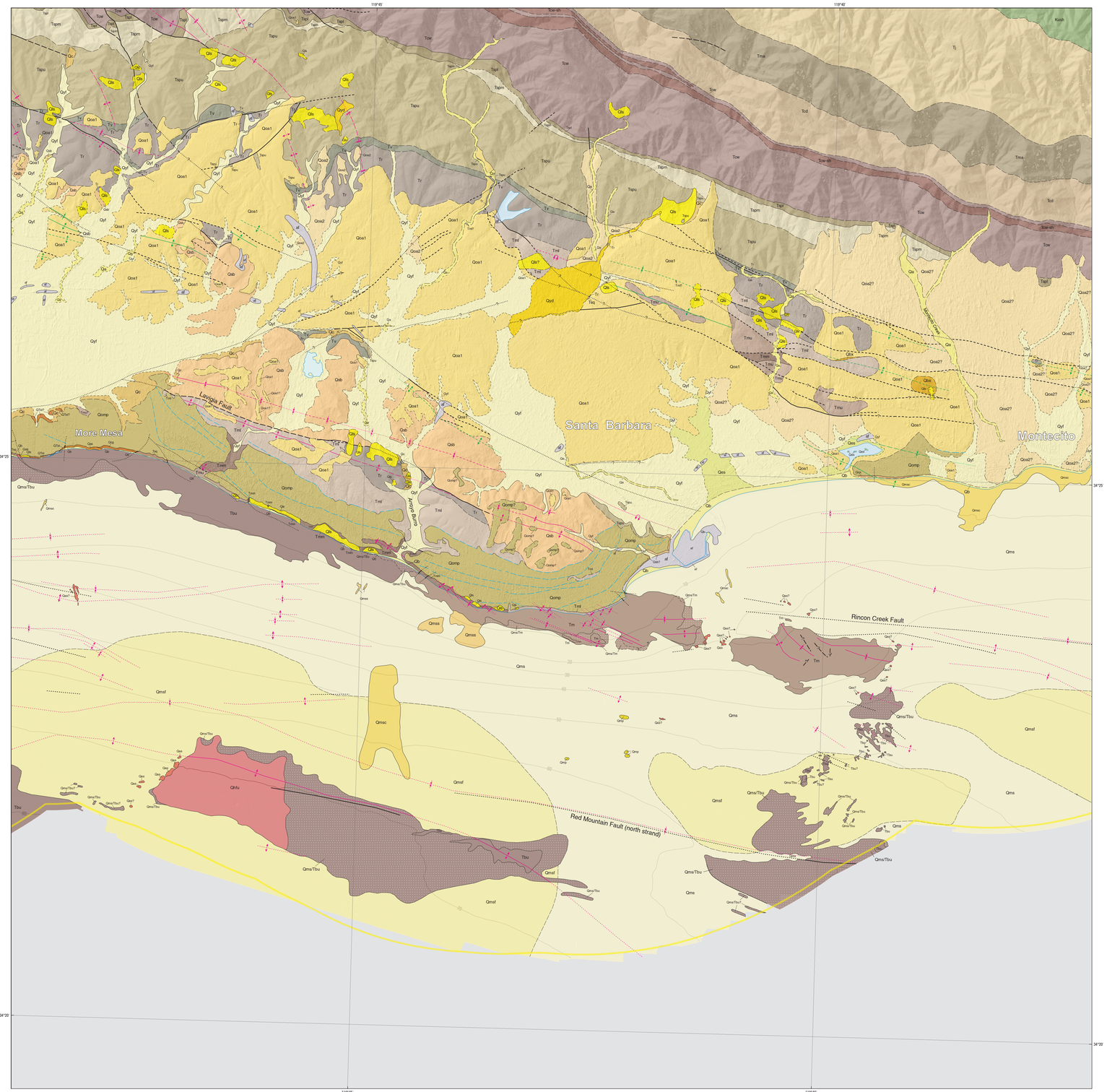
U.S. Department of the Interior
U.S. Geological Survey

Scientific Investigations Map 3281
Sheet 10 of 11
Pamphlet accompanies map



SCALE 1:24 000

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 0 1 KILOMETER

BATHYMETRIC CONTOUR INTERVAL 10 METERS

ONE MILE = 0.869 NAUTICAL MILES

APPROXIMATE MEAN DECLINATION, 2013

MAP LOCATION

Onshore elevation data from NOAA Coastal Services Center (data collected by EarthData International in 2002-2003) and from U.S. Army Corps of Engineers (data collected by Fugro Pelagos in 2009). Offshore shaded-relief bathymetry from map on sheet 2, this report. California's State Waters limit from NOAA Office of Coast Survey

Universal Transverse Mercator projection, Zone 11N

NOT INTENDED FOR NAVIGATIONAL USE

Offshore geology and geomorphology mapped by Samuel Y. Johnson, Andrew C. Ritchie, and Jamie E. Conrad, 2010-2011. Onshore geology and geomorphology compiled by Gordon D. Seitz and Carlos I. Gutierrez from Dibblee (1986a,b) and Minor and others (2010). Bathymetric contour intervals by Andrew C. Ritchie

GIS database and digital cartography by Andrew C. Ritchie and Eleyne L. Phillips

Edited by Taryn A. Lindquist

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Offshore and Onshore Geology and Geomorphology, Offshore of Santa Barbara Map Area, California

By

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2013

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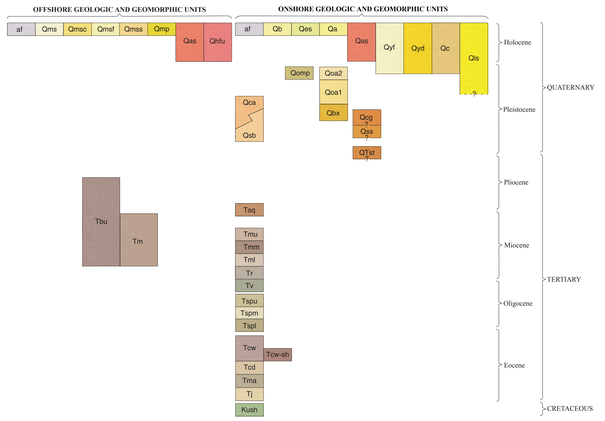
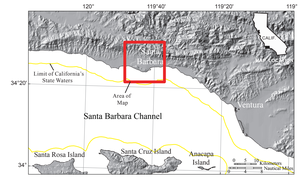
CORRELATION OF MAP UNITS

[See Description of Map Units (chapter 8, in pamphlet) for precise unit ages]





LIST OF MAP UNITS

[See Description of Map Units (chapter 8, in pamphlet) for complete map-unit descriptions]

OFFSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Note that composite units (gray-stippled areas) are designated on map by composite label indicating both overlying sediment cover and lower (older) unit, separated by slash (for example, Qms/Tm indicates that thin sheet of Qms overlies Tmu)]

- af — **Artificial fill (late Holocene)**—Rock, sand, and mud; placed and (or) dredged. Also includes seafloor substantially modified by human activity
- Qms — **Marine nearshore and shelf deposits (late Holocene)**—Mostly sand; ripples common
- Qmsc — **Coarse-grained marine nearshore and shelf deposits (late Holocene)**—Predominantly sand, gravel, and boulders
- Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Mostly mud to muddy sand
- Qmss — **Marine shelf scour depressions (late Holocene)**—Inferred to be coarse sand and gravel, in low-relief scours
- Qmp — **Marine pockmarks (late Holocene)**—Sand and mud, in circular to elliptical pockmarks
- Qas — **Asphalt deposits (Holocene)**—Asphalt (tar) derived from natural hydrocarbon seeps
- Qhfu — **Mixed hydrocarbon-seep-related features and marine deposits (Holocene)**—Probably includes mixed and coalescing mounds, pockmarks, carbonate mats, and mud volcanoes and cones
- Tbu — **Bedrock, undivided (Pliocene and Miocene)**—Undivided strata of the Pico, Sisquoc, and Monterey Formations
- Tm — **Monterey Formation (Miocene)**—Predominantly well-bedded siliceous and calcareous mudstone and shale

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units are compiled from Dibblee (1986a,b) and Minor and others (2009); unit ages, which are from these sources, reflect local stratigraphic relations]

- af — **Artificial fill (late Holocene)**—Engineered and (or) nonengineered
- Qb — **Beach deposits (late Holocene)**—Unconsolidated, loose, fine- to coarse-grained sand; well sorted
- Qes — **Coastal-estuarine deposits (late Holocene)**—Locally organic-rich clay, silt, and subordinate sand
- Qa — **Channel alluvium (late Holocene)**—Unconsolidated sediments, primarily pebble to boulder gravel
- Qas — **Asphalt deposits (Holocene)**—Black asphalt (tar) derived from nearby natural hydrocarbon seeps
- Qyf — **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Poorly consolidated silt, sand, and gravel deposits, in modern drainages and piedmont alluvial fans and floodplains
- Qyd — **Debris-flow deposits (Holocene and late Pleistocene)**—Massive, weakly consolidated rock-debris breccia
- Qc — **Colluvium (Holocene and late Pleistocene)**—Poorly consolidated, poorly stratified, and poorly sorted sediments; formed by weathering and downslope movement of bedrock debris
- Qls — **Landslide deposits (Holocene to middle Pleistocene)**—Ranges from poorly sorted and disrupted mixtures of rock fragments and soil to relatively intact bedrock slump blocks
- Qomp — **Marine-terrace deposits (late Pleistocene)**—Marine, fossiliferous gravel, sand, and silt
- Qoa2 — **Alluvial deposits (late Pleistocene)**—Stratified silt, sand, and gravel
- Qoa1 — **Older alluvial deposits (late and middle Pleistocene)**—Crudely stratified sand and sandstone, gravel, conglomerate, and breccia
- Qca — **Casitas Formation (late and middle Pleistocene)**—Nonmarine siltstone and silt, sandstone and sand, and conglomeratic and gravel; deposited mainly as alluvium
- Qbx — **Shale-clast sedimentary breccia (middle Pleistocene)**—Nonmarine breccia and conglomerate; mostly shale and mudstone clasts derived from the Monterey Formation
- Qsb — **Santa Barbara Formation (middle and early Pleistocene)**—Mostly marine sandstone, with intervals of shale, siltstone, and silty to clayey sandstone. Contains diverse assemblage of marine invertebrate fossils
  - **Unnamed sedimentary rocks east of Goleta Pier (Pleistocene and Pliocene?)**—Marine conglomerate, sandstone, siltstone, and mudstone. Mapped as the following three distinct units:
- Qcg — **Conglomeratic unit (middle and early Pleistocene)**—Conglomerate, sandstone, siltstone, and mudstone. Contains marine fossils and clasts derived from older units (Sisquoc Formation, Monterey Formation)
- Qss — **Sandstone-rich unit (early Pleistocene?)**—Laminated and bioturbated sandstone, siltstone, and subordinate mudstone and conglomerate. Contains marine fossils and clasts derived from older units (Sisquoc Formation, Monterey Formation)
- QTst — **Siltstone unit (early Pleistocene and late Pliocene?)**—Massive and extensively bioturbated siltstone, mudstone, and silty sandstone. Contains marine fossils
- Tsq — **Sisquoc Formation (early Pliocene and late Miocene)**—Marine diatomaceous mudstone and shale, conglomeratic, and subordinate dolomite
  - **Monterey Formation (Miocene)**—Marine, predominantly well-bedded, siliceous and calcareous mudstone and shale, with subordinate porcelanite and dolomite. Mapped as the following three subunits:
- Tmu — **Upper siliceous unit (late Miocene)**—Mudstone and shale, with subordinate dolomite and porcelanite
- Tmm — **Middle shale unit (late and middle Miocene)**—Shale, mudstone, dolomite, porcelanite, phosphorite, and subordinate tuff
- Tml — **Lower calcareous unit (middle and early Miocene)**—Calcareous, siliceous, and phosphatic mudstone and shale, with subordinate dolomite, porcelanite, breccia, sandstone, and tuff
- Tr — **Rincon Shale (early Miocene)**—Marine mudstone, with subordinate dolomite, siliceous shale, sandstone, and tuff
- Tv — **Vaqueros Formation (late Oligocene)**—Shallow-marine, massive, bioturbated, resistant sandstone
  - **Sespe Formation (Oligocene and late Eocene)**—Interbedded sandstone, siltstone, mudstone, and conglomerate. Mapped as the following three subunits:
- Tspu — **Upper sandstone and mudstone unit (late Oligocene)**—Interbedded sandstone, siltstone, and mudstone
- Tspm — **Middle conglomerate and sandstone unit (Oligocene)**—Interbedded conglomerate, sandstone, and mudstone
- Tspl — **Lower conglomerate and sandstone unit (early? Oligocene and late Eocene)**—Interbedded conglomerate, conglomeratic sandstone, sandstone, mudstone, and minor shale
- Tcw — **Coldwater Sandstone (late? and middle Eocene)**—Shallow-marine, thin- to thick-bedded sandstone, with subordinate siltstone, shale, and mudstone
- Tcw-sh — **Shale unit (late? and middle Eocene)**—Bedded siltstone and shale, with sandstone interbeds
- Tcd — **Cozy Dell Shale (Eocene)**—Silty micaceous shale and sandstone, with shale interbeds
- Tma — **Matilija Sandstone (Eocene)**—Arkosic sandstone, with thin shale partings
- Tj — **Juncal Formation (Eocene)**—Marine shale and sandstone
- Kush — **Jalama Formation (Late Cretaceous)**—Predominantly micaceous clay shale, with minor sandstone interbeds

EXPLANATION OF MAP SYMBOLS

- **Contact**—Solid where location is certain, long-dashed where location is approximate, short-dashed where location is inferred, queried where uncertain
- **Fault**—Solid where location is certain, long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed, queried where uncertain
- **Folds**—Solid where location is certain, long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed
- **Antiform**
- **Synform**
- **Overturned anticline**
- **Overturned syncline**
- **Anticlinal upwarp axis in Quaternary deposits**
- **Synclinal downwarp axis in Quaternary deposits**
- **Former shoreline or marine limit**
- **Approximate modern shoreline**—Defined as Mean High Water (MHW) (+1.33 m), North American Vertical Datum of 1988 (NAVD 1988)
- **3-nautical-mile limit of California's State Waters**
- **Area of "no data"**—Areas beyond 3-nautical-mile limit of California's State Waters were not mapped as part of California Seafloor Mapping Program

DISCUSSION

Marine geology and geomorphology were mapped in the Offshore of Santa Barbara map area from approximate Mean High Water (MHW) to the 3-nautical-mile limit of California's State Waters. MHW is defined at an elevation of 1.33 m above the North American Vertical Datum of 1988 (NAVD 88) (Weber and others, 2005). Offshore geologic units were delineated on the basis of integrated analyses of adjacent onshore geology with multibeam bathymetry and backscatter imagery (sheets 1, 2, 3), seafloor-sediment and rock samples (Reid and others, 2006), digital camera and video imagery (sheet 6), and high-resolution seismic-reflection profiles (sheet 8).

The onshore geology was compiled from Dibblee (1986a,b) and Minor and others (2009). Unit ages, which are derived from these sources, reflect local stratigraphic relations.

The offshore part of the map area largely consists of a relatively shallow (less than 75 m deep), gently offshore-dipping (less than 1°) shelf underlain by sediments derived primarily from relatively small coastal watersheds that drain the Santa Ynez Mountains. Shelf deposits are primarily sand (unit Qms) at water depths less than about 35 to 50 m and, at depths greater than about 35 to 50 m, are the more fine-grained sediments (very fine sand, silt, and clay) of unit Qmsf. The boundary between units Qms and Qmsf is based on observations and extrapolation from sediment sampling (see, for example, Reid and others, 2006) and camera ground-truth surveying (see sheet 6). It is important to note that the boundary between units Qms and Qmsf should be considered transitional and approximate and is expected to shift as a result of seasonal- to annual- to decadal-scale cycles in wave climate, sediment supply, and sediment transport.

Coarser grained deposits (coarse sand to boulders) of unit Qmsc, which are recognized on the basis of their high backscatter and, in some cases, their moderate seafloor relief (sheets 1, 2, 3), are found most prominently in a large (about 0.75 km²) lobe that is present from about 1,800 to 3,600 m offshore of the mouth of Arroyo Burro, in water depths of about 36 to 65 m. The lobe is inferred to consist of coarse-grained sediment (coarse sand to boulders) that is resistant to erosion. Although these coarse-grained deposits almost certainly are derived from Arroyo Burro, the lobe could represent either the underflow deposits of late Holocene floods or a relict geomorphologic feature, having been deposited in shallower marine deltaic (or even alluvial?) environments at lower sea levels in the latest Pleistocene and early Holocene. Unit Qmsc also is present in shallower water (depths of about 10 to 20 m), most notably in a small area (approximately 0.09 km²) that extends offshore from Montecito Creek, in the eastern part of the map area.

The presence of coarser grained sediment (coarse sand and possibly gravel) also is inferred in shallower water (depths of 10 to 20 m) offshore from Arroyo Burro, but these deposits are mapped as unit Qmss because they are found within arcuate scour depressions that have been referred to as "rippled scour depressions" (see, for example, Cacchione and others, 1984; Phillips, 2007) or "sorted bedforms" (see, for example, Murray and Thieler, 2004; Goff and others, 2005; Trembanis and Hume, 2011). Although the general area in which Qmss scour depressions are found is not likely to change substantially, the boundaries of the unit(s), as well as the locations of individual depressions and their intervening flat sand sheets, likely are ephemeral, changing during significant storm events.

Hydrocarbon-seep-induced topography, which is present most prominently along the axis of anticlines, includes many features (described by Keller and others, 2007) along the trend of the Mid-Channel Anticline, about 10 km south of the map area in the Santa Barbara Channel. Geologic map units associated with hydrocarbon emissions in the map area include grouped to solitary pockmarks (unit Qmp) and asphalt (tar) deposits (unit Qas), as well as areas of undifferentiated hydrocarbon-related features (unit Qhfu) that probably include a mix of mounds, mud volcanoes, pockmarks, carbonate mats, and other constructional and erosional "seabed forms" (see Keller and others, 2007), all of which are superimposed on consolidated, undivided Miocene and Pliocene bedrock (unit Tbu).

Offshore bedrock exposures are assigned to the Miocene Monterey Formation (unit Tm) and to the undivided Miocene and Pliocene bedrock unit (Tbu), primarily on the basis of extrapolation from the onland geologic mapping of Minor and others (2009), as well as the cross sections of Redin (2005), which are constrained by industry seismic-reflection data and petroleum well logs. Bedrock units typically are exposed in structural highs that include uplifts associated with the partly blind(?), south-dipping Rincon Creek Fault Zone and an anticline that developed above the south strand of the Red Mountain Fault in the southwestern part of the map area.

The Offshore of Santa Barbara map area is in the Ventura Basin, in the southern part of the Western Transverse Ranges geologic province, which is north of the California Continental Borderland (Fisher and others, 2009). This province has undergone significant north-south compression since the Miocene, and recent GPS data suggest north-south shortening of about 6 mm/yr (Larson and Webb, 1992). The active, east-west-striking Red Mountain and Rincon Creek Faults and their related folds are some of the structures on which this shortening occurs. This fault system, in aggregate, extends for about 100 km through the Ventura and Santa Barbara Basins and represents an important earthquake hazard (see, for example, Fisher and others, 2009). Very high uplift rates of onland marine terraces from More Mesa (2.2 mm/yr), in the western part of the map area, to Summerland (0.7 mm/yr), a few kilometers east of the map area, are further indication of rapid shortening in this region (Keller and Gurrola, 2000).

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