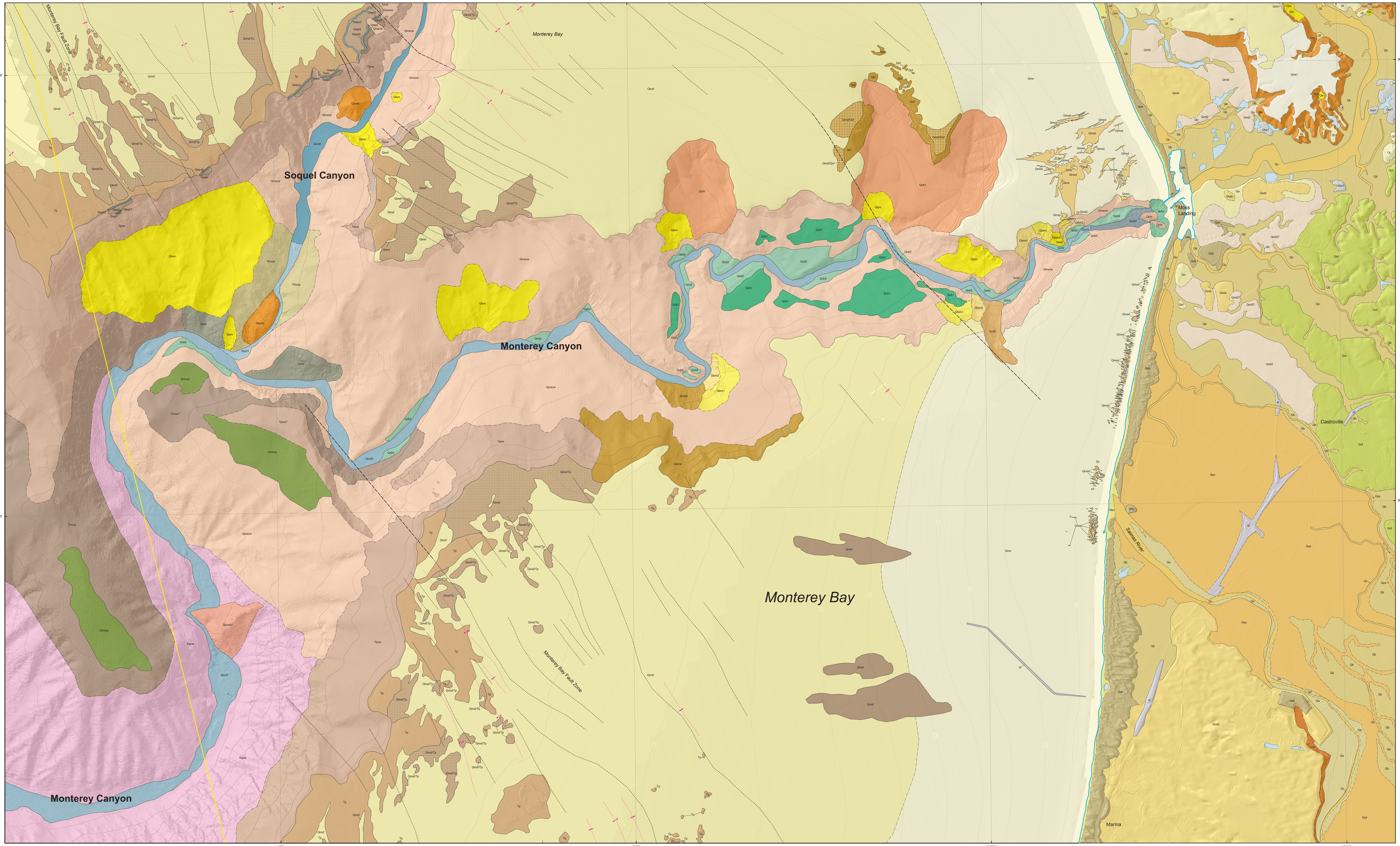
USGS
science for a changing world

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

Open-File Report 2016–1072
Sheet 10 of 10
Pamphlet accompanies map



Onshore elevation data from National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management's Digital Coast (available at http://www.csc.noaa.gov/digitalcoast/data/coastallidar/) and from U.S. Geological Survey's National Elevation Dataset (available at http://ned.usgs.gov/). 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 10N

NOT INTENDED FOR NAVIGATIONAL USE

13½° TRUE NORTH MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2016

SCALE 1:24 000

BATHYMETRIC CONTOUR INTERVALS 10 METERS, 50 METERS, AND 200 METERS

ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

Offshore geology mapped by Katherine L. Maier, Stephen R. Hartwell, and Samuel Y. Johnson, 2014. Onshore geology compiled by Clifton W. Davenport, 2014, from Graymer and others (2006) and Wagner and others (2002). Bathymetric contours by Mercedes D. Erdey, 2014

GIS database and digital cartography by Peter Dartnell and Stephen R. Hartwell

Manuscript approved for publication May 10, 2016

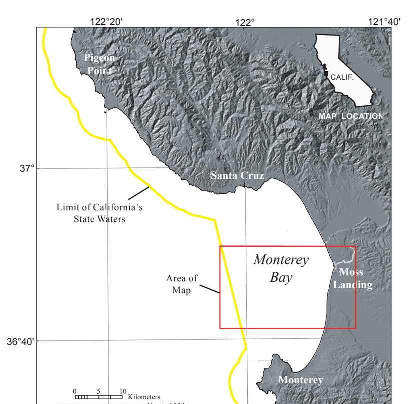
Offshore and Onshore Geology and Geomorphology, Monterey Canyon and Vicinity Map Area, California

By

Katherine L. Maier,[1] Stephen R. Hartwell,[1] Samuel Y. Johnson,[1] Clifton W. Davenport,[2] and H. Gary Greene[3]

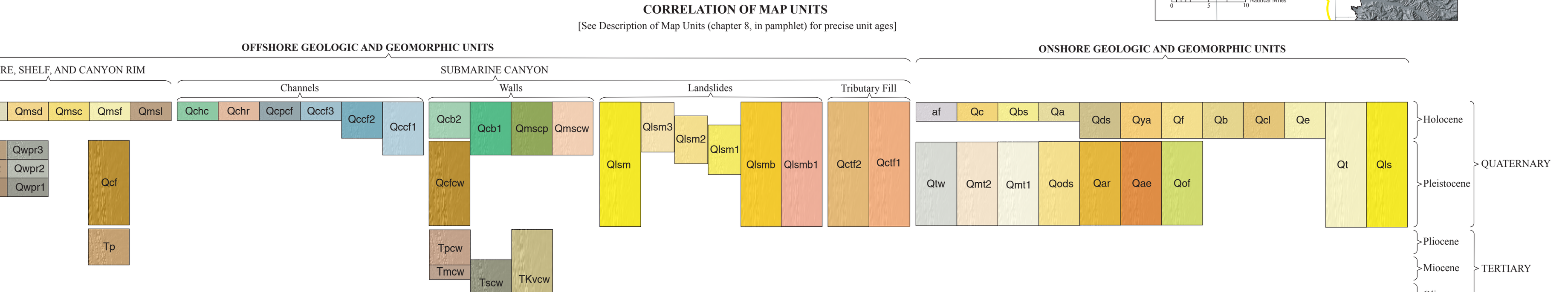
2016

[1]U.S. Geological Survey;
[2]California Geological Survey;
[3]Moss Landing Marine Laboratories



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- and white-stippled areas) are designated on map by composite label indicating both overlying sediment cover and lower (older) unit, separated by slash (for example, Qmsf/Tp indicates that thin sheet of Qmsf overlies Tp)]

NEARSHORE, SHELF, AND CANYON RIM

- af — **Artificial fill (late Holocene)**—Rock, sand, and mud; placed and (or) dredged. Also includes construction debris and seafloor significantly modified by humans
- Qms — **Marine nearshore and shelf deposits (late Holocene)**—Mostly sand; ripples common
- Qmsd — **Marine shelf scour depressions (late Holocene)**—Inferred to be coarse sand and gravel, in low-relief scours
- Qmsc — **Coarse-grained marine nearshore and shelf deposits (late Holocene)**—Coarse sand, gravel, cobbles, and possibly boulders
- Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Predominantly mud, very fine sand, and silt; commonly bioturbated
- Qmsl — **Marine shelf sediment lobes (late Holocene)**—Predominantly sandy, minimally consolidated lobes of recently mobilized marine sediments; lobes are elongate approximately perpendicular to shoreline
- Qwp3 — **Submerged wave-cut platform, about 96 to 100 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; bounded upslope by paleoshoreline angle and platform riser (Qwpr3)
- Qwpr3 — **Submerged wave-cut platform riser, base about 96 to 100 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; smooth, offshore-dipping surface
- Qwp2 — **Submerged wave-cut platform, about 108 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; bounded upslope by paleoshoreline angle and platform riser (Qwpr2)
- Qwpr2 — **Submerged wave-cut platform riser, base about 108 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; smooth, offshore-dipping surface
- Qwp1 — **Submerged wave-cut platform, about 120 to 125 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; bounded upslope by paleoshoreline angle and platform riser (Qwpr1)
- Qwpr1 — **Submerged wave-cut platform riser, base about 120 to 125 m deep (late Pleistocene)**—Inferred to be sand and gravel; may be draped with fine-grained sediment; smooth, offshore-dipping surface
- Qcf — **Paleochannel and canyon-fill deposits, undivided (Pleistocene)**—Channel-scour-and-fill deposits that extend west from mouth of Pajaro River into Monterey Canyon system
- Tp — **Purisima Formation, undivided (Pliocene and late Miocene)**—Thick-bedded siltstone; contains thick interbeds of fine-grained sandstone

SUBMARINE CANYON

Channels

- Qchc — **Submarine-canyon-head channel deposits (late Holocene)**—Primarily sand; characterized by dendritic pattern, crescent-shaped bedforms, and proximal position near modern shoreline
- Qchr — **Submarine-canyon-head interchannel ridges (late Holocene)**—Semiconsolidated sand and mud; extends above adjacent submarine-canyon head into proximal active axial channel
- Qcpcf — **Proximal active submarine-canyon axial-channel fill (late Holocene)**—Primarily sand; found in upper Monterey Canyon; characterized by crescent-shaped bedforms
- Qccf3 — **Active submarine-canyon axial-channel fill (late Holocene)**—Sand, gravel, and minor bedrock outcrops and landslide deposits; found in Monterey Canyon; characterized by curvilinear form and crescent-shaped bedforms
- Qccf2 — **Abandoned submarine-canyon axial-channel fill (Holocene)**—Marine and hemipelagic mud; found in upper Soquel Canyon
- Qccf1 — **Abandoned submarine-canyon axial-channel fill (Holocene and Pleistocene)**—Gravel, sand, and mud; found in lower Soquel Canyon; may include landslide deposits and bedrock exposures

Walls

- Qcb2 — **Submarine-canyon inner bench deposits (Holocene)**—Mud and sand; found in areas of lower gradient adjacent to axial channel that accumulate dominantly fine-grained sediments
- Qcb1 — **Submarine-canyon outer bench deposits (Holocene and Pleistocene)**—Mud and minimal sand; found in areas of lower gradient that accumulate dominantly fine-grained sediments within submarine-canyon-wall deposits (Qmscw)
- Qmscp — **Submarine-canyon platform deposits (Holocene and Pleistocene)**—Mud and minimal sand; found in relatively smooth areas of lower gradient on crests of bathymetric divides between submarine-canyon meanders
- Qmscw — **Submarine-canyon-wall deposits (Holocene and Pleistocene)**—Inferred to be draped by marine and hemipelagic sediments; may contain bedrock outcrops and landslide deposits
- Qcfcw — **Paleochannel and canyon-fill deposits, undivided (Pleistocene)**—Channel-scour-and-fill deposits that extend west from Salinas River into Monterey Canyon system; found within submarine-canyon walls
- Tpcw — **Purisima Formation, undivided (Pliocene and late Miocene)**—Thick-bedded siltstone that contains thick interbeds of fine-grained sandstone within submarine-canyon walls
- Tmcw — **Monterey Formation (Miocene)**—Predominantly thin-bedded, siliceous and calcareous mudstone and shale; found within submarine-canyon walls
- Tscw — **Sandstone, undivided (Miocene or Oligocene)**—Sandstone; possibly correlative with the Vaqueros Formation or the Santa Margarita Formation (Stakes and others, 1999); found in submarine-canyon walls
- TKvcw — **Tertiary and Cretaceous bedrock, undivided (Tertiary and Cretaceous)**—Volcanic, sedimentary, and granitic rocks; found in walls of Soquel Canyon (Stakes and others, 1999)
- Kgrcw — **Granitic rocks of Monterey (Cretaceous)**—Granitic rocks; found within submarine-canyon walls

Landslide Deposits

- Qlsm — **Landslide deposits, marine, undivided (Holocene and Pleistocene)**—Inferred to consist of lithologies similar to that of adjacent submarine-canyon walls. Scarps (concave), chutes, and lobes (hummocky mounds), in, or adjacent to, submarine-canyon walls
- Qlsm3 — **Landslide deposits, marine, third generation (Holocene and Pleistocene)**—Youngest of three divided landslide-deposit units; derived from second-generation landslide deposits (Qlsm2)
- Qlsm2 — **Landslide deposits, marine, second generation (Holocene and Pleistocene)**—Scarps, chutes, and lobes, located primarily in, or adjacent to, submarine-canyon walls; derived from first-generation landslide deposits (Qlsm1)
- Qlsm1 — **Landslide deposits, marine, first generation (Holocene and Pleistocene)**—Mapped in areas where unit is source of younger second-generation landslide deposits (Qlsm2)
- Qlsmb — **Landslide blocks, marine, undivided (Holocene and (or) Pleistocene)**—Commonly bedrock; found in submarine-canyon system; characterized by positive relief and deflection of submarine-canyon axial channel
- Qlsmb1 — **Granitic-rock block (Holocene and (or) Pleistocene)**—Consists of block of Cretaceous granitic rock; may be landslide block; commonly referred to as "Navy Slump" (Greene and others, 2002; Paull and others, 2005a)

Tributary Fill

- Qctf2 — **Tributary-submarine-canyon fill, Salinas River paleochannel(?) (Holocene and Pleistocene)**—Gravel, mud, and sand, in abandoned tributary submarine canyon on south flank of Monterey Canyon
- Qctf1 — **Tributary-submarine-canyon fill, Pajaro River paleochannels(?) (Holocene and Pleistocene)**—Marine mud and sand, in abandoned tributary submarine canyons on north flank of Monterey Canyon; may contain landslide deposits

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units compiled from Wagner and others (2002) and Graymer and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations. In addition, some Quaternary units modified by C.W. Davenport on basis of analysis of 2009 lidar imagery]

- af — **Artificial fill (late Holocene)**—Material deposited by humans; includes jetties at entrance to Moss Landing Harbor
- Qc — **Stream-channel deposits (late Holocene)**—Sand, silt, and gravel deposits within active stream channels and canals
- Qbs — **Beach-sand deposits (late Holocene)**—Fine to very-coarse sand; forms active beaches in coastal environments; may form veneer over bedrock platform
- Qa — **Alluvial deposits (late Holocene)**—Alluvium deposited adjacent to active stream channels
- Qds — **Dune-sand deposits (Holocene)**—Very well-sorted, fine to medium sand; forms both active and stabilized dunes in coastal environments
- Qya — **Alluvial deposits, undivided (Holocene)**—Alluvium deposited adjacent to active stream channels; also includes flood-plain deposits of Wagner and others (2002)
- Qf — **Alluvial fan deposits (Holocene)**—Relatively undissected, unconsolidated, fine-grained, heterogeneous layers of sand, silt, and gravel; deposited by streams emanating from canyons onto alluvial plains
- Qb — **Basin deposits (Holocene)**—Unconsolidated, fine-grained sediment; deposited in low-energy environments that include estuaries, lagoons, marsh-filled sloughs, and lakes
- Qcl — **Colluvium (Holocene)**—Loose to firm, unsorted sand, silt, clay, gravel, rock debris, and organic material, in varying proportions
- Qe — **Eolian sand (Holocene)**—Very well-sorted, fine to medium sand
- Qt — **Stream-terrace deposits (Holocene and Pleistocene)**—Sand, gravel, silt, and minor clay of uncertain age; underlies relatively flat ridges that are elevated above stream channels
- Qls — **Landslide deposits (Holocene and Pleistocene)**—Weathered and disintegrated rocks and soil; physically weathered
- Qtw — **Terrace deposits of Watsonville terrace (Pleistocene)**—Undivided fluvial and alluvial fan facies of semiconsolidated, moderately to poorly sorted silt, sand, clay, and gravel
- Qmt2 — **Lowest emergent marine-terrace deposits (Pleistocene)**—Semiconsolidated sand, less common gravel, and eolian deposits, on uplifted marine-abrasion platforms along coast
- Qmt1 — **Marine-terrace deposits, undivided (Pleistocene)**—Semiconsolidated sand, less common gravel, and colluvial deposits, on uplifted marine-abrasion platforms along coast
- Qods — **Older dune-sand deposits (Pleistocene)**—Very well-sorted, fine to medium sand; forms mounded topography on elevated platforms
- Qar — **Aromas Sand, undivided (Pleistocene)**—Heterogeneous unit of mainly eolian and fluvial sand, silt, clay, and gravel
- Qae — **Eolian lithofacies (Pleistocene)**—Moderately well-sorted eolian sand
- Qof — **Alluvial fan deposits (Pleistocene)**—Highly dissected and extensive alluvial fan deposits

EXPLANATION OF MAP SYMBOLS

- **Contact**—Solid where location is certain, dashed where location is approximate or inferred, queried where uncertain
- **Fault**—Solid where location is certain, dashed where location is approximate or inferred, dotted where location is concealed
- **Folds**—Dotted where location is concealed
  - **Anticline**
  - **Syncline**
- **Inferred former marine shoreline**
- **Approximate modern shoreline**—From National Oceanic and Atmospheric Administration's Shoreline Data Explorer (National Geodetic Survey, 2013)
- **Limit of California's State Waters**

DISCUSSION

Marine geology and geomorphology were mapped in the Monterey Canyon and Vicinity map area from approximate Mean High Water (MHW) across the continental shelf, as well as in Monterey Canyon to a water depth of about 1,750 m. This map area includes much of central Monterey Bay, extending just beyond the limit of California's State Waters (note that the California's State Waters limit, which generally is 3 nautical miles [5.6 km] from shore, extends farther offshore between Santa Cruz and Monterey, so that it encompasses all of Monterey Bay). The shoreline, which is from National Oceanic and Atmospheric Administration's Shoreline Data Explorer, is based on their analysis of lidar data (National Geodetic Survey, 2013). 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 (on the shelf, Reid and others, 2006; within Monterey Canyon, Stakes and others, 1999; Paull and others, 2005a,b, 2010), digital camera and video imagery (sheet 6), and high-resolution seismic-reflection profiles (sheet 8). Aerial photographs taken in multiple years were used to map the nearshore area (0 to 10 m water depth) and to link the offshore and onshore geology.

The onshore geology was compiled from Wagner and others (2002) and Graymer and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations. In addition, some Quaternary units were modified by C.W. Davenport on the basis of analysis of 2009 lidar imagery.

The offshore part of the Monterey Canyon and Vicinity map area contains two major geomorphic features, (1) the continental shelf, and (2) Monterey Canyon and its tributaries (the Monterey Canyon "system," including Soquel Canyon). The continental shelf in the map area is relatively flat and is characterized by a variably thick (and locally absent) cover of uppermost Pleistocene and Holocene sediment that overlies Neogene bedrock, as well as the Pleistocene undivided paleochannel and canyon-fill deposits (Qcf). Inner shelf and nearshore deposits are mostly sand (Qms), and they are thickest (as much as 32 m) in a shore-parallel bar that extends to the mouth of the Salinas River (see sheet 9). Slope failures off of the west flank of this delta-mouth bar have resulted in three east-west-trending, elongate sandy lobes (Qmsl); individual lobes, which are as much as 3,000 m long and 800 m wide, have as much as 150 cm of relief above the surrounding smooth seafloor, and they commonly are transitional to upslope chutes. Unit Qmsf, which lies offshore of unit Qms in the midshelf area, primarily consists of mud and muddy sand, and it commonly is extensively bioturbated. Sediment cover typically thins in the offshore direction and also toward Monterey Canyon (sheet 9); both the Pleistocene undivided paleochannel and canyon-fill deposits (Qcf) and the upper Miocene and Pliocene Purisima Formation (Tp; Powell and others, 2007) are exposed on the outer shelf and along the rims of the present-day Monterey Canyon system. Both the Purisima Formation and the Pleistocene undivided paleochannel and canyon-fill deposits are in places overlain by a thin (less than 1 m?) veneer of sediment, recognized on the basis of high backscatter, flat relief, continuity with moderate- to high-relief outcrops, and (in some cases) high-resolution seismic-reflection profiles; these areas, which are mapped as composite units Qmsf/Tp or Qmsf/Qcf, are interpreted as ephemeral sediment layers that may or may not be continuously present, depending on storms, seasonal and (or) annual patterns of sediment movement, or longer term climate cycles.

Sea level has risen about 125 to 130 m over about the last 21,000 years (see, for example, Stanford and others, 2011), leading to broadening of the continental shelf, progressive eastward migration of the shoreline, and associated transgressive erosion and deposition. Sea-level rise was apparently not steady, leading to development of pairs of shoreline angles and adjacent submerged wave-cut platforms (Kern, 1977) during pulses of relative stability. Latest Pleistocene paleoshorelines are best preserved along the flanks of Soquel Canyon, where three sets of wave-cut platforms (Qwp1, Qwp2, Qwp3) and paired risers (Qwpr1, Qwpr2, Qwpr3) are bounded by shoreline angles at water depths of about 120 to 125 m, about 108 m, and about 96 to 100 m, respectively.

Within the Monterey Canyon system, geologic and geomorphic units are delineated and characterized on the basis of multibeam bathymetry (sheet 1), acoustic backscatter (sheet 2), published seafloor-sediment and rock samples (Stakes and others, 1999; Paull and others, 2005a,b, 2010), and previously published descriptions of geology within the submarine-canyon system (see, for example, Greene, 1977; Barry and others, 1996; Wagner and others, 2002), as well as, where available, seismic-reflection profiles (sheet 8) and video observations (sheet 6). Major geologic and geomorphic features within the submarine canyons include the canyon-head area, canyon axial channels, canyon walls, and canyon benches and platforms.

The canyon-head area of Monterey Canyon includes sandy channel fill (Qchc; Paull and others, 2005a), as well as sediment-draped interchannel ridges (Qchr) that are inferred to have formed largely by erosion of the canyon head into older canyon and (or) channel-fill deposits. A gradational geomorphic transition exists from canyon-head channel fill (Qchc) downcanyon to proximal active axial-channel fill (Qcpcf); in addition, both channel-fill units include dynamic, crescent-shaped sandy bedforms (Paull and others, 2005a, 2010; Smith and others, 2005; Xu and others, 2008). Beyond the canyon-head area, the axial channel of Monterey Canyon forms a sinuous ribbon of coarse-grained deposits (Qccf3) that slopes about 3.5° to the west edge of the map area (Greene and others, 2002; Paull and others, 2005a, 2010; Xu and others, 2008). Xu and others (2002, 2008, 2013) and Paull and others (2010) documented modern sediment-gravity flows down the Monterey Canyon axial channel, indicating that it is an active conduit of sediment transport. Adjacent to the axial channel are canyon walls, benches, and landslides. Canyon walls that are relatively smooth are generally covered by muddy Quaternary sediments (Qmscw) (Paull and others, 2005a, 2010), whereas steeper and rougher segments of canyon walls commonly contain exposures of bedrock or incised Pleistocene paleochannel and canyon-fill deposits (Qcfcw). Outcrops of the Purisima Formation (here, mapped as unit Tpcw) are found in the upper canyon walls. At greater depths along canyon walls, older, underlying bedrock units (Greene, 1977; Barry and others, 1996; Stakes and others, 1999; Wagner and others, 2002) are exposed. These older units include the Miocene Monterey Formation (Tmcw), the undivided Oligocene or Miocene sandstone unit (Tscw), the undivided Cretaceous and Tertiary bedrock unit (TKvcw), and the Cretaceous granitic rocks of Monterey (Kgrcw). Exposures of these bedrock units and the (incised) undivided Pleistocene paleochannel and canyon-fill deposits (Qcfcw) in the canyon walls are inferred to result from a combination of erosion by dense sediment flows down the axial channel and continuing landslide failure of the canyon walls.

Relatively flat areas immediately adjacent to the axial channel or within the canyon walls are mapped as inner bench deposits (Qcb2) and outer bench deposits (Qcb1), respectively (the term "bench" is from Paull and others [2010] and Maier and others [2012]). Benches generally have lower slopes than surrounding canyon walls and, thus, can accumulate fine-grained sediments, including muddy marine, hemipelagic, turbidite, and landslide deposits (Paull and others, 2005a, 2010). Relatively flat, smooth, sediment-covered platforms on the crests of bathymetric divides between canyon meanders are mapped as canyon platform deposits (Qmscp).

Areas of the canyon walls that are characterized by steep, scallop-shaped scarps and paired hummocky mounds are mapped as landslide deposits (Qlsm). Multiple generations of landslide deposits are mapped (units Qlsm1, Qlsm2, and Qlsm3 are first, second, and third generation, respectively) where failure of older landslide deposits has yielded younger landslide deposits. Paull and others (2005b) noted that landslide scarps commonly are associated with chemosynthetic biological communities.

Landslide blocks in the Monterey Canyon system (Qlsmb) are distinguished by positive relief and deflection of an axial channel. Landslide blocks are inferred to consist of bedrock that is similar to bedrock found in the adjacent canyon walls. One particular block (Qlsmb1), informally named "Navy Slump" (see fig. 1–2 in pamphlet), in the distal (within the map area) part of the Monterey Canyon system has been identified as consisting of Cretaceous granitic rocks (Greene and others, 2002; Paull and others, 2005a).

Soquel Canyon is the most prominent of five mapped tributaries to Monterey Canyon. During the sea-level lowstand about 21,000 years ago, Soquel Creek fed directly into Soquel Canyon, carrying coarse-grained sediment directly to the Monterey Canyon system (see sheet 9). Sea-level rise isolated Soquel Canyon from its paired coastal watershed, and this abandoned tributary canyon is now being filled largely with Holocene hemipelagic sediment. Units in the Soquel Canyon axial channel are divided on the basis of the lithology of the fill deposits. In upper Soquel Canyon, the abandoned submarine-canyon axial-channel fill unit (Qccf2) consists of fine-grained sediment. In lower Soquel Canyon adjacent to Monterey Canyon, the abandoned submarine-canyon axial-channel fill unit (Qccf1) contains gravel, sand, and mud (Stakes and others, 1999), possibly derived from Holocene and Pleistocene landslide deposits, and it may also contain bedrock exposures.

Two other abandoned canyon tributaries likely were connected to the Pajaro River during the sea-level lowstand. These two tributaries (Qctf1) are mapped east of Soquel Canyon on the north flank of Monterey Canyon. Another abandoned tributary (Qctf2), mapped on the south flank of Monterey Canyon, appears to have been connected to the Salinas River during the sea-level lowstand.

In the Monterey Canyon and Vicinity map area, the shelf north and south of Monterey Canyon is cut by the diffuse zone of northwest-striking, steeply dipping to vertical faults of the Monterey Bay Fault Zone. This fault zone, originally mapped by Greene (1977, 1990), extends about 45 km across outer Monterey Bay (see Map E on sheet 9). Fault strands within the Monterey Bay Fault Zone are mapped with high-resolution seismic-reflection profiles (sheet 8). Seismic-reflection profiles that traverse this diffuse zone cross as many as nine faults over a width of about 8 km (see, for example, fig. 7 on sheet 8). The fault zone lacks a continuous "master fault" along which deformation is concentrated; fault strands are as long as about 20 km (on the basis of mapping outside the map area), but most strands are only about 2 to 7 km long. Faults in this diffuse zone cut through Neogene bedrock and locally appear to disrupt the overlying inferred Quaternary sediments. The presence of warped reflections along some fault strands suggests that both vertical and strike-slip offset may have occurred.

Mapping fault strands in the Monterey Bay Fault Zone across the Monterey Canyon system is problematic. The combination of steep relief, increased water depths, and massive to poorly stratified sediment fill generally results in poor quality of both high-resolution and deeper seismic-reflection profiles (sheet 8). High-resolution bathymetry does not reveal obvious tectonic landforms such as fault lineaments or scarps, likely owing to (1) deformation being distributed across a broad zone, (2) minimal late Quaternary deformation, and (3) active canyon processes. It is important to realize that the Monterey Bay Fault Zone almost certainly crosses the Monterey Canyon system and that the pattern of faulting likely is similar to what is observed on the continental shelf north and south of the canyon; however, this is not shown on the geologic map (sheet 10) or on structure maps (see Maps A, B, E on sheet 9) because conclusive evidence for the locations of individual fault strands within the submarine-canyon system is lacking.

On a regional scale, the Monterey Bay and Vicinity map area lies within a northward-narrowing zone between the San Andreas Fault Zone (about 34 km east of the map area) and the San Gregorio Fault Zone (about 5 km west of the map area), two major structures in the right-lateral transform-fault plate boundary between the North American and Pacific plates. Deformation associated with the Monterey Bay Fault Zone and other structures in the map area accommodates strain that results from this dynamic tectonic setting.

REFERENCES CITED

Barry, J.P., Greene, H.G., Orange, D.L., Baxter, C.H., Robison, B.H., Kochevar, R.E., Nybakken, J.W., Reed, D.L., and McHugh, C.M., 1996, Biologic and geologic characteristics of cold seeps in Monterey Bay, California: Deep-Sea Research I, v. 43, p. 1,739–1,762.

Graymer, R.W., Bryant, W., McCabe, C.A., Hecker, S., and Prentice, C.S., 2006, Map of Quaternary-active faults in the San Francisco Bay region: U.S. Geological Survey Scientific Investigations Map 2919, scale 1:275,000, available at http://pubs.usgs.gov/sim/2006/2919/.

Greene, H.G., 1977, Geology of the Monterey Bay region: U.S. Geological Survey Open-File Report 77–718, 347 p.

Greene, H.G., 1990, Regional tectonics and structural evolution of the Monterey Bay region, central California, *in* Garrison, R.E., Greene, H.G., Hicks, K.R., Weber, G.E., and Wright, T.L., eds., Geology and tectonics of the central California coastal region, San Francisco to Monterey: American Association of Petroleum Geologists, Pacific Section, Guidebook GB67, p. 31–56.

Greene, H.G., Maher, N.M., and Paull, C.K., 2002, Physiography of the Monterey Bay National Marine Sanctuary and implications about continental margin development: Marine Geology, v. 181, p. 55–82.

Kern, J.P., 1977, Origin and history of upper Pleistocene marine terraces, San Diego, California: Geological Society of America Bulletin, v. 88, p. 1,553–1,566.

Maier, K.L., Fildani, A., McHargue, T.R., Paull, C.K., Graham, S.A., and Caress, D.W., 2012, Punctuated deep-water channel migration—High-resolution subsurface data from the Lucia Chica channel system, offshore California, U.S.A.: Journal of Sedimentary Research, v. 82, p. 1–8.

National Geodetic Survey, 2013, NOAA Shoreline Data Explorer: National Oceanic and Atmospheric Administration, National Geodetic Survey, data viewer and database, accessed September 6, 2013, at http://www.ngs.noaa.gov/NSDE/.

Paull, C.K., Mitts, P., Ussler, W., III, Keaten, R., and Greene, H.G., 2005a, Trail of sand in upper Monterey Canyon—Offshore California: Geological Society of America Bulletin, v. 117, p. 1,134–1,145.

Paull, C.K., Schlining, B., Ussler, W., III, Paduan, J.B., Caress, D., and Greene, H.G., 2005b, Distribution of chemosynthetic biological communities in Monterey Bay, California: Geology, v. 33, p. 85–88.

Paull, C.K., Ussler, W., III, Caress, D.W., Lundsten, E., Covault, J.A., Maier, K.L., Xu, J., and Augenstein, S., 2010, Origins of large crescent-shaped bedforms within the axial channel of Monterey Canyon, offshore California: Geosphere, v. 6, p. 755–774.

Powell, C.L., II, Barron, J.A., Sarna-Wojcicki, A.M., Clark, J.C., Perry, F.A., Brabb, E.E., and Fleck, R.J., 2007, Age, stratigraphy, and correlations of the late Neogene Purisima Formation, central California Coast Ranges: U.S. Geological Survey Professional Paper 1740, 32 p., available at http://pubs.usgs.gov/pp/2007/1740/.

Reid, J.A., Reid, J.M., Jenkins, C.J., Zimmerman, M., Williams, S.J., and Field, M.E., 2006, usSEABED—Pacific Coast (California, Oregon, Washington) offshore surficial-sediment data release: U.S. Geological Survey Data Series 182, available at http://pubs.usgs.gov/ds/2006/182/.

Smith, D.P., Ruiz, G., Kvitek, R., and Iampietro, P.J., 2005, Semiannual patterns of erosion and deposition in upper Monterey Canyon from serial multibeam bathymetry: Geological Society of America Bulletin, v. 117, p. 1,123–1,133.

Stakes, D.S., Rigsby, C.A., and Baucom, P.C., 1999, Igneous and sedimentary rocks from Monterey Canyon, California and implications for regional tectonics, *in* Moore, J.C., Garrison, R.E., Aiello, I.W., Thompson, B.J., Stakes, D.S., and Salamy, K.A., eds., Late Cenozoic fluid seeps and tectonics along the San Gregorio Fault Zone in the Monterey Bay region, California: American Association of Petroleum Geologists, Pacific Section, Field Trip Guide, April 28, 1999, v. 76, p. 75–92.

Stanford, J.D., Hemingway, R., Rohling, E.J., Challenor, P.G., Medina-Elizalde, M., and Lester, A.J., 2011, Sea-level probability for the last deglaciation—A statistical analysis of far-field records: Global and Planetary Change, v. 79, p. 193–203, doi:10.1016/j.gloplacha.2010.11.002.

Wagner, D.L., Greene, H.G., Saucedo, G.J., and Pridmore, C.L., 2002, Geologic map of the Monterey 30' × 60' quadrangle and adjacent areas, California: California Geological Survey Regional Geologic Map Series, scale 1:100,000, available at http://www.quake.ca.gov/gmaps/RGM/monterey/monterey.html.

Xu, J.P., Barry, J.P., and Paull, C.K., 2013, Small-scale turbidity currents in a big submarine canyon: Geology, v. 41, p. 143–146.

Xu, J.P., Noble, M., Eittreim, S.L., Rosenfeld, L.K., Schwing, F.B., and Pilskaln, C.H., 2002, Distribution and transport of suspended particulate matter in Monterey Canyon, California: Marine Geology, v. 181, p. 215–234.

Xu, J.P., Wong, F.L., Kvitek, R., Smith, D.P., and Paull, C.K., 2008, Sandwave migration in Monterey Submarine Canyon, central California: Marine Geology, v. 248, p. 193–212.

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

This map was printed on an electronic plotter directly from digital files. Dimensional calibration may vary between electronic plotters and between X and Y directions on the same plotter, and paper may change size due to atmospheric conditions; therefore, scale and proportions may not be true on plots of this map.

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1–888–ASK–USGS

Digital files available at http://dx.doi.org/10.3133/ofr20161072

Suggested Citation: Maier, K.L., Hartwell, S.R., Johnson, S.Y., Davenport, C.W., and Greene, H.G., 2016, Offshore and onshore geology and geomorphology, Monterey Canyon and Vicinity map area, California, *sheet 10 in* Dartnell, P., Maier, K.L., Erdey, M.D., Dieter, B.E., Golden, N.E., Johnson, S.Y., Hartwell, S.R., Cochrane, G.R., Ritchie, A.C., Finlayson, D.P., Kvitek, R.G., Sliter, R.W., Greene, H.G., Davenport, C.W., Endris, C.A., and Krigsman, L.M. (P. Dartnell and S.A. Cochran, eds.), California State Waters Map Series—Monterey Canyon and Vicinity: U.S. Geological Survey Open-File Report 2016–1072, pamphlet 48 p., 10 sheets, scale 1:24,000, http://dx.doi.org/10.3133/ofr20161072.

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20161072