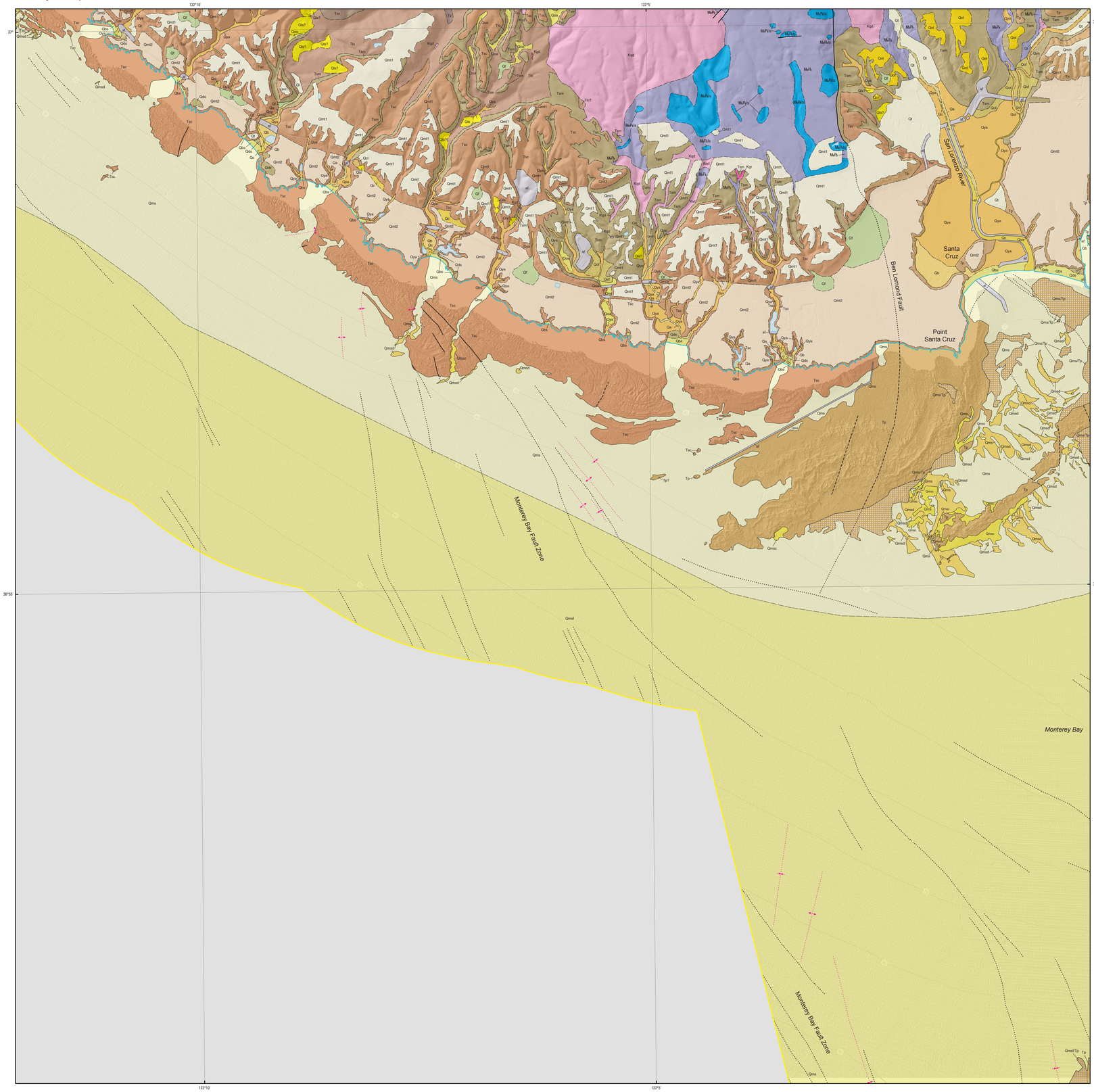
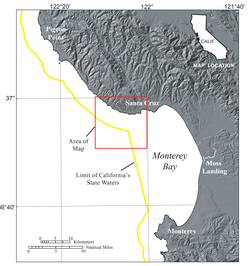
U.S. Department of the Interior
U.S. Geological Survey

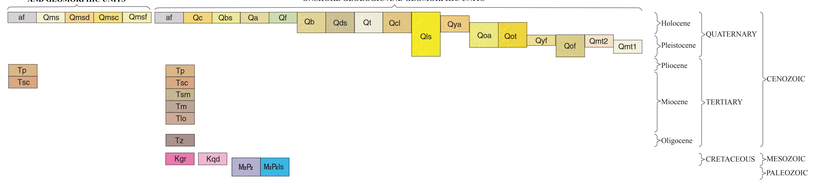
Open-File Report 2016–1024
Sheet 10 of 10
Pamphlet accompanies map





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, Qms/Tp indicates that thin sheet of Qms overlies Tp)]

- af — **Artificial fill (late Holocene)**—Mapped at Santa Cruz Municipal Wharf and at wastewater-outfall pipe
- 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)**—Predominantly coarse sand and gravel
- Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Predominantly mud, very fine sand, and silt
- Tp — **Purisima Formation (Pliocene and late Miocene)**—Thick-bedded, tuffaceous and diatomaceous siltstone that contains thick interbeds of fine-grained sandstone
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Thin- to thick-bedded, siliceous organic mudstone and nonsiliceous mudstone, siltstone, and minor amounts of sandstone

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units compiled from Brabb (1997) and Wagner and others (2002); 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 placed by humans
- Qc — **Stream-channel deposits (late Holocene)**—Sand and gravel deposits within active stream channels
- Qbs — **Beach-sand deposits (late Holocene)**—Fine to very coarse sand that forms active beaches in coastal environments; may form veneer over bedrock platform
- Qa — **Alluvial deposits (late Holocene)**—Alluvium deposited along active stream channels; mapped where deposits within channel cannot be delineated at map scale
- Qf — **Alluvial fan deposits (late Holocene)**—Relatively undissected, unconsolidated, heterogeneous layers of sand, silt, and gravel deposited by streams emanating from canyons
- Qb — **Basin deposits (Holocene)**—Unconsolidated, heterogeneous, moderately sorted silt and sand that contains lenses of clay and silty clay
- Qds — **Dune-sand deposits (Holocene)**—Very well-sorted, fine to medium sand that forms both active and stabilized dunes in coastal environments
- Qt — **Stream-terrace deposits (Holocene)**—Relatively smooth, undissected, low-lying terraces adjacent to active stream channels
- Qcl — **Colluvium (Holocene)**—Loose to firm, unsorted sand, silt, clay, gravel, rock debris, and organic material, in varying proportions; typically mapped in hillside swales and narrow immature drainages
- Qls — **Landslide deposits (Holocene and Pleistocene)**—Weathered and disintegrated rocks and soil. Internal contacts differentiate individual landslide bodies
- Qya — **Alluvial deposits, undivided (Holocene)**—Alluvium deposited adjacent to active stream channels; may include small marine-terrace and channel deposits where such units are too small to delineate at map scale
- Qoa — **Alluvial deposits, undivided (Holocene and late Pleistocene)**—Found on gently sloping to level terrace surfaces adjacent to stream channels, where separate units could not be delineated at map scale
- Qot — **Stream-terrace deposits (Holocene and late Pleistocene)**—Sand, gravel, silt, and minor clay of uncertain age; underlies relatively flat platforms adjacent to, and elevated above, stream channels
- Qyf — **Alluvial fan deposits (late Pleistocene)**—Sediment (sand, gravel, silt, clay) deposited by streams emanating from canyons; age indicated by greater degree of dissection than that of adjacent, inferred Holocene fans
- Qof — **Alluvial fan deposits (Pleistocene)**—Discontinuous deposits of semiconsolidated, moderately to poorly sorted silty clay, silt, sand, and gravel; deposited by streams, sheet flows, and debris flows adjacent to mountains
- Qmt2 — **Lowest emergent marine-terrace deposits (Pleistocene)**—Semiconsolidated sand and less common gravel deposits, on uplifted marine-abrasion platforms along coast
- Qmt1 — **Marine-terrace deposits, undivided (Pleistocene)**—Semiconsolidated sand and less common gravel deposits, on uplifted marine-abrasion platforms along coast; found at elevations higher than that of Qmt2
- Tp — **Purisima Formation (Pliocene and late Miocene)**—Thick-bedded, yellowish-gray, tuffaceous and diatomaceous siltstone that contains thick interbeds of blueish-gray, fine-grained andesitic sandstone
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Pale-yellowish-brown, siliceous organic mudstone and porcellanite that contains nonsiliceous mudstone, siltstone, and minor sandstone
- Tsm — **Santa Margarita Sandstone (late Miocene)**—Friable, yellowish-gray to white, medium- to fine-grained arkosic sandstone; locally calcareous and bituminous; base of section has local pebble conglomerate
- Tm — **Monterey Formation (middle Miocene)**—Medium- to thick-bedded and laminated, olive-gray to light-gray, semisiliceous organic mudstone and silty sandstone that has some dolomite interbeds
- Tlo — **Lompico Sandstone (middle Miocene)**—Thick-bedded to massive, yellowish-gray, medium- to fine-grained, calcareous arkosic sandstone
- Tz — **Zayante Sandstone (Oligocene)**—Thick-bedded, yellowish-orange, arkosic sandstone that contains thin beds of greenish and reddish siltstone and thick interbeds of pebble to cobble conglomerate
- Kgr — **Granitic rocks (Cretaceous)**
- Kqd — **Quartz diorite (Cretaceous)**
- MzPs — **Metasedimentary rocks (Mesozoic or Paleozoic)**—Mainly pelitic schist and quartzite
- MzPsls — **Metasedimentary carbonate rocks (Mesozoic or Paleozoic)**—Marble, locally interbedded with schist and calc-silicate rocks

EXPLANATION OF MAP SYMBOLS

- **Contact**—Solid where location is certain; dashed where location is approximate, inferred, or concealed
- **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**
- **Approximate modern shoreline**—Defined as Mean High Water (MHW) (+1.46 m), North American Vertical Datum of 1988 (NAVD 88)
- **Limit of California's State Waters**
- **Area of "no data"**—Areas beyond 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 Cruz map area from approximate Mean High Water (MHW) to 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 south of Santa Cruz, so that it encompasses all of Monterey Bay). MHW is defined at an elevation of 1.46 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). 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 Brabb (1997) and Wagner and others (2002); 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 map area lies south and southwest of the southwest flank of the Santa Cruz Mountains, on the open Pacific Coast and also in northwestern Monterey Bay. This offshore area extends from the shoreline across the gently dipping (about 0.7° to 0.8°) continental shelf to water depths of about 75 to 90 m at the limit of California's State Waters. The shelf is underlain by Neogene bedrock and a variably thick (as much as 32 m) upper Quaternary sediment cover (see sheet 9). Sea level has risen about 120 to 130 m during 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 wave-cut platform, and associated transgressive erosion and deposition. Most of the Offshore of Santa Cruz map area is now subjected to full, and sometimes severe, wave energy and strong currents. Shelf morphology and geology also are affected by local faulting, folding, and uplift.

In the offshore, the western part of the map area is cut by the northern part of the Monterey Bay Fault Zone (Greene, 1990), a distributed, northwest-striking, about 5-km-wide fault zone. Mapping (based on seismic-reflection profiles; see sheet 8) reveals that the zone can include as many as ten or more vertical to steeply dipping strands, which range in length from about 1 to 20 km in the Monterey Bay area (see Map E on sheet 9). Greene (1990) suggested that the fault zone may have both vertical and strike-slip offset on the basis of the presence of warped reflections along some fault strands. Fault-related deformation clearly affects Neogene bedrock, but faults in this zone do not appear to offset Quaternary deposits. The Monterey Bay Fault Zone lies subparallel to the active San Gregorio Fault Zone (McCulloch, 1987; Dickinson and others, 2005), which extends through the southwest corner of the map area (outside California's State Waters) and has an estimated 156 km of right-lateral offset.

The northwest-striking strike-slip deformation associated with the San Gregorio and Monterey Bay Fault Zones appears to largely postdate deformation along the north-striking Ben Lomond Fault. Using gravity anomalies, Stanley and McCaffrey (1983) extended mapping of the Ben Lomond fault for 3 km, from bedrock exposures in the Santa Cruz Mountains, beneath emergent marine-terrace deposits, to the shoreline about 930 m west of Point Santa Cruz. This offshore-onshore geologic map shows the Ben Lomond Fault as extending offshore an additional 4 km south, on the basis of interpretation of high-resolution bathymetry (sheets 1, 2) and seismic-reflection profiles (sheet 8).

From the northwest corner of the map area southeastward to the western part of Santa Cruz, about 1,400 m west of Point Santa Cruz, the upper Miocene Santa Cruz Mudstone (unit Tsc) forms continuous outcrops that extend from coastal bluffs into the offshore to depths of as much as 35 m. To the southeast, similarly continuous, onshore-to-offshore outcrops of the younger (upper Miocene and Pliocene) Purisima Formation (unit Tp; Powell and others, 2007) extend southwestward from the bluffs at Point Santa Cruz and also from the area between the mouth of the San Lorenzo River and the Santa Cruz Small Craft Harbor. Seafloor outcrops of the Santa Cruz Mudstone (Tsc) are characterized by differentially eroded layers (harder and softer interbeds) that are folded and densely fractured, creating a relatively "shattered" appearance on shaded-relief maps (see sheets 1, 2). Nearby or adjacent seafloor outcrops of the Purisima Formation (Tp) are similarly folded, but they have less distinct and more diffuse bedding surfaces (in part, owing to shallower dips) and are notably less fractured, and, thus, they have a distinctly different seafloor geomorphic expression.

Modern nearshore and inner shelf to midshelf sediments are mostly sand (unit Qms) and a mix of sand and gravel (units Qmsc and Qmsd). In addition to its presence on the broad shelf, unit Qms notably also is present in well-defined paleochannels that cut through nearshore bedrock exposures at the mouths of several small coastal watersheds, including Liddell Creek, Yellow Bank Creek, Laguna Creek, Majors Creek, Baldwin Creek, Wilder Creek, and Moore Creek (see fig. 1–2 in pamphlet; see also, Maps A, B on sheet 9). These distinct channels, which extend to water depths of 20 to 30 m, were formed by subaerial erosion during sea-level lowstands (Anima and others, 2002).

The coarser grained sands and gravels (units Qmsc and Qmsd) are recognized primarily on the basis of bathymetry and (or) high backscatter (see sheets 1, 2, 3). Unit Qmsc mainly is found adjacent to bedrock, in water depths of less than 35 m. Unit Qmsd typically is mapped as erosional lags in scour depressions, at water depths that range from about 15 to 35 m. These Qmsd depressions typically are irregular to lenticular and a few tens of centimeters deep, and they range in size from a few tens of square meters to as much as about 550,000 m². The depressions are bounded either by relatively sharp (or, less commonly, diffuse) contacts with sand sheets of unit Qms or by abrupt contacts with bedrock on the margins of lowstand paleochannels. Qmsd depressions are most abundant in a northeast-trending zone between bedrock outcrops offshore of Point Santa Cruz. Such scour depressions are common along this stretch of the California coast (see, for example, Cacchione and other, 1984; Hallenbeck and others, 2012; Davis and others, 2013), where offshore sandy sediment can be relatively thin (and, thus, is unable to fill the depressions) owing to low sediment supply from rivers and also to significant erosion and offshore transport of sediment during large northwest winter swells. Such features have been referred to as "rippled scour depressions" (see, for example, Cacchione and others, 1984) or "sorted bedforms" (see, for example, Goff and others, 2005; Trembanis and Hume, 2011). Although the general areas in which both unit Qmsd scour depressions and surrounding Qms sand sheets are found are not likely to change substantially, the boundaries of the unit(s) likely are ephemeral, changing seasonally and during significant storm events. Active sediment transport in this nearshore regime also can lead to the significant but ephemeral burial and exhumation of offshore bedrock reefs of units Tsc and Tp (Storlazzi and others, 2011).

An offshore transition from unit Qms to the finer grained marine sediments of unit Qmsf is present at water depths of 35 to 50 m. Unit Qmsf commonly is extensively bioturbated and primarily consists of mud and muddy sand. Edwards (2002) and Grossman and others (2006) suggested that these finer grained sediments form an extensive midshelf mud belt that is sourced primarily by the San Lorenzo River and smaller coastal watersheds.

Artificial fill (unit af) is mapped in the offshore at the Santa Cruz Municipal Wharf (about 800 m west of the mouth of the San Lorenzo River; see fig. 1–2 in pamphlet) and also at the location of a wastewater-outfall pipe that cuts across the nearshore about 1,350 m west of Point Santa Cruz.

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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

SCALE 1:24 000

1 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

Offshore geology and geomorphology mapped by Samuel Y. Johnson and Stephen R. Hartwell, 2013–2014. Onshore geology and geomorphology compiled by Clifton W. Davenport, 2014, from Brabb (1997) and Wagner and others (2002). Bathymetric contours by Mercedes D. Erdey, 2014

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

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

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