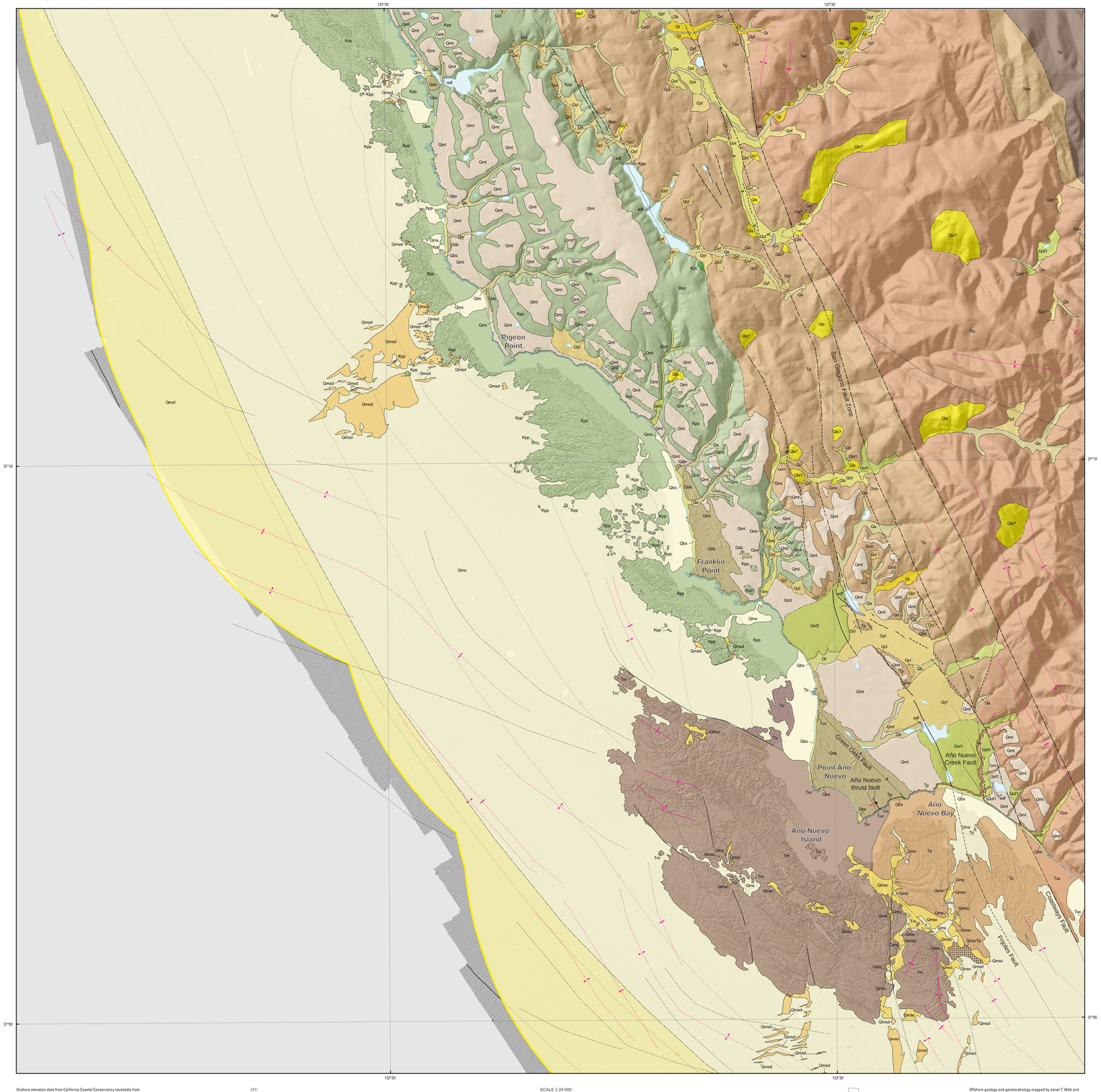
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2015–1232
Sheet 10 of 10
Pamphlet accompanies map



Onshore elevation data from California Coastal Conservancy (available from National Oceanic and Atmospheric Administration [NOAA] Coastal Service Center's Digital Coast at http://www.csc.noaa.gov/digitalcoast/data/coastallidar/) and the U.S. Geological Survey's National Elevation Dataset (available at http://ned.usgs.gov/). Shoreline and offshore 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

15° / APPROXIMATE MEAN DECLINATION, 2015

SCALE 1:24 000

1 0 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

CALIF. MAP LOCATION

Offshore geology and geomorphology mapped by Janet T. Watt and Stephen R. Hartwell, 2013–2014. Onshore geology and geomorphology compiled by Clifton W. Davenport, 2014, from Weber and Lajoie (1980), Smith (1981), California Geological Survey (1982a,b), Brabb (1997), Brabb and others (1998), Clark and others (1999), and Graymer and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations. In addition, some units modified by C.W. Davenport on basis of analysis of 2012 lidar imagery.

Offshore geology and geomorphology compiled by Janet T. Watt, Stephen R. Hartwell, and Peter Dartnell

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Offshore and Onshore Geology and Geomorphology, Offshore of Pigeon Point Map Area, California

By
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2015

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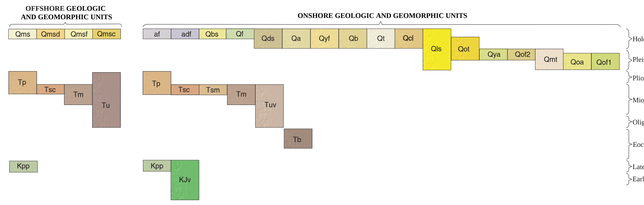
CORRELATION OF MAP UNITS

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

- 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
- Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Mostly mud, very fine sand, and silt
- Qmsc — **Coarse-grained marine nearshore and shelf deposits (late Holocene)**—Predominantly coarse sand and gravel
- Tp — **Purisima Formation (Pliocene and late Miocene)**—Mostly gray and greenish-gray to buff, fine-grained marine sandstone, siltstone, and mudstone
- Tu — **Sedimentary and volcanic rocks, undivided (late Pliocene to Oligocene)**—Consists of rocks of the Purisima Formation (Tp), the Monterey Formation (Tm), and the unnamed sedimentary and volcanic rocks unit (Tuv)
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Thin- to thick-bedded, siliceous mudstone that has carbonate concretions
- Tm — **Monterey Formation (late and middle Miocene)**—Thin-bedded, siliceous shale, interbedded with arkosic sandstone
- Kpp — **Pigeon Point Formation (Late Cretaceous)**—Sandstone and conglomerate, interbedded with siltstone and mudstone

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units compiled from Weber and Lajoie (1980), Smith (1981), California Geological Survey (1982a,b), Brabb (1997), Brabb and others (1998), Clark and others (1999), and Graymer and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations. In addition, some units modified by C.W. Davenport on basis of analysis of 2012 lidar imagery]

- af — **Artificial fill (late Holocene)**—Rock, sand, and mud, deposited by humans
- adf — **Artificial-dam fill (late Holocene)**—Earth- or rock-fill dams, embankments, and levees; constructed to impound land-locked water bodies
- Qbs — **Beach-sand deposits (late Holocene)**—Active beaches in coastal environment; may form over bedrock platform
- Qf — **Alluvial fan deposits (late Holocene)**—Alluvial fan deposits; judged to be late Holocene (less than 1,000 years) in age, on the basis of records of historical inundation or presence of youthful braid bars and distributary channels
- Qds — **Dune sand (Holocene)**—Active and recently stabilized dunes, in coastal environments
- Qa — **Alluvial deposits, undivided (Holocene)**—Alluvium; deposited in fan, terrace, or basin environments
- Qyf — **Alluvial fan deposits (Holocene)**—Sediment deposited by streams emanating from canyons onto alluvial plains; includes sand, gravel, silt, and clay; identified primarily by fan morphology and topographic expression
- Qb — **Basin deposits (Holocene)**—Fine-grained sediment that accumulates from standing or slow-moving water in topographic basins and, locally, between adjacent alluvial fans
- Qt — **Stream-terrace deposits (Holocene)**—Relatively smooth, undissected, relatively 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
- Qls — **Landslide deposits (Holocene and Pleistocene)**—Disintegrated bedrock; physically weathered; unit ranges from deep-seated landslides to active colluvium; queried where uncertain
- Qot — **Stream-terrace deposits (Holocene and late Pleistocene)**—Sand, gravel, silt, and minor clay of uncertain age; underlies relatively flat platforms adjacent to stream channels
- Qya — **Alluvial deposits, undivided (late Pleistocene)**—Mapped on gently sloping to level terrace surfaces, where late Pleistocene age is indicated by depth of stream incision
- Qoaf2 — **Alluvial fan deposits (late Pleistocene)**—Mapped where older age is indicated by greater degree of dissection than, or where geomorphic feature is at higher elevation than, that of Holocene fans
- Qmt — **Marine-terrace deposits (Pleistocene)**—Sand and gravel; deposited on uplifted marine-abrasion platforms along coast; queried where uncertain
- Qoa — **Older alluvial deposits, undivided (Pleistocene)**—Moderately to deeply dissected alluvial deposits, commonly consists of gently rolling hills that have little to no original planar surface preserved
- Qoaf1 — **Alluvial fan deposits (Pleistocene)**—Moderately to deeply dissected alluvial fan deposits; mapped where some original fan-surface morphology is preserved
- Tp — **Purisima Formation (Pliocene and late Miocene)**—Medium-grained to very fine-grained, poorly indurated to friable sandstone, siltstone, and claystone; also includes conglomerate lenses and a few beds of white volcanic ash
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Siliceous mudstone, interbedded with nonsiliceous mudstone, siltstone, and minor sandstone
- Tsm — **Santa Margarita Sandstone (late Miocene)**—Friable, very fine- to very coarse-grained, arkosic sandstone; quartz- and feldspar-pebble conglomerate crops out locally at base of section
- Tm — **Monterey Formation (late and middle Miocene)**—Porcelaneous shale and chert, porcelaneous mudstone, calcareous claystone; includes small amounts of siltstone and sandstone near base
- Tuv — **Unnamed sedimentary and volcanic rocks (Miocene and Oligocene)**—Dark gray, hard mudstone
- Tb — **Butano Sandstone (middle and early Eocene)**—Very fine- to very coarse-grained, arkosic sandstone, interbedded with mudstone and shale; conglomerate is present locally in lower part of section
- Kpp — **Pigeon Point Formation (Late Cretaceous)**—Sandstone and conglomerate, interbedded with siltstone and mudstone
- KJv — **Unnamed volcanic rocks (Cretaceous or Jurassic)**—Finely-crystalline, felsic volcanic rock that contains quartz and albite phenocrysts

EXPLANATION OF MAP SYMBOLS

- **Contact**—Solid where location is certain, dashed where location is approximate
- **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; sawtooth located on upthrown block
- **Folds**—Solid where location is certain, 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)
- **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 Pigeon Point 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 1.46 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.

Onshore geology was compiled from Weber and Lajoie (1980), Smith (1981), California Geological Survey (1982a,b), Brabb (1997), Brabb and others (1998), Clark and others (1999), and Graymer and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations. In addition, some units were modified by C.W. Davenport on the basis of analysis of 2012 lidar imagery.

The offshore part of the map area, which includes the seafloor off the prominent headland of Point Año Nuevo, extends from the shoreline to water depths of about 70 m. This offshore area is largely characterized by a relatively flat (less than 1°) bedrock platform that is overlain by a variably thick (as much as 22 m) veneer of upper Quaternary sediment (see Map B on sheet 9). Sea level has risen 120 to 130 m during the last about 21,000 years (see, for example, Stanford and others, 2011), leading to a broadening of the continental shelf, progressive eastward migration of the shoreline and wave-cut platform, and associated transgressive erosion and deposition. Land-derived sediment was carried into this setting and subjected to Pacific Ocean wave energy and strong currents before deposition or offshore transport. Shelf morphology and geology result from local faulting, folding, uplift, and subsidence.

Most of the Offshore of Pigeon Point map area encompasses a part of the continental shelf that lies between the Ascension Fault and the San Gregorio Fault Zone, along the northeastern margin of the Outer Santa Cruz Basin and the southwest limb of the Pigeon Point high (fig. 1; McCulloch, 1987). The northwest-striking San Gregorio Fault Zone (Weber and others, 1995; Dickinson and others, 2005), an important right-lateral strike-slip fault within the San Andreas Fault System, cuts across land through the northeast corner of the map area before moving offshore at Point Año Nuevo. In the map area, the San Gregorio Fault system forms a distributed shear zone about 1 to 4 km wide that includes two main diverging fault strands (fig. 1). The west strand (known as the Frijoles Fault), which comes onshore approximately 0.5 km east of Año Nuevo Creek, coincides with a topographic trough to the north (Clark and others, 1999). The east strand (known as the Coastways Fault) forms a prominent scarp offshore, where rocks of the Santa Cruz Mudstone east of the fault are juxtaposed with those of the Purisima Formation west of the fault. Paleoseismic data presented by Simpson and others (1997) suggest a post–late Pleistocene slip rate of 3.5 to 4.5 mm/yr for the onshore part of the east strand. This estimated rate represents a minimum for the San Gregorio Fault system because fault strands to the west, including the Frijoles Fault, are also active. Cumulative lateral slip on this fault zone is thought to range from 4 to 10 mm/yr in this area (Weber and others, 1995).

The northwest-striking Ascension Fault (fig. 1) is a high-angle reverse fault (Nagel and others, 1986; Wagner and others, 2002; Dickinson and others, 2005) that is also considered to be active (U.S. Geological Survey and California Geological Survey, 2010) and is characterized by a series of northeast-dipping thrust faults sub-parallel to the San Gregorio Fault Zone. The offshore area between the Ascension Fault and the San Gregorio Fault Zone is characterized by a number of steeply dipping, predominantly northwest-striking unnamed faults and also northwest-trending folds.

The Upper Cretaceous Pigeon Point Formation (unit Kpp), which represents the oldest bedrock unit exposed in the offshore part of the map area, crops out on the seafloor in shallow water (less than 20 meters deep) north of Point Año Nuevo and west of the San Gregorio Fault Zone. These basement rocks are unconformably overlain by Tertiary marine sedimentary rocks, which include the middle and upper Miocene Monterey Formation (unit Tm), the upper Miocene Santa Cruz Mudstone (unit Tsc), and the upper Miocene and Pliocene Purisima Formation (unit Tp; age from Powell and others, 2007). The undivided Oligocene to upper Pliocene sedimentary rocks unit Tu is mapped in the offshore where assignment to a particular formation is uncertain; this undivided unit may also include a relatively thin (85 m thick) section of volcanic rocks, which has been mapped onshore along the coast at Point Año Nuevo as the unnamed sedimentary and volcanic rocks unit (Tuv).

The Santa Cruz Mudstone (Tsc) is mapped east of the Coastways Fault (east strand of the San Gregorio Fault Zone) both in the nearshore and onshore in the seacliff. However, the Santa Cruz Mudstone is not present within the Tertiary section onshore west of the Coastways Fault, where the Purisima Formation unconformably overlies either the Pigeon Point Formation or the Monterey Formation. The Purisima Formation is exposed on the seafloor in Año Nuevo Bay between the Coastways and Frijoles Faults. Seafloor exposure of the Purisima Formation and the underlying Monterey Formation are difficult to distinguish west of the Frijoles Fault in multibeam bathymetry imagery (see sheets 1, 2); however, the faulted unconformity between the Purisima and Monterey Formations is clearly visible in seismic-reflection profiles southeast of Point Año Nuevo (see fig. 9 on sheet 8).

Modern nearshore sediments are mostly sand (unit Qms) and a mix of sand, gravel, and cobbles (units Qmsc and Qmsd). Unit Qms notably is present, in addition to on the shelf, in well-defined channels that cut through nearshore bedrock exposures north of Pigeon Point. 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 high backscatter (see sheets 1, 2, 3). Unit Qmsc mainly is found adjacent to bedrock, in water depths of less than 40 m.

Unit Qmsd typically is mapped as erosional lags in scour depressions (see, for example, Cacchione and others, 1984) that are bounded by relatively sharp or, less commonly, diffuse contacts with the horizontal sand sheets of unit Qms. These depressions typically are a few tens of centimeters deep and range in size from a few tens of square meters to more than 1 km2. Such scour depressions are common along this stretch of the California coast (see, for example, Cacchione and others, 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 lack of 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, Murray and Thieler, 2004; 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.

A transition to finer grained marine sediments (unit Qmsf) is seen offshore Pigeon Point and southwest of Point Año Nuevo, at water depths of 50 to 60 m. Unit Qmsf, which commonly is extensively bioturbated, primarily consists of mud and muddy sand. These fine-grained shelf sediments are derived from local coastal watersheds, bluff erosion, and the northward advection of sediment from fluvial sources within, and north of, Monterey Bay (Edwards, 2002).

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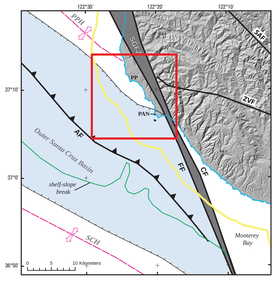

Figure 1. Schematic map showing major offshore structural features northwest of Monterey Bay (modified from Nagel and others, 1986; McCulloch, 1987; Wagner and others, 2002; Dickinson, 2005). Red box, Offshore of Pigeon Point map area. Yellow line, offshore limit of California's State Waters. Outer Santa Cruz Basin (modified from McCulloch, 1987) shown by blue shading and hachured lines (hachures point into basin). Solid black lines show traces of faults: AF, Ascension Fault (sawteeth on upper plate); CF, Coastways Fault; FF, Frijoles Fault; SGFZ, San Gregorio Fault Zone (also shown by dark-gray shading); SAF, San Andreas Fault; ZVF, Zayante-Vergeles Fault. Dashed magenta lines show axes of structural highs: PPH, Pigeon Point high; SCH, Santa Cruz high. Other abbreviations: PAN, Point Año Nuevo; PP, Pigeon Point.

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