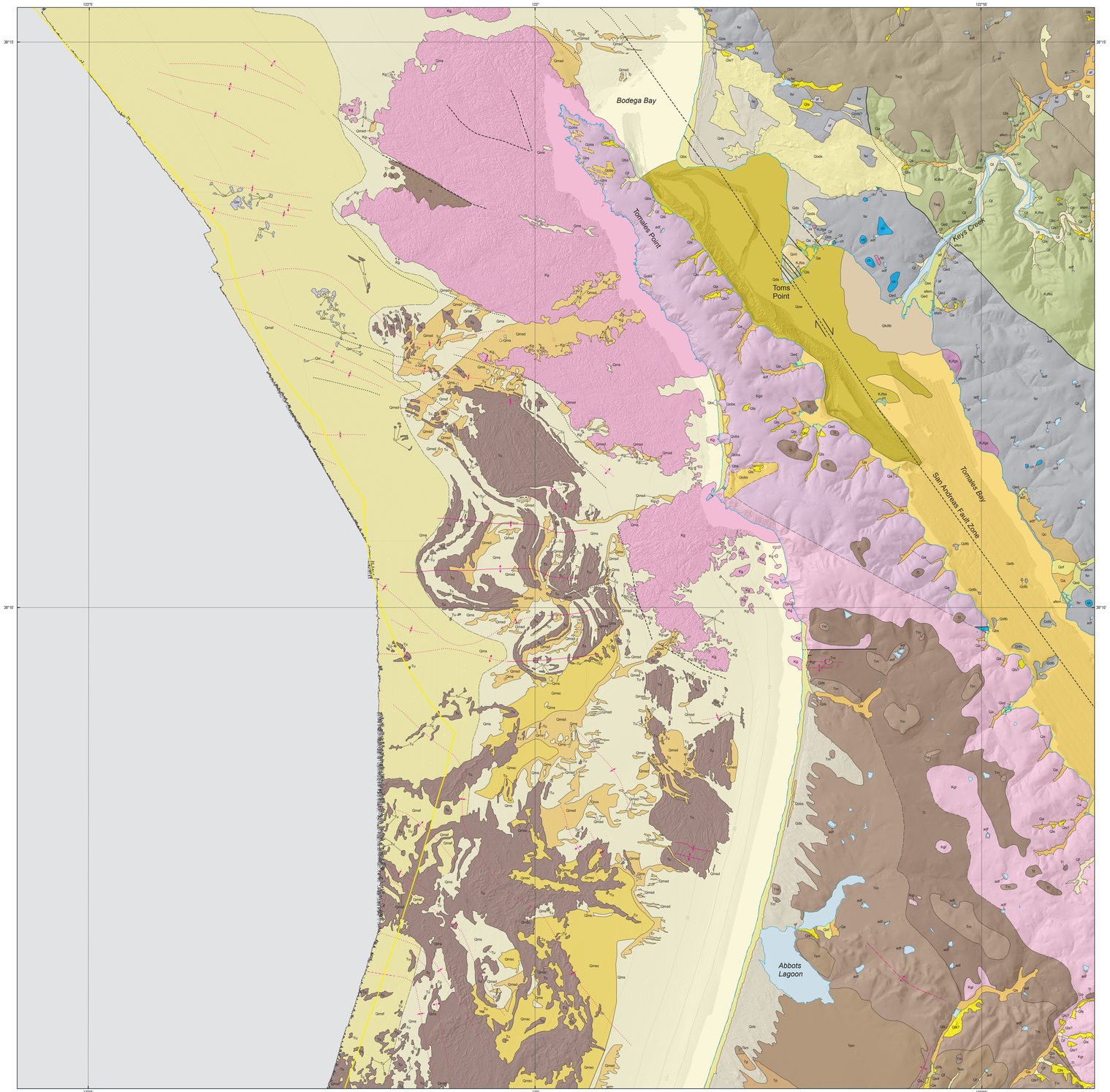
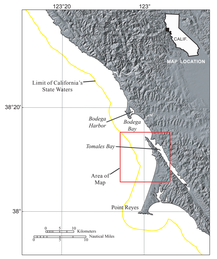
U.S. Department of the Interior
U.S. Geological Survey

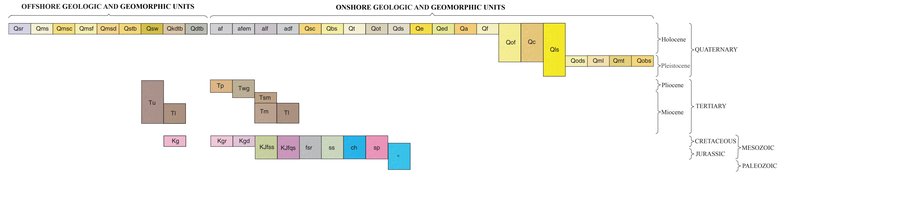
Open-File Report 2015–1088
Sheet 10 of 10
Pamphlet accompanies map





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

Qsr — **Marine shelf deposits, rough seafloor (late Holocene)**—Randomly distributed to northwest-trending, irregular "lumps" (as large as 20,000 m²) with as much as 1 m of positive relief above the seafloor, interpreted as marine debris

Qms — **Marine nearshore and shelf deposits (late Holocene)**—Mostly sand; ripples common

Qmsc — **Coarse-grained marine nearshore and shelf deposits (late Holocene)**—Coarse sand, gravel, and cobbles

Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Mostly mud to muddy sand

Qmsd — **Marine shelf scour depressions (late Holocene)**—Inferred to be coarse sand and gravel in low-relief scours

Qstb — **Sediments of central Tomales Bay (late Holocene)**—Sand, silt, and clay (Anima and others, 2008)

Qsw — **Sand at the mouth of Tomales Bay (late Holocene)**—Coarse to medium sand forming sand waves, dunes, and flats at mouth of Tomales Bay (Anima and others, 2008)

Qkdtb — **Subaqueous delta at the mouth of Walker Creek (late Holocene)**—Semicircular subaqueous delta extending into Tomales Bay from the mouth of Walker Creek

Qdtb — **Seafloor depressions in Tomales Bay (late Holocene)**—Oval to oblate depressions within the sedimentary fill of Tomales Bay

Tu — **Sedimentary rocks, undivided (late Pliocene to middle Miocene)**—Consists of Laird Sandstone (unit Tl), Monterey Formation (unit Tm), Santa Margarita Sandstone (unit Tsm), and Purisima Formation (unit Tp)

Tl — **Laird Sandstone (middle Miocene)**—Marine arkosic sandstone, includes basal granitic conglomerate

Kg — **Granitic rocks (Cretaceous)**—Offshore equivalent of the Tonalite of Tomales Point (unit Kgd) and the Granodiorite and granite of Inverness Ridge (unit Kgr)

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units are compiled from Clark and Brabb (1997), Witter and others (2006), and Wagner and Gutierrez (2010)]

af — **Artificial fill (late Holocene)**—Material placed by humans

afem — **Artificial fill over estuarine mud (late Holocene)**—Material deposited by humans over estuarine sediments

alf — **Artificial levee fill (late Holocene)**—Constructed levees bordering rivers, streams, sloughs and islands for the purpose of containing flood or tidal waters

adf — **Artificial dam fill (late Holocene)**—Earth- or rock-fill dams, embankments, and levees; constructed to impound land-locked water bodies

Qac — **Stream channel deposits (late Holocene)**—Fluvial deposits within active, natural stream channels

Qbs — **Beach-sand deposits (late Holocene)**—Active beaches in coastal environment; may form veneer over bedrock platform

Qt — **Stream terrace deposits (late Holocene)**—Stream terrace deposits judged to be late Holocene (less than 1,000 years) based on records of historical inundation or identification of youthful ocean bar-and-swale or bead bars

Qot — **Stream terrace deposits (Holocene)**—Stream terrace sediments deposited in point bar and overbank environments

Qds — **Dune sand (Holocene)**—Active dunes and recently stabilized dunes in coastal environments

Qe — **Estuarine deposits (Holocene)**—Heterogeneous mixture of coarse and fine estuarine sediment deposited in Drakes Estero (southern edge of map) and at Toms Point on the east shore of Tomales Bay

Qed — **Estuarine delta deposits (Holocene)**—Heterogeneous mixture of coarse and fine estuarine sediment; deposited in a delta at the mouths of tidally influenced coastal streams where fresh water mixes with seawater

Qa — **Alluvial deposits, undivided (Holocene)**—Alluvium deposited in fan, terrace, or basin environments

Qf — **Alluvial fan deposits, undivided (Holocene)**—Sediment deposited by streams emanating from mountain canyons onto alluvial valley floors or alluvial plains

Qof — **Alluvial fan deposits, undifferentiated (latest Pleistocene to Holocene)**—Mapped in small valleys where separate fan, basin, and terrace units could not be delineated at the scale of this mapping

Qc — **Colluvium (Holocene and late Pleistocene)**—Unsorted clay, silt, sand, gravel, and rock debris, in varying proportions

Qls — **Landslide deposits (Holocene and Pleistocene)**—Weathered and disintegrated rocks and soil

Qods — **Older dune sand (late Pleistocene?)**—Dunes stabilized by vegetation; forms large complex east of the mouth of Tomales Bay

Qmt — **Millerton Formation (late Pleistocene)**—Alluvial and estuarine clay, silt, sand, and gravel deposited on terraces along the eastern margin of Tomales Bay

Qmt — **Marine-terrace deposits (late Pleistocene)**—Marine sediments uplifted to form terraces along east coast of Tomales Bay and on southeast coast of Bodega Bay

Qobs — **Beach sand in uplifted marine terraces (late Pleistocene?)**—Reddish-brown, friable sand and gravel; occurs on west coast of Tomales Point, north of Abbots Lagoon

Tp — **Purisima Formation (late Pliocene to late Miocene)**—Marine siltstone, sandstone, and mudstone; locally contains diatomite

Twg — **Wilson Grove Formation (Pliocene and late Miocene)**—Marine sandstone and conglomerate

Tsm — **Santa Margarita Sandstone (late Miocene)**—Massive marine glauconitic and bituminous arkosic sandstone

Tm — **Monterey Formation (middle to late Miocene)**—Marine, thin-bedded chert, porcelanite, shale, and sandstone

Tl — **Laird Sandstone (middle Miocene)**—Arkosic sandstone that contains basal granitic-boulder conglomerate

Kgr — **Granodiorite and granite of Inverness Ridge (Late Cretaceous)**—Granodiorite and granite; aplite and alaskite dikes and masses are locally abundant

Kgd — **Tonalite of Tomales Point (Late Cretaceous)**—Hornblende-biotite tonalite that contains dark dioritic inclusions

Franciscan Complex

KJfss — **Sandstone and shale in the Nicasio Reservoir terrane (Cretaceous and Jurassic)**

KJfgs — **Greenstone in Central belt (Cretaceous and Jurassic)**

fsr — **Mélange in Central belt (Cretaceous and Jurassic)**—Sheared argillite, graywacke, and minor green tuff matrix enclosing blocks and lenses of sandstone, shale, chert, metachert, and serpentinite

ss — **Sandstone and shale blocks within mélange**

ch — **Chert and metachert blocks within mélange**

sp — **Serpentinite blocks and lenses within mélange of the Central belt**

***** — **Metamorphic rocks (Age uncertain, probably Mesozoic or Paleozoic)**—Intruded by Cretaceous granitic rocks; includes mica schist, quartzite, calc-hornfels, and marble (Clark and Brabb, 1997)

EXPLANATION OF MAP SYMBOLS

Contact—Solid where location is certain, dashed where location is approximate, dotted where location is concealed

Fault—Long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed, queried where uncertain. Arrows show direction of relative movement

Folds—Solid where location is certain, long-dashed where location is approximate, short-dashed where location is inferred, 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 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 Tomales 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 bedrock mapping is compiled from Galloway (1977), Clark and Brabb (1997) and Wagner and Gutierrez (2010). Onshore Quaternary mapping is compiled from Witter and others (2006) and Wagner and Gutierrez (2010), with some additional mapping by M.W. Manson (this report); in addition, some units are modified by M.W. Manson on the basis of analysis of 2012 lidar imagery. Traces of San Andreas Fault are compiled from California Geological Survey (1974).

The morphology and the geology of the offshore part of the Offshore of Tomales Point map area result from the interplay between tectonics, sea-level rise, local sedimentary processes, and oceanography. The map area is cut by the northwest-trending San Andreas Fault, a right-lateral transform boundary between the North American and Pacific tectonic plates (fig. 1). The San Andreas strikes through Tomales Bay, the northern part of a linear valley that extends from Bolinas through Olema Valley to Bodega Bay, which separates mainland California from the Point Reyes Peninsula. Onshore investigations indicate that this section of the San Andreas Fault has an estimated slip rate of about 17 to 25 mm/yr (Bryant and Lundberg, 2002; Grove and Niemi, 2005). The devastating great 1906 California earthquake (M7.8, 4/18/1906) is thought to have nucleated on the San Andreas Fault about 60 kilometers south of this map area offshore of San Francisco (see, for example, Bolt, 1968; Lomax, 2005), with the rupture extending northward through the Offshore of Tomales Point map area to the south flank of Cape Mendocino (Lawson, 1908; Brown and Wolfe, 1972).

The Point Reyes Peninsula is bounded to the south and west in the offshore by the north- and east-dipping Point Reyes Thrust Fault (fig. 1; McCulloch, 1987; Heck and others, 1990), located about 20 km west of Tomales Point. Granitic basement rocks are offset about 1.4 km on this thrust fault offshore of Point Reyes (McCulloch, 1987), and this uplift combined with west-side-up offset on the San Andreas Fault (Grove and Niemi, 2005) resulted in uplift of the Point Reyes Peninsula, including Tomales Point and the adjacent continental shelf. Grove and others (2010) reported uplift rates of as much as 1 mm/yr for the south flank of the Point Reyes Peninsula based on marine terraces, but reported no datable terrace surfaces that could constrain uplift for the flight of 4–5 terraces exposed farther north along Tomales Point.

Because of this Quaternary uplift and relative lack of sediment supply from coastal watersheds, there is extensive rugged, rocky seafloor beneath the continental shelf in the Offshore of Tomales Point map area. Granitic rocks (unit Kg) on the seafloor are mapped on the basis of massive character, roughness, extensive fractures, and high backscatter (sheet 3). Neogene sedimentary rocks (units Tl and Tu) commonly form distinctive "ribs," created by differential seafloor erosion of dipping beds of variable resistance. The more massive offshore outcrops of unit Tu in the southern part of the map area are inferred to represent more uniform lithologies. Slopes on the granitic seafloor (generally 1° to 1.3°) are greater than those over sedimentary rock (generally about 0.5° to 0.6°).

Sediment-covered areas occur in gently sloping (less than about 0.6°) middelf environments west and north of Tomales Point, and at the mouth of Tomales Bay. Sediment supply is local, limited to erosion from local coastal bluffs and dunes, small coastal watersheds, and sediment flux out of the mouths of Tomales Bay. Shelf morphology and evolution largely result from eustacy; sea level has risen about 125 to 130 m over about the last 21,000 years (for example, Lambeck and Chappell, 2001), leading to broadening of the continental shelf, progressive eastward migration of the shoreline and wave-cut platform, and associated transgressive erosion and deposition.

Given present exposure to high wave energy, modern nearshore to middelf sediments are mostly sand (unit Qmsd) and a mix of sand, gravel, and cobbles (units Qmsc and Qmsf). These sediments are distributed between rocky outcrops at water depths of as much as 65 m (see below). The coarser grained sands and gravels (units Qmsc and Qmsd) are primarily reoxygrined on the basis of bathymetry and high backscatter (sheets 1, 2, 3). Unit Qmsd forms erosional lags in scoured depressions that are bounded by relatively sharp contacts with bedrock, or sharp to diffuse contacts with units Qms and Qmsc. These depressions are typically a few tens of centimeters deep and range in area from a few tens of square meters to more than one square kilometer.

Similar unit Qmsd scour depressions are common along this stretch of the California coast (see, for example, Cacchione and others, 1984; Davis and others, 2013) where sufficient offshore sandy sediment is relatively thin (unable to fill the depressions) owing to lack of sediment supply and to erosion and 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, Trembanis and Hume, 2011). Although the general areas in which both unit Qmsd scour depressions and surrounding Qms sand sheets occur are not likely to change substantially, the boundaries of the unit(s) likely are ephemeral, changing seasonally and during significant storm events.

Unit Qmsf consists primarily of mud and muddy sand and is commonly extensively bioturbated. The location of the inboard contact at water depths of about 65 m is based on meager sediment sampling and photographic data (sheets 5, 6) and the inference that if must lie offshore of the outer boundary of coarse-grained units Qmsd and Qmsc. This is notably deeper than the inner contact of unit Qmsf offshore of the nearby Russian River (about 50 m; Kline, 1984), which may result from both increased wave energy and significantly decreased supply of muddy sediment.

There are two areas of high-backscatter (sheet 3), rough seafloor at water depths of 65 to 70 m west of northern Tomales Point. These areas are notable in that each includes several small (less than about 20,000 m²), randomly distributed to northwest-trending, irregular "mounds," with as much as 1 m of positive relief above the seafloor (unit Qsr). Seismic-reflection data (for example, sheet 8, fig. 4) reveal this lumpy material rests on several meters of uppermost Pleistocene to Holocene sediment and is thus not bedrock outcrop. We interpret this sediment to be marine debris, possibly derived from the more than 60 shipwrecks that have occurred offshore of the Point Reyes Peninsula between 1849 and 1940 (National Park Service, 2012). It is also conceivable that this lumpy terrane consists of biological "hardgrounds" (that is, groups of fauna on the seafloor that have rigid, often calcareous, shells that exhibit high reflectivity, similar to lithified rock).

Units Qsw, Qstb, Qdtb, and Qkdtb comprise sediments in Tomales Bay. Anima and others (2008) conducted a high-resolution bathymetric survey of Tomales Bay and noted that strong tidal currents at the mouth of the bay had created a large field of sandwaves, dunes, and flats (unit Qsw). Unit Qkdtb is a small subaqueous sandy delta deposited at the mouth of Keys Creek, the largest coastal watershed draining into this northern part of Tomales Bay. Unit Qstb occurs south of units Qsw and Qdtb, and comprises largely flat seafloor underlain by mixed sand and silt. Unit Qdtb consists of depressions within the sedimentary fill of Tomales Bay. These depressions commonly occur directly offshore of coastal promontories, cover as much as 74,000 m², and are as deep as 9 m.

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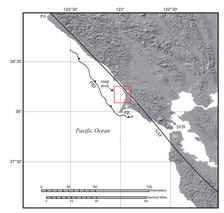

Figure 1. Regional map showing the location of Offshore of Tomales Point map area, San Andreas Fault (SAF), and Point Reyes Fault (PRF). Other abbreviations: PA, Point Arena; PR, Point Reyes; SF, San Francisco; SFB, San Francisco Bay.

Onshore elevation data from California Coastal Conservancy, available at http://www.csc.noaa.gov/digitalcoast/data/coastallidar and from U.S. Geological Survey, 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

MAP LOCATION

Offshore geology and geomorphology mapped by Stephen R. Hartwell and Samuel Y. Johnson, 2012–2013. Onshore geology and geomorphology compiled by Michael W. Manson, 2012–2012, from California Geological Survey (1974), Galloway (1976), Clark and Brabb (1997), Wagner and Gutierrez (2010), and M.W. Manson (unpublished). Bathymetric contours by Mercedes D. Erdey, 2013

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

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

By

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2015

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