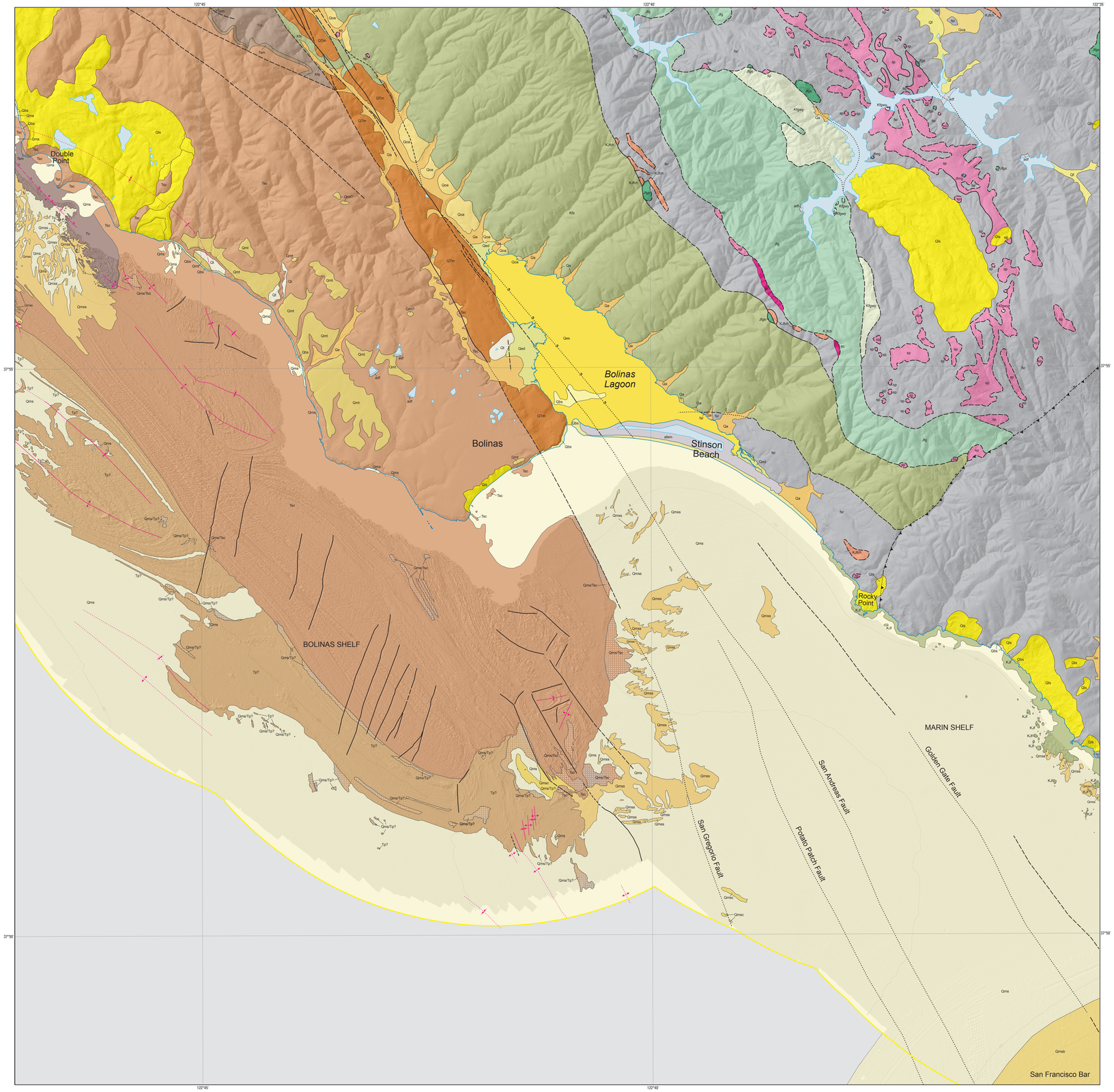
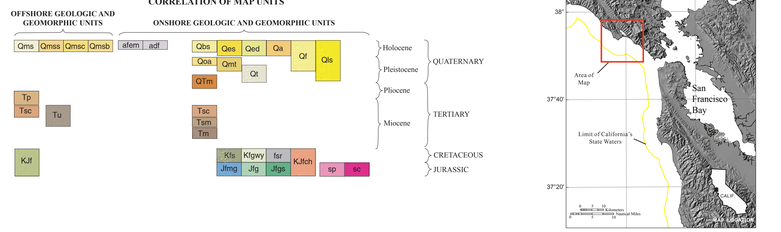
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2015–1135
Sheet 10 of 10
Pamphlet accompanies map



CORRELATION OF MAP UNITS



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
- Qmss — **Marine shelf scour depressions (late Holocene)**—Inferred to be coarse sand and gravel
- Qmsc — **Coarse-grained marine nearshore and shelf deposits (late Holocene)**—Coarse sand, gravel, and cobbles
- Qmsb — **Marine ebb-tidal bar deposits (late Holocene)**—Sandy sediment that forms horseshoe-shaped bar outside mouth of San Francisco Bay
- Tp — **Purisima Formation (Pliocene and late Miocene)**—Marine sandstone, siltstone, and mudstone
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Thin- to thick-bedded siliceous mudstone
- Tu — **Sedimentary rocks, undivided (late Miocene)—**May consist of Santa Cruz Mudstone (unit Tsc) or Santa Margarita Sandstone (mapped onland as unit Tsm)
- Klf — **Franciscan Complex, undivided (Cretaceous and Jurassic)**—Mostly mélange, graywacke, and shale

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units compiled from California Geological Survey (1974), Clark and Brabb (1997), Blake and others (2000), and Witter and others (2006); unit ages, which are from these sources, reflect local stratigraphic relations]

- afem — **Artificial fill over estuarine mud (late Holocene)**—Material deposited by humans over estuarine sediments
- 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 environments; may form veneer over bedrock platform
- Qes — **Estuarine deposits (Holocene)**—Heterogeneous mixture of coarse and fine estuarine sediment; deposited in Bolinas Lagoon
- Qed — **Estuarine-delta deposits (Holocene)**—Heterogeneous mixture of coarse and fine estuarine sediment; deposited in delta at 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 and late Pleistocene)**—Mapped in small valleys where separate fan, basin, and terrace deposits could not be delineated at map scale
- Qls — **Landslide deposits (Holocene and Pleistocene)**—Disintegrated bedrock; physically weathered; ranges from deep-seated landslides to active colluvium. Internal contacts differentiate individual landslide bodies
- Qoa — **Older alluvial deposits, undivided (late Pleistocene)**—Mapped on gently sloping to level alluvial fan or terrace surfaces; age indicated by depth of stream incision, degree of soil development, and other criteria
- Qmt — **Marine-terrace deposits (Pleistocene)**—Sand and gravel, deposited on uplifted marine-abrasion platforms along coast
- Qt — **Stream-terrace deposits (middle and early Pleistocene)**—Sediment deposited in point-bar and overbank environments
- QTm — **Merced Formation (Pleistocene and Pliocene)**—Sandy siltstone, silty sandstone, and interbedded pebble conglomerate
- Tsc — **Santa Cruz Mudstone (late Miocene)**—Siliceous mudstone, nonsiliceous mudstone, siltstone, and minor sandstone
- Tsm — **Santa Margarita Sandstone (late Miocene)**—Massive, coarse- to fine-grained, semifriable arkosic sandstone
- Tm — **Monterey Formation (late and middle Miocene)**—Thin-bedded, marine porcelanite, shale, sandstone, and mudstone
- **Franciscan Complex (Cretaceous and Jurassic)**—Mostly graywacke and shale. Locally divided into following subunits:
- Kls — **Sandstone and shale in San Bruno Mountain terrane (Cretaceous)**
- Klgwy — **Graywacke in Nicasio Reservoir terrane (Cretaceous)**
- fsr — **Central Belt Mélange (Cretaceous)**
- KJfch — **Chert in Marin Headlands terrane (Cretaceous and Jurassic)**
- Jmg — **Metamorphic rocks (Jurassic)**—Within Central Belt Mélange
- Jfg — **Greenstone in Nicasio Reservoir terrane (Jurassic)**
- Jfgs — **Greenstone in Marin Headlands terrane (Jurassic)**
- **Coast Range ophiolite (Jurassic)**—Locally divided into:
- sp — **Serpentinite (Jurassic)**
- sc — **Silica-carbonate rock (Jurassic)**

EXPLANATION OF MAP SYMBOLS

- **Contact**—Solid where location is certain, dashed where approximately located
- **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
- **Thrust fault**—Long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed, queried where uncertain. Sawteeth on upper plate
- **Folds**—Solid where location is certain, dashed where location is approximate, dotted where location is concealed, queried where uncertain
- **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"**—Area 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 Bolinas 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).

Onshore geology was compiled from California Geological Survey (1974), Clark and Brabb (1997), Blake and others (2000), and Witter and others (2006).

The continental shelf within California's State Waters in the Offshore of Bolinas map area is shallow (less than about 30 m) and flat, with a very gentle (less than 0.3°) offshore dip. The seafloor of the Marin shelf east of the San Andreas Fault is smooth and covered with sediment, whereas the seafloor of the Bolinas shelf west of this fault has extensive areas of bedrock outcrop from the nearshore to depths of about 25 m, as well as much less sediment cover (see sheets 1, 2, 8, 9). Shelf morphology and evolution are the result of the interplay between local tectonics (local faulting, folding, uplift, and subsidence) and sedimentation as sea level rose about 125 to 130 m during the last about 21,000 years (see, for example, Stanford and others, 2011). This sea-level rise lead to both the progressive eastward migration (a few tens of kilometers) of the shoreline and wave-cut platform and the associated transgressive erosion and deposition (see, for example, Catuneanu, 2006). The Offshore of Bolinas map area is now an open-ocean shelf that is subjected to the full, and sometimes severe, wave energy and strong currents of the Pacific Ocean (Storlazzi and Wingfield, 2005).

Given the relatively shallow depths and high energy, modern shelf deposits are mostly sand (unit Qms). Coarser grained sands and gravels (units Qmsc and Qmsb) are recognized primarily on the basis of bathymetry and high backscatter (sheets 1, 2, 3). Unit Qmsc is mapped in two areas, (1) west of the rocky outcrops on the Bolinas shelf, and (2) in three mounds south of Bolinas, along the San Gregorio Fault near the limit of California's State Waters, at water depths of about 25 m. The largest of these mounds is about 450 m long and 70 m wide, and it has 80 cm of positive relief.

Unit Qmss is much more extensive and forms erosional lags in scour depressions (see, for example, Cacchione and others, 1984) that typically are a few tens of centimeters deep and bounded by mobile sand sheets. The depressions are mapped in four distinct locations. (1) The first unit Qmss location lies adjacent to bedrock outcrops within 2 km of the shoreline south of Double Point (near the west edge of the map area), at water depths of 10 to 25 m. (2) The second unit Qmss location is in an area that extends from about 1 to 6 km south of Bolinas Lagoon, along the east flank of the exposed bedrock on the Bolinas shelf, at similar water depths. (3) The third, more restricted unit Qmss location is near the east edge of the map area, about 4 km southeast of Rocky Point, adjacent to and offshore of small bedrock uplifts within 1 km of the shoreline, at water depths of about 10 to 12 m. (4) The fourth unit Qmss location, 2 km south of Stinson Beach and 2 km east of the Marin shelf seafloor bedrock outcrops, is notably different; the single Qmss polygon in this area encloses more than 100 much smaller (less than 20 m long) oval depressions and intervening sand sheets.

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. Although the general areas in which both unit Qmss scour depressions and surrounding mobile 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.

Areas where shelf sediments form thin (less than 2.5 m) veneers over low-relief rocks of Neogene bedrock units (the Santa Cruz Mudstone and the Purisma Formation) are mapped as units Qms/Tsc and Qms/Tp?, respectively. These composite units are recognized on the basis of the combination of flat relief, continuity with moderate- to high-relief bedrock outcrops, high-resolution seismic-reflection data (see sheet 8), and (in some cases) moderate to high backscatter. Overlying sediment is interpreted as an ephemeral and dynamic sediment layer that may or may not be continuously present at a specific location, depending on storms, seasonal and (or) annual patterns of sediment movement, or longer term climate cycles. Storlazzi and others (2011) described the seasonal burial and exhumation of submerged bedrock in a similar high-energy setting in northern Monterey Bay, about 115 km south of the map area.

The southeast part of the map area includes part of the outer flank of the horseshoe-shaped "San Francisco Bar" (unit Qmsb), which has formed at the mouth of the San Francisco ebb-tidal delta (Barnard and others, 2007). The "San Francisco Bar" is shaped by both tidal currents and waves, the latter of which regularly exceed 6 m in height on the continental shelf during major winter storms (Barnard and others, 2007). This mix of tidal-current and wave influences has resulted in a variably hummocky, mottled, and rilled seafloor.

The Offshore of Bolinas map area, which straddles the right-lateral transform boundary between the North American and Pacific plates, is cut by several active faults that cumulatively form a distributed shear zone. These active faults include the San Andreas Fault, the east strand of the San Gregorio Fault Zone, the Golden Gate Fault, and the Potato Patch Fault (see sheets 8, 9; see also, Bruns and others, 2002; Ryan and others, 2008). The offshore parts of these faults, which are buried by sediment (mostly unit Qmss) and, thus, have no surface expression, are mapped on the basis of seismic-reflection data (see sheet 8). The San Andreas Fault, which is the dominant plate-boundary structure, extends offshore through the southern part of the map area before moving onshore at Bolinas Lagoon. In this area, the San Andreas Fault has an estimated slip rate of 17 to 24 mm/yr (U.S. Geological Survey and California Geological Survey, 2010), and the devastating great 1906 California earthquake (M7.8) is thought to have nucleated on the San Andreas Fault a few kilometers south of the map area, offshore of San Francisco (see, for example, Bolt, 1968; Lomax, 2005).

The San Andreas Fault forms the boundary between two distinct basement terranes: to the east are Jurassic and Cretaceous mélange and graywacke of the Franciscan Complex; to the west on the Point Reyes peninsula are Late Cretaceous granitic and older metamorphic rocks of the Salinian block. Rocks of the Franciscan Complex (undivided unit KJf) form seafloor outcrops near the shoreline southeast of Stinson Beach that commonly are continuous with onshore coastal outcrops (Blake and others, 2000). Granitic rocks of the Salinian block, which crop out in the adjacent "Drakes Bay and Vicinity" map area (Watt and others, 2015), are overlain by a thick section of Neogene marine sedimentary rocks. These sedimentary rocks include the middle and upper Miocene Monterey Formation (mapped onland as unit Tm), the upper Miocene Santa Margarita Sandstone (mapped onland as unit Tsm), the upper Miocene Santa Cruz Mudstone (unit Tsc), and the upper Miocene and Pliocene Purisima Formation (unit Tp) (Clark and Brabb, 1997). Unit Tu consists of undivided Santa Margarita Sandstone and Santa Cruz Mudstone

The Santa Cruz Mudstone at Bolinas is more than 1,000 m thick, measured at an oil test well (Clark and Brabb, 1997), and it forms coastal bluffs and tidal-zone exposures that extend offshore onto the adjacent, emergent bedrock shelf. The Santa Cruz Mudstone thins markedly to the northwest, and it disappears from the section about 14 km northwest of the map area (onshore of Drakes Bay) where the Purisima Formation unconformably overlies the Santa Margarita Sandstone. We infer that this angular and erosional unconformity extends offshore and southeastward into the map area, on the basis of discordant bedding and surface textures seen in the high-resolution bathymetry (see sheets 1, 2). Below the unconformity (to the northeast), rocks of the Santa Cruz Mudstone typically are more thinly bedded, forming "ribbed" outcrops, whereas above the unconformity (to the southwest), rocks inferred to be the Purisima Formation are more variably bedded and yield both "ribbed" and more massive seafloor outcrops. Both units (above and below the unconformable contact) are cut by dense, crosscutting fractures. It should be noted that this stratigraphic interpretation (the Purisima Formation unconformably overlying the Santa Cruz Mudstone in the offshore) is based on onshore outcrop trends and has not been confirmed by offshore lithologic sampling. An alternate interpretation may be that the angular unconformity is present within the Santa Cruz Mudstone, and all of the emergent rock on the Bolinas shelf belongs to that unit. We consider this alternative unlikely; to indicate this uncertainty, we have queried the Purisima Formation (unit Tp?) in the offshore part of the map area.

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Onshore elevation data collected by Earth Eye in 2010 for San Francisco State University and U.S. Geological Survey (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

APPROXIMATE MEAN DECLINATION, 2015

SCALE 1:24 000

1 MILE
1 KILOMETER

BATHYMETRIC CONTOUR INTERVAL 10 METERS
ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

Offshore geology and geomorphology mapped by Samuel Y. Johnson, H. Gary Greene, Stephen R. Hartwell, Charles A. Endris, and Janet T. Watt, 2010–2012. Onshore geology compiled by Michael W. Manson from California Geological Survey (1974), Clark and Brabb (1997), Blake and others (2000), and Witter and others (2006). Bathymetric contours by Mercedes D. Erdey, 2012

GIS database and digital cartography by Stephen R. Hartwell, Elayne L. Phillips, and Florence L. Wong

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Offshore and Onshore Geology and Geomorphology, Offshore of Bolinas Map Area, California

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