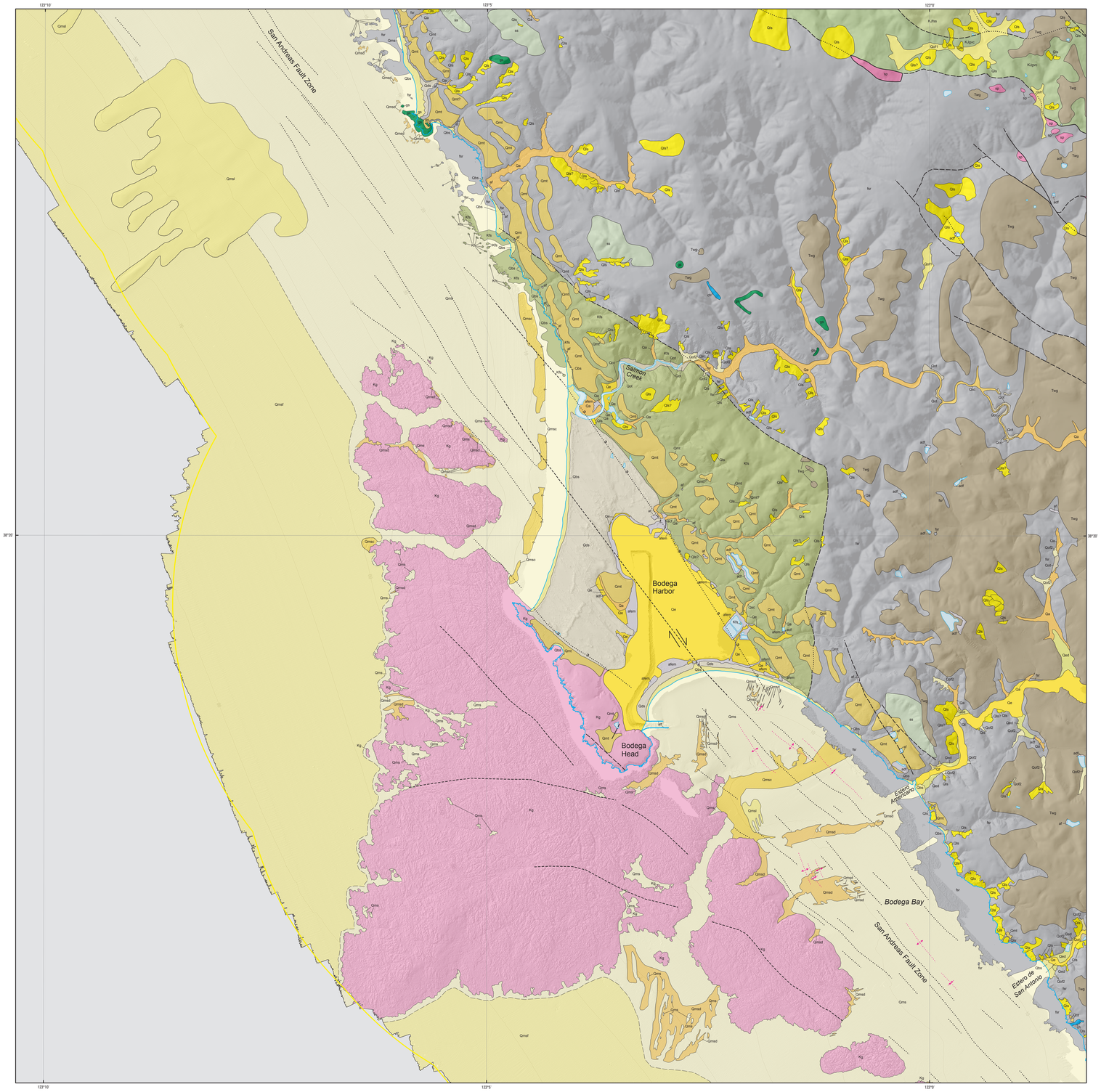
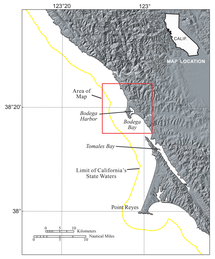
U.S. Department of the Interior
U.S. Geological Survey

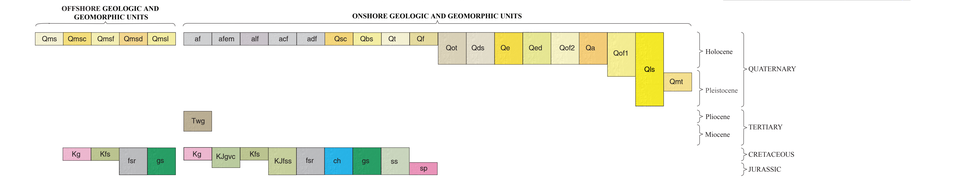
Open-File Report 2015–1140
Sheet 10 of 10
Pamphlet accompanies map





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

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

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

Qmsf — **Fine-grained marine shelf deposits (late Holocene)**—Predominantly mud, very fine sand, and silt

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

Qmsl — **Marine sediment lobes (late Holocene)**—Fields of elongate, paired sediment lobes and chutes

Kg — **Granitic rocks of Bodega Head (Late Cretaceous)**—Seafloor outcrops mapped on basis of high backscatter and rough, massive, and fractured seafloor texture

Franciscan Complex (Cretaceous and Jurassic)

Kfs — **Sandstone in Central Belt (Cretaceous)**—Massive to distinctly bedded feldspathic and feldspathic-lithic wacke

fsr — **Mélange in Central Belt (Cretaceous and (or) Jurassic)**—Matrix of sheared argillite, graywacke, and minor green tuff that encloses blocks and lenses of diverse sedimentary, volcanic, and metamorphic rocks

gs — **Greenstone blocks within mélange (Cretaceous and (or) Jurassic)**—Includes massive and pillowed greenstone and basalt

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Units compiled from Blake and others (2002), Witter and others (2006), and Wagner and Gutierrez (2010; unpub. data); unit ages, which are from these sources, reflect local stratigraphic relations; some units modified by M.W. Manson (this report) on basis of interpretation of 2003 and 2012 lidar imagery]

af — **Artificial fill (late Holocene)**—Material deposited 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

acf — **Artificial-channel fill (late Holocene)**—Deposited in historically active stream channel where flow has been rerouted

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

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

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

Qt — **Stream terrace deposits (late Holocene)**—Point-bar and overbank deposits elevated above modern stream channel

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

Qot — **Stream-terrace deposits (Holocene)**—Point-bar and overbank deposits elevated above modern stream channel; older than unit Qt

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

Qe — **Estuarine deposits (Holocene)**—Heterogeneous mixture of coarse and fine estuarine sediment

Qed — **Estuarine-delta deposits (Holocene)**—Coarse and fine estuarine sediment; deposited at mouths of tidally influenced coastal watersheds

Qof2 — **Alluvial fan deposits, undivided (Holocene)**—Sediment deposited by streams emanating from canyons onto alluvial valley floors or alluvial plains

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

Qof1 — **Alluvial fan deposits, undivided (Holocene and late Pleistocene)**—Mapped in small valleys where separate fan, basin, and terrace units could not be delineated at map scale

Qls — **Landslide deposits (Holocene and Pleistocene)**—Weathered rocks and soil. Internal contacts differentiate individual landslide bodies

Qmt — **Marine-terrace deposits (late Pleistocene)**—Sand, gravel, and cobbles; deposited on marine-abrasion platforms and later uplifted to present-day elevations along coast

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

Kg — **Granitic rocks of Bodega Head (Late Cretaceous)**—Tonalite, granodiorite, and porphyritic granodiorite

KJgvc — **Great Valley sequence conglomerate of Healdsburg terrane (Late Cretaceous to Late Jurassic)**—Pebble to boulder conglomerate

Franciscan Complex (Cretaceous and Jurassic)

Kfs — **Sandstone of Central belt (Cretaceous)**—Massive to distinctly bedded feldspathic and feldspathic-lithic wacke

KJfss — **Sandstone and shale of Central Belt (Cretaceous and (or) Jurassic)**—Massive to distinctly bedded, lithic wacke, siltstone, shale, and slate, grading into mélange

fsr — **Mélange of Central Belt (Cretaceous and (or) Jurassic)**—Matrix of sheared argillite, graywacke, and minor green tuff that encloses blocks and lenses of diverse sedimentary, volcanic, and metamorphic rocks

ch — **Chert and metachert blocks within mélange (Cretaceous and (or) Jurassic)**—Includes massive and thinly bedded red, green, and white chert and metachert

gs — **Greenstone blocks within mélange (Cretaceous and (or) Jurassic)**—Includes massive and pillowed greenstone and basalt

ss — **Sandstone and shale blocks within mélange (Cretaceous and (or) Jurassic)**

sp — **Ultramafic rocks of Coast Range Ophiolite (Late and Middle Jurassic)**—Partly to completely serpentinized peridotite

EXPLANATION OF MAP SYMBOLS

Contact—Solid where location is certain, dashed where location is approximate, queried where uncertain

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. Arrows show relative motion on strike-slip fault

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 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 Bodega Head 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 Blake and others (2002) and Wagner and Gutierrez (2010; unpub. data). 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 2003 and 2012 lidar imagery. Traces of the San Andreas Fault are compiled from Brown and Wolfe (1972), California Geological Survey (1974a,b,c), and previously unpublished mapping by M.W. Manson.

The geology and geomorphology of the offshore part of the Offshore of Bodega Head map area are the result of the interplay between tectonics, sea-level rise, local sedimentary processes, and oceanography. The map area is cut by the northwest-striking San Andreas Fault (fig. 1), the right-lateral transform boundary between the North American and Pacific plates. From southeast to northwest, this fault runs through Bodega Bay and Bodega Harbor, crosses the Bodega Head isthmus south of the mouth of Salmon Creek, and extends offshore for about 20 km before passing onland at Fort Ross, about 10 km north of the map area. The San Andreas Fault (fig. 1) juxtaposes Jurassic and Cretaceous Franciscan Complex rocks on the northeast with Cretaceous granitic rocks on the southwest. Uplift of the granitic rocks (unit **Kg**) on the southwest side of the San Andreas Fault has created an extensive, rugged and rocky seafloor, centered offshore of Bodega Head, that extends northwestward for about 15 km, from the west flank of Bodega Bay to the shelf offshore of the mouth of Salmon Creek. This rocky seafloor reaches water depths of about 40 and 50 m to the south and north of Bodega Head, respectively; west of Bodega Head, the rocky seafloor reaches water depths of 80 m. Northeast of the San Andreas Fault, offshore rocky outcrops of the Franciscan Complex (units **Kfs**, **KJfss**, **fsr**) are found only in the nearshore (water depths of less than 15 m).

Sediment-covered areas of the offshore part of the map area are found in gently sloping (less than about 1°) nearshore, inner shelf, and midshelf environments. Sediment supply to the shelf north and west of Bodega Head is predominantly from coastal watersheds, which include the Russian River (4.5 km north of the map area) and Salmon Creek. Sediment supply to Bodega Bay and the shelf in the southern part of the map area is from small coastal watersheds and estuaries such as Estero Americano and Estero de San Antonio, and it also most likely is from sediment flux out of the mouth of Tomales Bay, 2 km south of the map area. Shelf morphology and evolution largely reflects eustasy; sea level has risen about 125 to 130 m over about the last 21,000 years (see, for example, Lambeck and Chappell, 2001; Peltier and Fairbanks, 2006), leading to a broadening of the continental shelf, the progressive eastward migration of the shoreline and wave-cut platform, and the associated transgressive erosion and deposition.

Given the present exposure to high wave energy, modern nearshore to inner shelf sediments are mostly sand (unit Qms) and (or) a mix of sand, gravel, and cobbles (units Qmsc and Qmsd). Coarser grained sands and gravels (units Qmsc and Qmsd) are recognized primarily on the basis of bathymetry and high backscatter (sheets 1, 2, 3). Unit Qmsc is mapped in two areas, (1) as a linear nearshore bar (water depths of less than 10 m) offshore of Salmon Creek (the eastern contact of this unit is queried because of the lack of data in the surf zone), and (2) as an east-west-trending bar at the north end of Bodega Bay.

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 area from a few tens of square meters to more than one square kilometer. 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 (thus 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.

Unit Qmsf, which lies offshore of unit Qms, consists primarily of mud and muddy sand, and it commonly is extensively bioturbated. The water depth of the transition from sand-dominated marine sediment (unit Qms) to mud-dominated marine sediment (Qmsf) is about 45 to 50 m, except for the area offshore of Bodega Head where bedrock outcrops that extend to depths of 80 m at the limit of California's State Waters have little or no sediment cover.

The smooth seafloor in the northern part of the map area, between water depths of 40 and 70 m, includes an about 3.5-km-wide field of elongate, shore-normal sediment lobes (unit Qmsl). Individual lobes within the field, which are as much as 1,000 m long and 150 m wide, have as much as 4 m of relief above the surrounding smooth seafloor, and they commonly are transitional to upslope chutes. This sediment-lobe field lies just 1 km west of the San Andreas Fault, and we infer that strong ground motions generated by large earthquakes on this structure triggered slope failures, mobilizing sediment flows that moved down the gently sloping shelf and were deposited as lobes. Unit Qmsl also is present as a 250-m-wide field that consists of four discrete lobes and paired arcuate, low-relief scours, mapped on the south flank of the east-west-trending bar (unit Qmsc) in northern Bodega Bay.

Onshore investigations indicate that the San Andreas Fault in this area has an estimated slip rate of about 17 to 25 mm/yr (U.S. Geological Survey and California Geological Survey, 2010). Emergent marine terraces near Bodega Bay record rates of uplift associated with the fault system of about 0.1 mm/yr (Landis and others, 2004). The destructive great 1906 California earthquake (M7.8, 418/1906) is thought to have nucleated on the San Andreas Fault offshore of San Francisco (see, for example, Bolt, 1968; Lomax, 2005), about 70 kilometers south of the map area. Fault rupture in the 1906 earthquake extended about 300 km northward from the epicenter through the Offshore of Bodega Head map area (Lawson, 1908; Brown and Wolfe, 1972)

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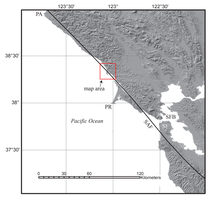

Figure 1. Regional map showing location of Offshore of Bodega Head map area (red box) and San Andreas Fault (SAF). Other abbreviations: PA, Point Arena; PR, Point Reyes; SF, San Francisco; SFB, San Francisco Bay.

Onshore elevation data from California Coastal Conservancy (available at http://www.csc.noaa.gov/digitalcoast/data/coastallidar) and from U.S. Geological Survey'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, 2012–2013. Onshore geology and geomorphology compiled by Michael W. Manson, 2014, from Wagner and Gutierrez (2010; unpub. data), California Geological Survey (1974), Blake and others (2002), Witter and others (2006), Wagner and Gutierrez (unpub. data), and M.W. Manson (unpub. data). 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 Bodega Head Map Area, California

By

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