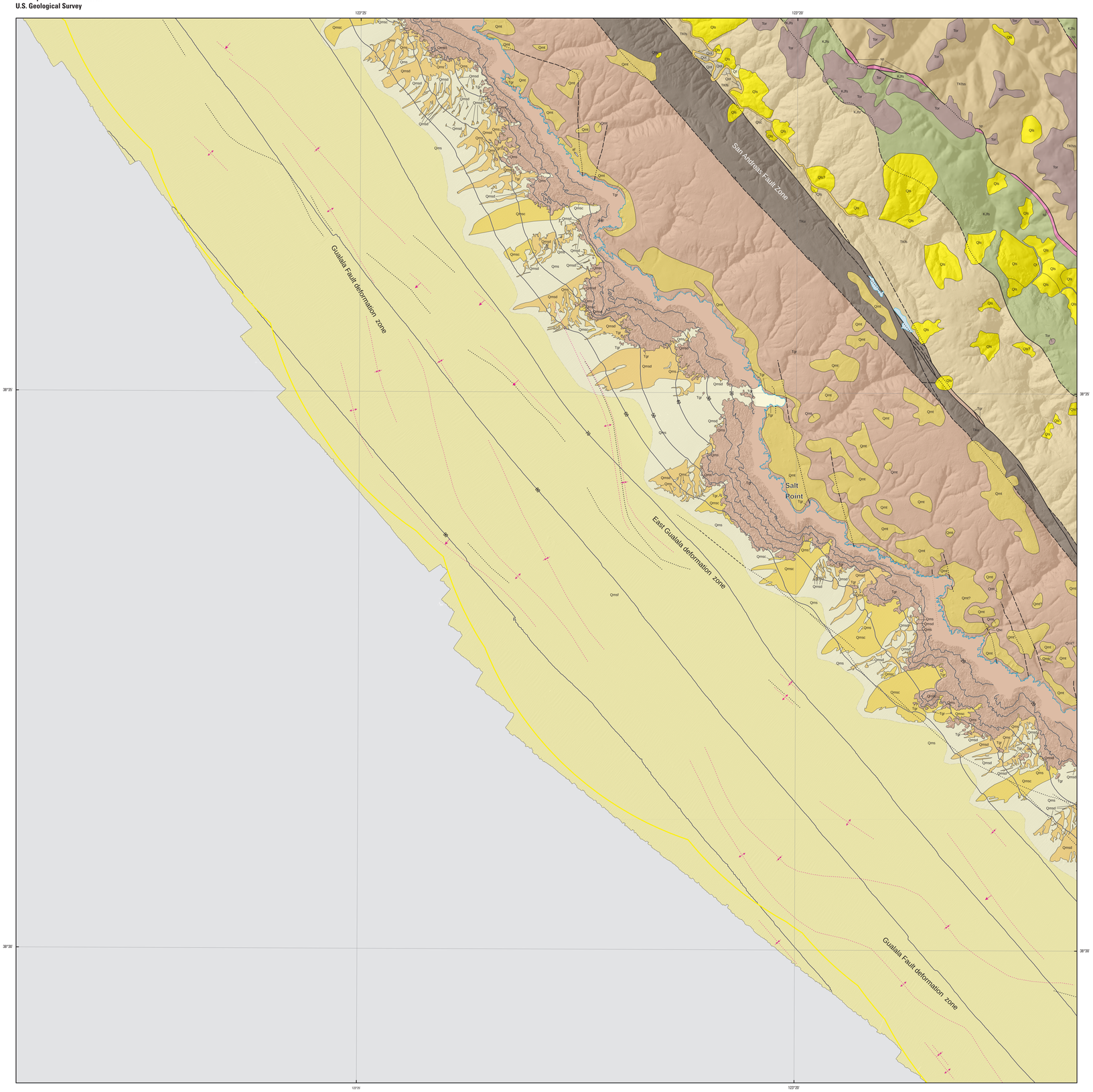
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2015–1098
Sheet 10 of 10
Pamphlet accompanies map



Onshore elevation data from National Aeronautics and Space Administration and U.S. Geological Survey, available at http://www.opentopography.org/, and from U.S. Geological Survey, National Elevation Dataset, available at http://ned.usgs.gov/.
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 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

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, 2012-2013, from California Geological Survey (1974), Huffman (1972), Blake and others (2002), Fuller and others (2002), and Manson and others (2006). Bathymetric contours by Peter Dartnell

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

Manuscript approved for publication May 12, 2015

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

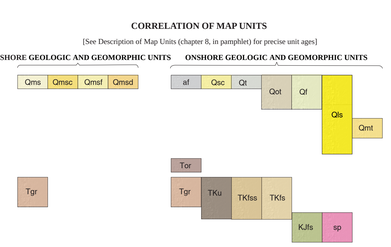
By
Stephen R. Hartwell,[1] Samuel Y. Johnson,[1] and Michael W. Manson[2]

2015

[1]U.S. Geological Survey;
[2]California Geological Survey

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)**—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

Tgr **German Rancho Formation (Elder, 1998) (Eocene and Paleocene)**—Well-bedded, fine- to medium-grained sandstone, mudstone, and conglomerate

ONSHORE GEOLOGIC AND GEOMORPHIC UNITS

[Bedrock units compiled from Huffman (1972), California Geological Survey (1974), Blake and others (2002), Fuller and others (2002), and Manson and others (2006). Quaternary unit designations are from Witter and others (2006)]

af **Artificial fill (late Holocene)**—Engineered and (or) nonengineered

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

Qt **Stream terrace deposits (late Holocene)**—Stream terrace deposits inferred to have formed in the last 1,000 years

Qot **Stream terrace deposits (Holocene)**—Stream terrace deposits that formed in point bar and overbank environments

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

Qls **Landslide deposits (Holocene and Pleistocene)**—Weathered rocks and soil; intra-unit contacts separate different landslide bodies

Qmt **Marine terrace deposits (late Pleistocene)**—Sand, gravel and cobbles deposited on wave-cut platforms, later uplifted to their present elevations along the coast

Tor **Ohlson Ranch Formation (Blake and others, 2002) (Pliocene)**—Horizontal, thickly bedded, well-consolidated sandstone

Tgr **German Rancho Formation (Elder, 1998) (Eocene and Paleocene)**—Well-bedded, fine- to medium-grained sandstone, mudstone and conglomerate

TKu **German Rancho and Gualala Formations, undivided (Elder, 1998) (Eocene, Paleocene, and Late Cretaceous)**—sandstone, conglomerate, mudstone, and shale

Franciscan Complex (Eocene, Paleocene, Cretaceous, and Jurassic)

TKlss **Sandstone within the Coastal Belt (late Eocene to Late Cretaceous)—Mostly massive, feldspathic and feldspathic-lithic wacke**

TKls **Sandstone within the Coastal or Central Belts (late Eocene to Late Cretaceous)**—Mostly massive, feldspathic-lithic wacke

KJfs **Graywacke and mélange within the Central Belt (Cretaceous and Jurassic)**—Massive to well-bedded lithic wacke, siltstone, shale, and slate, grading into mélange

sp **Serpentinite blocks and lenses within mélange of the Central Belt (Cretaceous and(or) Jurassic)**

EXPLANATION OF MAP SYMBOLS

Contact—Solid where location is certain, long-dashed where location is approximate

Fault—Long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed, queried where uncertain

Folds—Dotted where location is approximate or concealed

Anticline

Syncline

Significant inflection (change in dip) within limb of fold

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 the 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 Salt 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 geologic mapping was compiled from Huffman (1972), California Geological Survey (1974), Blake and others (2002), Fuller and others (2002), and Manson and others (2006). Quaternary unit designations are adapted from Witter and others (2006).

The morphology and the geology of the Offshore of Salt Point map area result from the interplay between local sea-level rise, sedimentary processes, oceanography, and tectonics. The offshore part of the map area extends from the shoreline to water depths of about 90 to 100 m on the mid-continental shelf; the shelf break occurs about 20 km farther offshore at water depths of about 200 m. The nearshore and inner shelf (to water depths of about 50 to 60 m) typically dips seaward about 1.0° to 1.5°; the mid to outer shelf dips more gently, generally less than 0.5°. Sea level has risen about 125 to 130 m during the last about 21,000 years (for example, Lambeck and Chappell, 2001; Peltier and Fairbanks, 2006), leading to 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 dynamic setting, then subjected to full Pacific Ocean wave energy and strong currents before deposition or offshore transport. Tectonic influences impacting shelf morphology and geology are related to local faulting, folding, uplift, and subsidence (see below).

Bedrock of the Paleocene and Eocene German Rancho Formation (Elder, 1998) (unit Tgr) underlies much of the inner shelf, extending to water depths of as much as 60 m. Although onshore coastal outcrops of this unit are well bedded, seafloor outcrops imaged on high-resolution bathymetry (sheets 1, 2) have a hackly surface texture and abundant fractures. Embayments in the outer margin of the seafloor bedrock outcrops are commonly paired with the mouths of coastal watersheds and are inferred to have formed by fluvial erosion during the last sea-level lowstand. One of the more prominent embayments occurs about one kilometer north of Salt Point at the mouth of Miller Creek (see fig. 1–2 in pamphlet). These coastal watersheds are relatively small and steep, extending to a drainage divide just 2 to 3 km east of the shoreline, and are inferred sources of coarse-grained sediments. Immediately east of this onshore topographic divide, drainage along this part of the coast is captured by the northwest-flowing South Fork of the Gualala River (pamphlet fig. 1–2), which runs parallel to the coast along the trace of the San Andreas Fault.

Given relatively shallow water depths (0 to about 50 m) and exposure to high wave energy, modern nearshore to midshelf sediments are mostly sand (unit Qmsc) and a mix of sand, gravel, and cobbles (units Qmsc and Qmsd). The coarser grained sands and gravels (units Qmsc and Qmsd) are primarily recognized on the basis of bathymetry and high backscatter (sheets 1, 2, 3). Both Qmsc and Qmsd typically have abrupt landward contacts with bedrock (unit Tgr) and form irregular to lenticular exposures that are commonly elongate in the shore-normal direction. Contacts between units Qmsc and Qmsd are typically gradational. Unit Qmsd forms erosional lags in scoured depressions that are bounded by relatively sharp and less commonly diffuse contacts with unit Qms horizontal sand sheets. These depressions are typically a few tens of centimeters deep and range in size 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; Hallenbeck and others, 2012) where surficial offshore sandy sediment is relatively thin (thus unable to fill the depressions) due to both 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, Goff and others, 2005; Trembanis and Hume, 2011). Although the general areas in which both unit Qmsd scour depressions and surrounding mobile sand sheets occur are not likely to change substantially, the boundaries of the individual Qmsd depressions are likely ephemeral, changing seasonally and during significant storm events.

The offshore decrease in slope at midshelf water depths (about 60 m) approximately coincides with a transition to finer grained marine sediments (unit Qmsf), which extends to the outer (3-nautical-mile) limit of California's State Waters. Unit Qmsf consists primarily of mud and muddy sand and is commonly extensively bioturbated. These fine-grained sediments are inferred to have been derived from the Russian River, the mouth of which is about 15 km south of the map area. Both Drake and Cacchione (1985) and Sherwood and others (1994) have documented seasonal, midshelf, northwest-directed, bottom currents capable of transporting fine-grained, suspended sediment from the Russian River to the Offshore of Salt Point map area.

The onshore part of the Offshore of Salt Point map area is cut by the northwest-striking San Andreas Fault—the right-lateral transform boundary between the North American and Pacific tectonic plates. The San Andreas Fault extends into the offshore about 5 km south of the map area near Fort Ross, and about 50 km north of the map area on the east flank of Point Arena. The coast between Fort Ross and Point Arena, the northwesternmost exposed section west of the San Andreas Fault, is known as the "Gualala Block" (fig. 1) on the basis of its distinctive geology, which has been widely used to develop paleogeographic reconstructions of coastal California that restore as much as 150 to 180 km of right-lateral slip on the combined San Andreas and San Gregorio Fault systems (see, for example, Wentworth, 1968; Wentworth and others, 1998; Jachens and others, 1998; Dickinson and others, 2005; Burnham, 2009). The Gualala Block is underlain by a thick (as much as 9 to 11 km, in aggregate), discontinuous Upper Cretaceous to Miocene stratigraphic section (summarized in Elder, 1998; Wentworth and others, 1998), however only the Paleocene and Eocene German Rancho Formation (unit Tgf) is exposed onshore and is inferred to form seafloor bedrock outcrops in the Offshore of Salt Point map area. The German Rancho Formation consists of sandstone, mudstone, and conglomerate interpreted as deep-water, submarine-fan deposits.

The western boundary of the Gualala Block is located offshore. Using seismic-reflection data, McCulloch (1987; his fig. 14) mapped a shore-parallel fault about 3 to 5 km offshore, which Dickinson and others (2005) subsequently named the Gualala Fault. Jachens and others (1998) evaluated aeromagnetic and gravity data across this zone and modeled this structure as a steep fault within the Salinian basement block, characterized by 3 to 5 km of right-lateral offset. In contrast, Dickinson and others (2005) consider the Gualala Fault a late Miocene strand of the San Andreas Fault, separating Salinian and Franciscan basement rocks, with minimum right-lateral slip of 70 km. Our analysis of deeper industry seismic-reflection data within California's State Waters shows the Gualala Fault as a steep, northeast-dipping structure (figs. 5, 8 on sheet 8). Shallower seismic-reflection crossing the Gualala Fault reveal a thick late(?) Pleistocene section characterized by recent faulting and gentle asymmetric folding (figs. 1, 2, 3, 4, 6, 7, 9, 10 on sheet 8). Hence, the Gualala Fault appears to be a recently active "blind" structure that has deformed young sediments. Our mapping also documents a more nearshore zone of deformation that we refer to as the "east Gualala deformation zone." This zone extends through the central and southern parts of the Offshore of Salt Point map area and is similarly characterized by steep faults and gentle folds that deform inferred upper Pleistocene strata.

This northern California section of the San Andreas Fault has an estimated slip rate of about 17 to 25 mm/yr (Bryant and Lundberg, 2002). The devastating great 1906 California earthquake (M7.8, 4/18/1906) is thought to have nucleated on the San Andreas Fault about 100 kilometers south of this map area offshore of San Francisco (for example, Bolt, 1968; Lomax, 2005), with the rupture extending northward through the onshore part of the Offshore of Salt Point map area to the south flank of Cape Mendocino (Lawson, 1908; Brown and Wolfe, 1972). Emergent marine terraces along the coast in the Offshore of Salt Point map area record recent contractional deformation associated with the San Andreas Fault system. Prentice and Kelson (2006) reported uplift rates of 0.3 to 0.6 mm/yr for a nearby late Pleistocene terrace (exposed at Fort Ross, about 5 km south of the map area) and this recent uplift must also have affected the nearshore and inner shelf, at least as far west as the Gualala Fault.

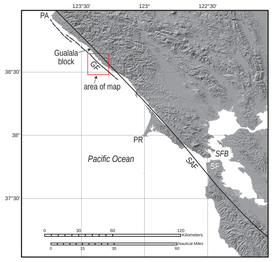


Figure 1. Regional map showing the location of the Offshore of Salt Point map area (red square); the San Andreas Fault (SAF); the Gualala Fault (GF; location from this work and McCulloch, 1987), and the Gualala block (Elder, 1998). Dickinson and others (2005) interpreted the Gualala Fault as the western boundary of the Gualala block, whereas Jachens and others (1998) inferred the block boundary was much farther offshore. PA, Point Arena; PR, Point Reyes; SF, San Francisco; SFB, San Francisco Bay.

REFERENCES CITED

Blake, M.C., Jr., Graymer, R.W., and Stamski, R.E., 2002, Geologic map and map database of western Sonoma, northernmost Marin, and southernmost Mendocino counties, California: U.S. Geological Survey Miscellaneous Field Studies Map 2402, scale 1:100,000.

Bolt, B.A., 1968, The focus of the 1906 California earthquake: Bulletin of the Seismological Society of America, v. 58, p. 457–471.

Brown, R.D., Jr., and Wolfe, E.W., 1972, Map showing recently active breaks along the San Andreas Fault between Point Delgada and Bolinas Bay, California: U.S. Geological Survey Miscellaneous Investigations Map I-692, scale 1:24,000.

Bryant, W.A., and Lundberg, M.M., compilers, 2002, Fault number 1b, San Andreas fault zone, North Coast section, in Quaternary fault and fold database of the United States: U.S. Geological Survey website, accessed April 4, 2013 at http://earthquakes.usgs.gov/hazards/qfaults/.

Burnham, K., 2009, Predictive model of San Andreas Fault system paleogeography, Late Cretaceous to early Miocene, derived from detailed multidisciplinary conglomerate correlations: Tectonophysics 464, p. 195–258, doi:10.1016/j.tecto.2007.11.056.

Cacchione, D.A., Drake, D.E., Grant, W.D., and Tate, G.B., 1984, Rippled scour depressions on the inner continental shelf off central California: Journal of Sedimentary Petrology, v. 54, p. 1,280–1,291.

California Geological Survey, 1974, Alquist-Priolo Earthquake Fault Zone Maps of Annapolis and Plantation quadrangles, scale 1:24,000, available at http://www.quake.ca.gov/gmaps/WH/regulatorymaps.htm.

Dickinson, W.R., Ducea, M., Rosenberg, L.I., Greene, H.G., Graham, S.A., Clark, J.C., Weber, G.E., Kidder, S., Ernst, W.G., and Brabb, E.E., 2005, Net dextral slip, Neogene San Gregorio–Hosgri fault zone, coastal California—Geologic evidence and tectonic implications: Geological Society of America Special Paper 391, 43 p, doi:10.1130/2005.2391.

Drake, D.E., and Cacchione, D.A., 1985, Seasonal variation in sediment transport on the Russian River shelf, California: Continental Shelf Research, v. 4, p. 495–514, doi:10.1016/0278-4343(85)90007-x.

Elder, W.P., ed., 1998, Geology and tectonics of the Gualala Block, northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 84, 222 p.

Fuller, M.S., Haydon, W.D., Purcell, M.G., and Cunitis, K., 2002, Geologic and geomorphic features related to landsliding, Gualala River watershed, Sonoma and Mendocino counties, California: California Geological Survey Watershed Mapping Series, Map Set 5, Plate 1, Sheet 3 of 3, scale 1:24,000, available at http://www.conservation.ca.gov/cgs/fwgp/Pages/gualala.aspx/.

Goff, J.A., Mayer, L.A., Traykovski, P., Buynevich, I., Wilkens, R., Raymond, R., Glang, G., Evans, R.L., Olson, H., and Jenkins, C., 2005, Detailed investigations of sorted bedforms, or "rippled scour depressions," within the Martha's Vineyard Coastal Observatory, Massachusetts: Continental Shelf Research, v. 25, p. 461–484, doi:10.1016/j.csr.2004.09.019.

Hallenbeck, T.R., Kvitek, R.G., and Lindholm, J., 2012, Rippled scour depressions add ecologically significant heterogeneity to soft-bottom habitats on the continental shelf: Marine Ecology Progress Series, v. 468, p. 119–133, doi:10.3354/meps09948.

Huffman, M.E., 1972, Geology for planning on the Sonoma County coast between the Russian and Gualala Rivers: California Division of Mines and Geology Preliminary Report 16, 38 p., 4 plates, scale 1:24,000.

Jachens, R.C., Wentworth, C.M., and McLaughlin, R.J., 1998, Pre-San Andreas location of the Gualala Block inferred from magnetic and gravity anomalies, *in* Elder, W.P., ed., Geology and tectonics of the Gualala block, northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 84, p. 27–53.

Lambeck, K., and Chappell, J., 2001, Sea level change through the last glacial cycle: Science, v. 292, p. 679–686, doi: 10.1126/science.1059549.

Lawson, A.C., ed., 1908, The California earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission: Carnegie Institution of Washington Publication 87, v. 1, 1,451 p. and atlas.

Lomax, A., 2005, A reanalysis of the hypocentral location and related observations for the Great 1906 California earthquake: Bulletin of the Seismological Society of America, v. 95, p. 861–877, doi:10.1785/0120040141.

Manson, M.W., Huyette, C.M., Wills, C.J., Huffman, M.E., Smelser, G.G., Fuller, M.E., Domrose, C., and Gutierrez, C., 2006, Landslides in the Highway 1 corridor between Bodega Bay and Fort Ross, Sonoma County, California: California Geological Survey Special Report 196, 26 p., 2 plates, 38 maps, scale 1:12,000.

McCulloch, D.S., 1987, Regional geology and hydrocarbon potential of offshore Central California, *in* Scholl, D.W., Grantz, A., and Vedder, J.G., eds., Geology and resource potential of the continental margin of western North America and adjacent ocean basins—Beaufort Sea to Baja California: Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series, v. 6, p. 353–401.

Peltier, W.R., and Fairbanks, R.G., 2006, Global glacial ice volume and Last Glacial Maximum duration from an extended Barbados sea level record: Quaternary Science Reviews, v. 25, p. 3,322–3,337, doi:10.1016/j.quascirev.2006.04.010.

Prentice, C.S., and Kelson, K.I., 2006, The San Andreas fault in Sonoma and Mendocino counties, *in* Prentice, C.S., Scotchmoor, J.G., Moores, E.M., and Kiland, J.P, eds., 1906 San Francisco Earthquake Centennial Field Guides: Field trips associated with the 100th Anniversary Conference, 18–23 April 2006, San Francisco, California: Geological Society of America Field Guide 7, p. 127–156, doi:10.1130/2006.1906SF(11).

Reid, J.A., Reid, J.M., Jenkins, C.J., Zimmerman, M., Williams, S.J., and Field, M.E., 2006, usSEABED—Pacific Coast (California, Oregon, Washington) offshore surficial-sediment data release: U.S. Geological Survey Data Series 182, available at http://pubs.usgs.gov/ds/2006/182/.

Sherwood, C.R., Butman, B., Cacchione, D.A., Drake, D.E., Gross, T.F., Sternberg, R.W., Wiberg, P.L., and Williams, A.J., III, 1994, Sediment transport events on the northern California continental shelf during the 1990–1991 STRESS experiment: Continental Shelf Research, v. 14, p. 1063–1099, doi:10.1016/0278-4343(94)90029-9.

Trembanis, A.C., and Hume, T.M., 2011, Sorted bedforms on the inner shelf off northeastern New Zealand—Spatiotemporal relationships and potential paleo-environmental implications: Geo-Marine Letters, v. 31, p. 203–214, doi:10.1007/s00367-010-0225-8.

Weber, K.M., List, J.H., and Morgan, K.L.M., 2005, An operational Mean High Water datum for determination of shoreline position from topographic lidar data: U.S. Geological Survey Open-File Report 2005–1027, available at http://pubs.usgs.gov/of/2005/1027/.

Wentworth, C.M., 1968, Upper Cretaceous and lower Tertiary strata near Gualala, California, and inferred large right slip on the San Andreas fault, in Dickinson, W.R., and Grantz, A., eds. Proceedings of conference on geologic problems of San Andreas fault system: Stanford University Publications, Geological Sciences, v. 11, p. 130–143.

Wentworth, C.M., Jones, D.L., and Brabb, E.E., 1998, Geology and regional correlation of the Cretaceous and Paleogene rocks of the Gualala block, California, *in* Elder, W.P., ed., Geology and tectonics of the Gualala block, northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 84, p. 3–26.

Witter, R.C., Knudsen, K.L., Sowers, J.M., Wentworth, C.M., Koehler, R.D., Randolph, C.E., Brooks, S.K., and Gans, K.D., 2006, Maps of Quaternary deposits and liquefaction susceptibility in the central San Francisco Bay region, California: U.S. Geological Survey Open-File Report 2006–1037, scale 1:24,000, available at http://pubs.usgs.gov/of/2006/1037/.

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20151098

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government

This map was printed on an electronic plotter directly from digital files. Dimensional calibration may vary between electronic plotters and between X and Y directions on the same plotter, and paper may change size due to atmospheric conditions; therefore, scale and proportions may not be true on plots of this map.

For sale by U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225, 1–888–ASK–USGS

Digital files available at http://dx.doi.org/10.3133/ofr20151098 or http://pubs.usgs.gov/of/2015/1098/

Suggested Citation: Hartwell, S.R., Johnson, S.Y., and Manson, M.W., 2015, Offshore and onshore geology and geomorphology, Offshore of Salt Point map area, California, *sheet 10 in* Johnson, S.Y., Dartnell, P., Golden, N.E., Hartwell, S.R., Erdey, M.D., Greene, H.G., Cochrane, G.R., Kvitek, R.G., Manson, M.W., Endris, C.A., Dieter, B.E., Watt, J.T., Kriganus, L.M., Sliter, R.W., Lowe, E.N., and Chin, J.L. (S.Y. Johnson and S.A. Cochran, eds.), California State Waters Map Series—Offshore of Salt Point, California: U.S. Geological Survey Open-File Report 2015–1098, pamphlet 37 p., 10 sheets, scale 1:24,000, http://dx.doi.org/10.3133/ofr20151098.