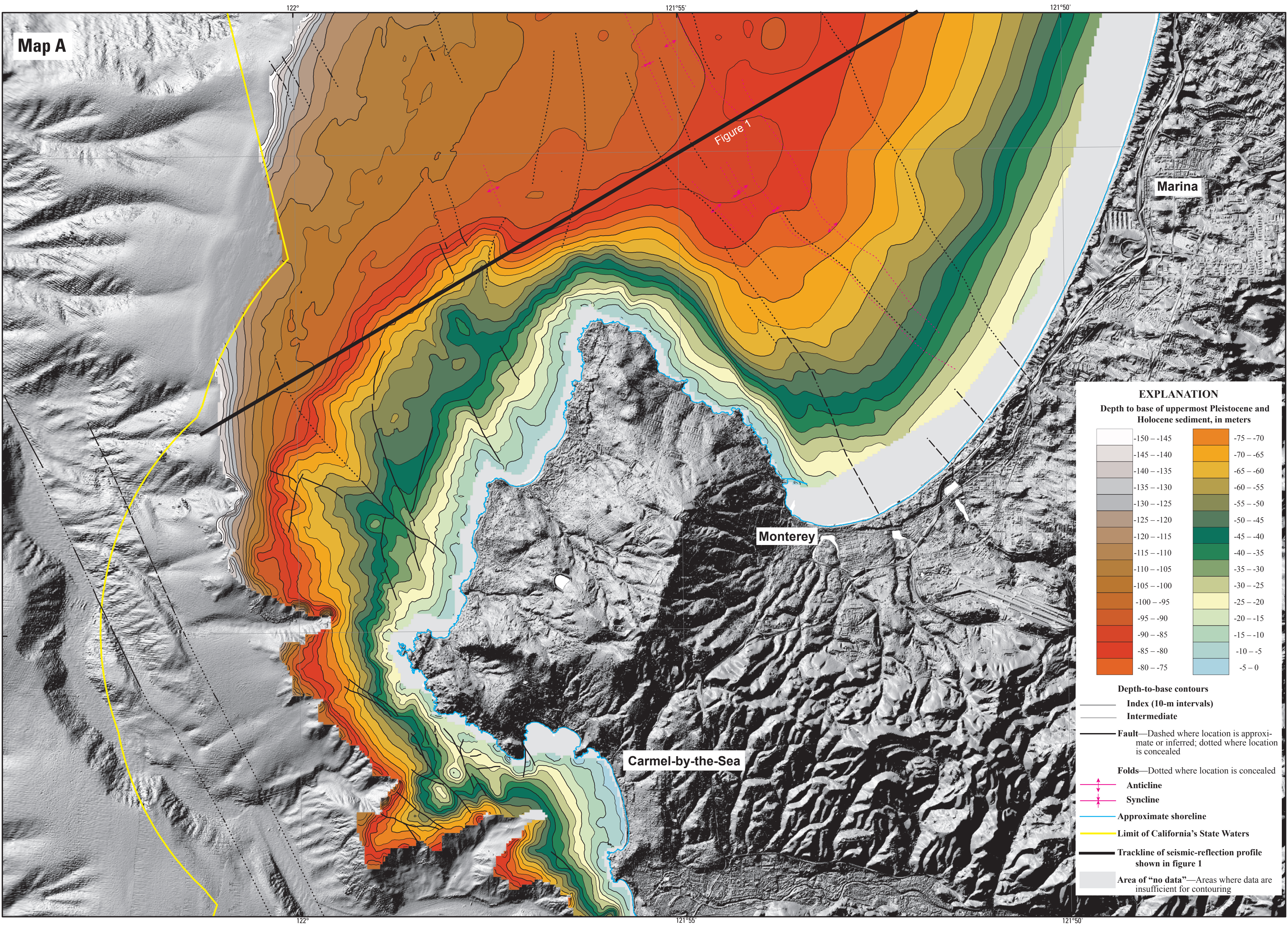
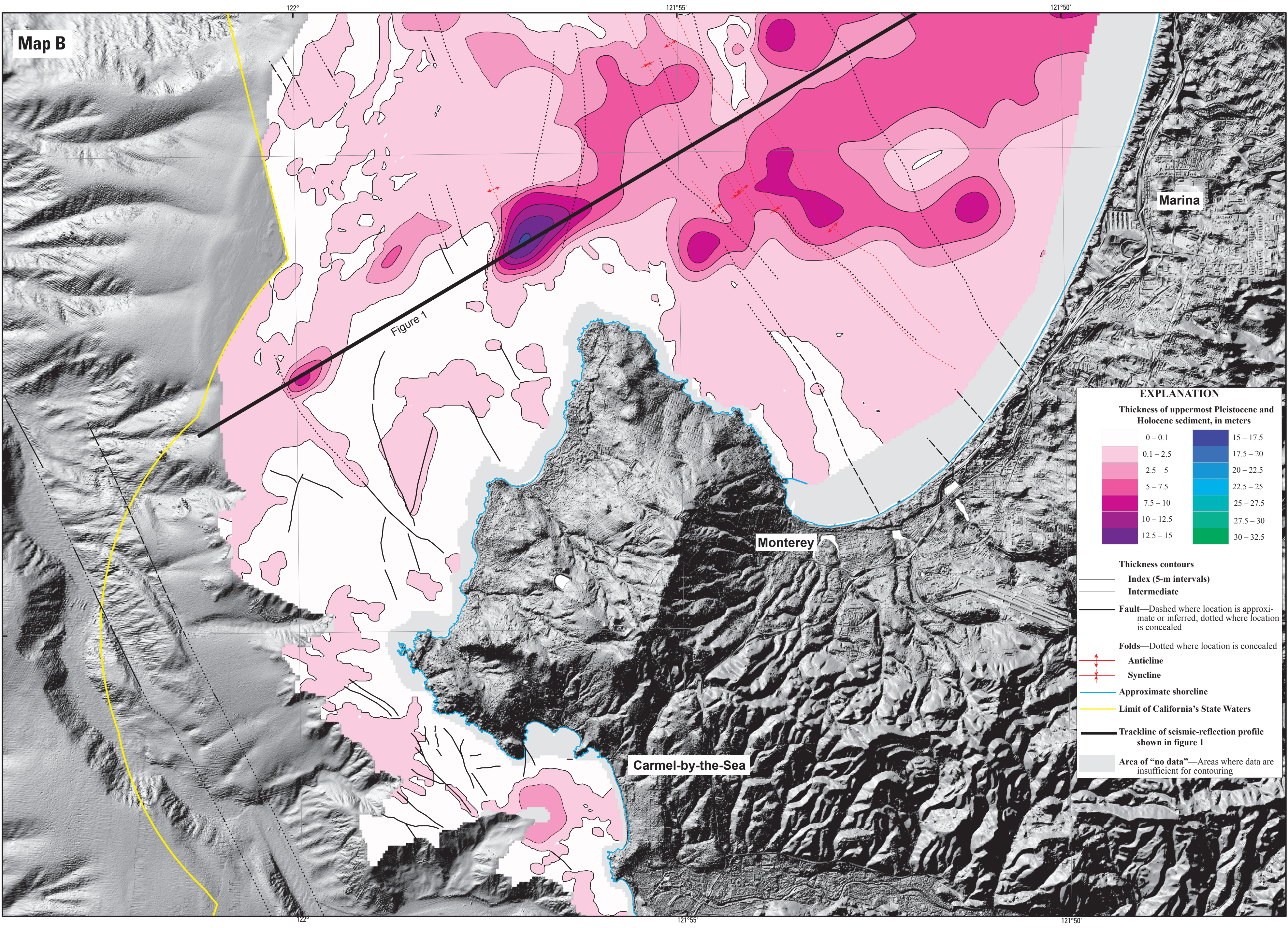
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2016–1110
Sheet 9 of 10
Pamphlet accompanies map





Onshore elevation data 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

13½°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2016

SCALE 1:50 000

ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

DISCUSSION

This sheet includes maps that show the interpreted thickness and the depth to base of uppermost Pleistocene and Holocene deposits in California's State Waters for the Offshore of Monterey map area (Maps A, B), as well as for a larger area that extends about 87 km along the coast from the Pigeon Point area to southern Monterey Bay (Maps C, D) to establish a regional context. Mapping, which is based on high-resolution seismic-reflection profiles (fig. 1; see also, sheet 8), is restricted to the continental shelf. Note that data from within the Monterey Canyon system (including Carmel Canyon), in the southern part of the Pigeon Point to southern Monterey Bay region, is excluded from this analysis because available seismic-reflection data are insufficient to map sediment distribution and thickness in the extremely variable submarine-canyon environment.

High-resolution seismic-reflection profiles (fig. 1; see also, figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13 on sheet 8) image Cretaceous granitic bedrock, folded Neogene sedimentary rocks, Quaternary(?) paleochannel deposits of inferred fluvial origin, and an upper unit of inferred upper Quaternary marine sediments (blue shading on fig. 1; see also, sheet 8). This upper stratigraphic unit commonly is characterized by low- to moderate-amplitude, low- to high-frequency, parallel to subparallel, continuous to moderately continuous reflections (terminology from Mitchum and others, 1977). The contact between this upper stratigraphic unit and underlying bedrock or paleochannel deposits is a prominent, locally angular unconformity, commonly marked by minor channeling and an upward change to lower amplitude, more diffuse reflections. This unconformity is an inferred transgressive surface of erosion, and the upper stratigraphic unit is inferred to have been deposited during the post–Last Glacial Maximum (LGM) sea-level rise of the last about 21,000 years (see, for example, Stanford and others, 2011).

To make these maps, water bottom and depth to base of the post-LGM horizons were mapped from seismic-reflection profiles (fig. 1; see also, sheet 8). The difference between the two horizons was exported for every shot point as XY coordinates (UTM zone 10) and two-way travel time (TWT). The thickness of the post–LGM unit (Maps B, D) was determined by applying a sound velocity of 1,600 m/sec to the TWT. The thickness points were interpolated to a preliminary continuous surface, overlaid with zero-thickness bedrock outcrops (see sheet 10), and contoured, following the methodology of Wong and others (2012).

The thickness of the uppermost Pleistocene and Holocene sediments on the continental shelf in the Offshore of Monterey map area ranges from 0 to 16 m (Map B). Mean sediment thickness on the shelf in the map area is 2.0 m, and the total sediment volume on the shelf is 281×10^6 m^3 (table 7–1 in pamphlet). The thickest sediment in the map area (about 16 m) is found in a broad depression 2 km northwest of the northernmost tip of the Monterey peninsula, at water depths of about 75 to 85 m (see Map B). Most of the shelf in the Offshore of Monterey map area consists of either exposed bedrock or bedrock overlain by a thin (<5 m) cover of sediment. The thinness of the sediment cover is the result of a combination of factors that include uplift of the Monterey peninsula, high wave energy, and limited sediment supply. Much of the sediment derived from the two largest watersheds in this area, the Salinas River and the Carmel River, is transported into the Monterey Canyon system (including Carmel Canyon) rapidly, with low residence time on the relatively narrow shelf.

Seven different informal "domains" of thickness of uppermost Pleistocene to Holocene sediment (see table 7–1 in pamphlet) are recognized on the regional sediment-thickness map (Map D), each with its own diverse set of geologic and (or) oceanographic controls. Again, data from within the Monterey Canyon system (including Carmel Canyon) were excluded from this analysis. Note that, on previously published maps of the Pigeon Point to southern Monterey Bay region (see, for example, Johnson and others, 2015), the first two domains listed below (Monterey shelf, Salinas River delta) were combined into the southern Monterey Bay domain.

(1) The Monterey shelf domain extends from Carmel and Monterey Canyons and the limit of California's State Waters on the west to the shoreline along the Monterey peninsula and the southern part of Monterey Bay on the south and east. The domain includes all of the shelf within the Offshore of Monterey map area. Mean and maximum sediment thicknesses are 2.1 and 16 m, respectively. Small changes in sediment thickness over the shelf are largely controlled by irregular bedrock and, to a lesser degree, by faults, including the Monterey Bay Fault Zone (see Map E; see also, Greene, 1990).

(2) The Salinas River delta domain is bounded on the south by the sediment-poor Monterey shelf domain, on the east by the Monterey Bay shoreline, and on the north by Monterey Canyon. This domain consists of a large, shore-parallel, subaqueous delta that progrades across a thinly sediment-mantled bedrock shelf. Sediment thickness is as much as 32 m.

(3) The northern Monterey Bay domain is bounded on the south by Monterey Canyon, on the north and east by the Monterey Bay shoreline, and on the west by the limit of California's State Waters. The head of Monterey Canyon extends nearly to the shoreline, and the canyon forms a sediment trap that effectively separates the littoral- and shelf-sediment transport systems north and south of the canyon. The northern Monterey Bay domain is characterized by (a) a sediment-poor inner shelf cut by paleochannels of the San Lorenzo River, the Pajaro River, and Soquel Creek; (b) a midshelf depocenter that has sediment as thick as 32 m, much of which was deposited in a pre-LGM prograding delta and (or) shoreface complex and was preserved above a decrease in slope on the underlying unconformity; and (c) a midshelf to outer shelf zone in which sediment generally becomes progressively thinner in the offshore direction.

(4) The Davenport shelf domain extends from the northern limit of Monterey Bay northward to the southern margin of the Waddell Creek depocenter (to the north in the Waddell Creek delta domain). The Davenport shelf domain, as well as the three domains farther north, occupy a section of open, wave-dominated coast that is exposed to wave energy higher than that of the domains to the south in Monterey Bay and around Monterey peninsula. The Davenport shelf domain includes the Davenport depocenter, a prominent midshelf, shore-parallel depocenter present between Davenport and Santa Cruz that mostly consists of a lower, pre-LGM, clinoform-bearing unit of inferred prograding-shoreface origin. Sediment in this depocenter also is preserved in accommodation space linked to an offshore decrease in the slope of the underlying unconformity. Sediment thickness within the Davenport shelf domain decreases to both the northwest and southeast of this depocenter, owing to the presence of elevated bedrock and (or) the related absence of the lower clinoform-bearing unit.

(5) The Waddell Creek delta domain lies offshore of the mouth of the Waddell Creek coastal watershed, and it is connected to it by a submerged channel. The domain is both distinguished and delineated by the significant Waddell Creek depocenter (maximum sediment thickness of 19 m), which forms a moundlike delta that consists entirely of inferred post-LGM deposits whose primary source is Waddell Creek. Sediment thins both north and south of this moundlike delta; its preservation is attributable to its semiprotected (from erosive wave energy) location on the south flank of Point Año Nuevo.

(6) The Año Nuevo shelf domain lies offshore of Point Año Nuevo, from just north of Franklin Point on the north to just north of the mouth of Waddell Creek on the south. Bedrock exposures, which locally reach water depths of 45 m, cover a substantial part of this wave-exposed domain; in deeper waters farther offshore, sediment cover is relatively thin. Sediment thickness in this domain appears to be limited both by the lack of sediment supply (because of its distance from large coastal watersheds) and by the presence of uplifted bedrock, which is linked to a local zone of transpression in the San Gregorio Fault Zone (Weber, 1990). The uplift has raised this domain and exposed it to the high wave energy that is characteristic of this area (Storlazzi and Wingfield, 2005).

(7) The Pigeon Point shelf domain lies on the west flank of the Pigeon Point high (McCulloch, 1987). Sediment in the Pigeon Point shelf domain is thickest in a shore-parallel band that overlies a slope break in the underlying bedrock surface. Much of the sediment probably was derived from Pescadero Creek, a large coastal watershed that enters the Pacific Ocean about 3 km north of the Pigeon Point to southern Monterey Bay regional map area (see Maps C, D). The Pigeon Point shelf domain is transitional to the Pacifica-Pescadero shelf domain just north of it (see Watt and others, 2014).

Map E shows the regional pattern of major faults and of earthquakes occurring between 1967 and April 2014 that have inferred or measured magnitudes of 2.0 and greater. Fault locations, which have been simplified, are compiled from our mapping within California's State Waters (see sheet 10), from Wagner and others (2002), and from the U.S. Geological Survey's Quaternary fault and fold database (U.S. Geological Survey and California Geological Survey, 2010). Earthquake epicenters are from the Northern California Earthquake Data Center (2014), which is maintained by the U.S. Geological Survey and the University of California, Berkeley, Seismological Laboratory. The 1989 Loma Prieta earthquake (M6.9, 10/17/1989), on the San Andreas Fault Zone in the Santa Cruz Mountains (Spudich, 1996), is the most significant event in the region. The largest recorded earthquake in the Offshore of Monterey map area (M3.4, 12/30/1974) occurred onshore in the Monterey Bay Fault Zone, near the city of Monterey.

REFERENCES CITED

Greene, H.G., 1990, Regional tectonics and structural evolution of the Monterey Bay region, central California, *in* Garrison, R.E., Greene, H.G., Hicks, K.R., Weber, G.E., and Wright, T.L., eds., Geology and tectonics of the central California coastal region, San Francisco to Monterey: American Association of Petroleum Geologists, Pacific Section, Guidebook GB67, p. 31–56.

Johnson, S.Y., Hartwell, S.R., Watt, J.T., Sliter, R.W., and Maier, K.L., 2015, Local (Offshore of Scott Creek map area) and regional (offshore from Pigeon Point to southern Monterey Bay) shallow-subsurface geology and structure, California, *sheet 9 in* Cochrane, G.R., Dartnell, P., Johnson, S.Y., Greene, H.G., Erdey, M.D., Dieter, B.E., Golden, N.E., Endris, C.A., Hartwell, S.R., Kvitek, R.G., Davenport, C.W., Watt, J.T., Krigsman, L.M., Ritchie, A.C., Sliter, R.W., Finlayson, D.P., and Maier, K.L. (G.R. Cochrane and S.A. Cochran, eds.), California State Waters Map Series—Offshore of Scott Creek, California: U.S. Geological Survey Open-File Report 2015–1191, pamphlet 40 p., 10 sheets, scale 1:24,000, available at http://dx.doi.org/10.3133/ofr20151191.

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.

Mitchum, R.M., Jr., Vail, P.R., and Sangree, J.B., 1977, Seismic stratigraphy and global changes of sea level, part 6—Stratigraphic interpretation of seismic reflection patterns in depositional sequences, *in* Payton, C.E., ed., Seismic stratigraphy—Applications to hydrocarbon exploration: Tulsa, Okla., American Association of Petroleum Geologists, p. 117–133.

Northern California Earthquake Data Center, 2014, Northern California earthquake catalog: Northern California Earthquake Data Center database, accessed April 5, 2014, at http://www.ncedc.org/ncsn/.

Spudich, P., ed., 1996, The Loma Prieta, California, earthquake of October 17, 1989—Main shock characteristics: U.S. Geological Survey Professional Paper 1550–A, 297 p., available at http://pubs.usgs.gov/pp/pp1550/pp1550a/.

Stanford, J.D., Hemingway, R., Rohling, E.J., Challenor, P.G., Medina-Elizalde, M., and Lester, A.J., 2011, Sea-level probability for the last deglaciation—A statistical analysis of far-field records: Global and Planetary Change, v. 79, p. 193–203, doi:10.1016/j.gloplacha.2010.11.002.

Storlazzi, C.D., and Wingfield, D.K., 2005, Spatial and temporal variations in oceanographic and meteorologic forcing along the central California coast, 1980–2002: U.S. Geological Survey Scientific Investigations Report 2005–5085, 39 p., available at http://pubs.usgs.gov/sir/2005/5085/.

U.S. Geological Survey and California Geological Survey, 2010, Quaternary fault and fold database of the United States: U.S. Geological Survey database, accessed April 5, 2014, at http://earthquake.usgs.gov/hazards/qfaults/.

Wagner, D.L., Greene, H.G., Saucedo, G.J., and Pridmore, C.L., 2002, Geologic map of the Monterey 30' × 60' quadrangle and adjacent areas, California: California Geological Survey Regional Geologic Map Series, scale 1:100,000, available at http://www.quake.ca.gov/gmaps/RGM/monterey/monterey.html.

Watt, J.T., Hartwell, S.R., Johnson, S.Y., Sliter, R.W., Phillips, E.L., Ross, S.L., and Chin, J.L., 2014, Local (Offshore of San Gregorio map area) and regional (offshore from Bolinas to Pescadero) shallow-subsurface geology and structure, California, *sheet 9 in* Cochrane, G.R., Dartnell, P., Greene, H.G., Watt, J.T., Golden, N.E., Endris, C.A., Phillips, E.L., Hartwell, S.R., Johnson, S.Y., Kvitek, R.G., Erdey, M.D., Bretz, C.K., Manson, M.W., Sliter, R.W., Ross, S.L., Dieter, B.E., and Chin, J.L. (G.R. Cochrane and S.A. Cochran, eds.), California State Waters Map Series—Offshore of San Gregorio, California: U.S. Geological Survey Scientific Investigations Map 3306, pamphlet 38 p., 10 sheets, scale 1:24,000, available at http://dx.doi.org/10.3133/sim3306.

Weber, G.E., 1990, Late Pleistocene slip rates on the San Gregorio fault zone at Point Año Nuevo, San Mateo County, California, *in* Greene, H.G., Weber, G.E., Wright, T.L., and Garrison, R.E., eds., Geology and tectonics of the central California coast region—San Francisco to Monterey: American Association of Petroleum Geologists, Pacific Section, volume and guidebook, v. 67, p. 193–204.

Wong, F.L., Phillips, E.L., Johnson, S.Y., and Sliter, R.W., 2012, Modeling of depth to base of Last Glacial Maximum and seafloor sediment thickness for the California State Waters Map Series, eastern Santa Barbara Channel, California: U.S. Geological Survey Open-File Report 2012–1161, 16 p., available at http://pubs.usgs.gov/of/2012/1161/.

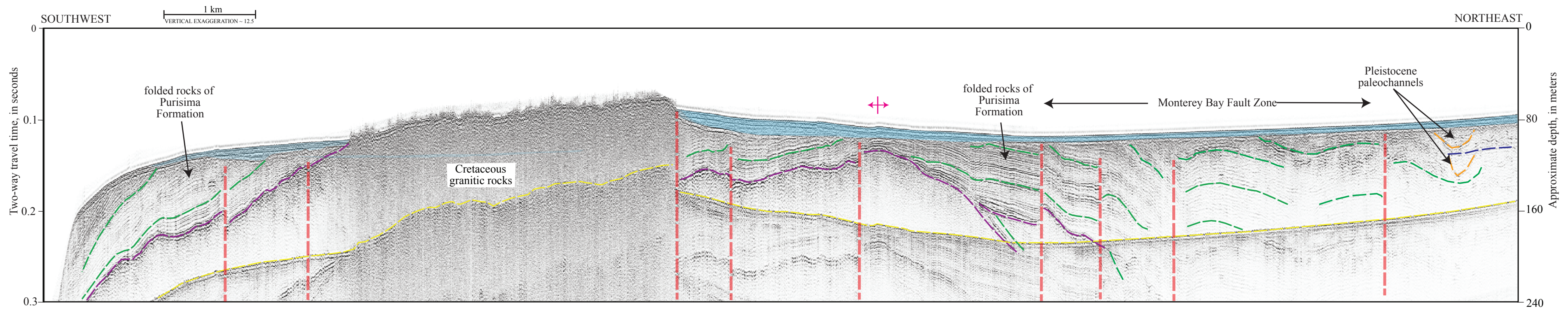
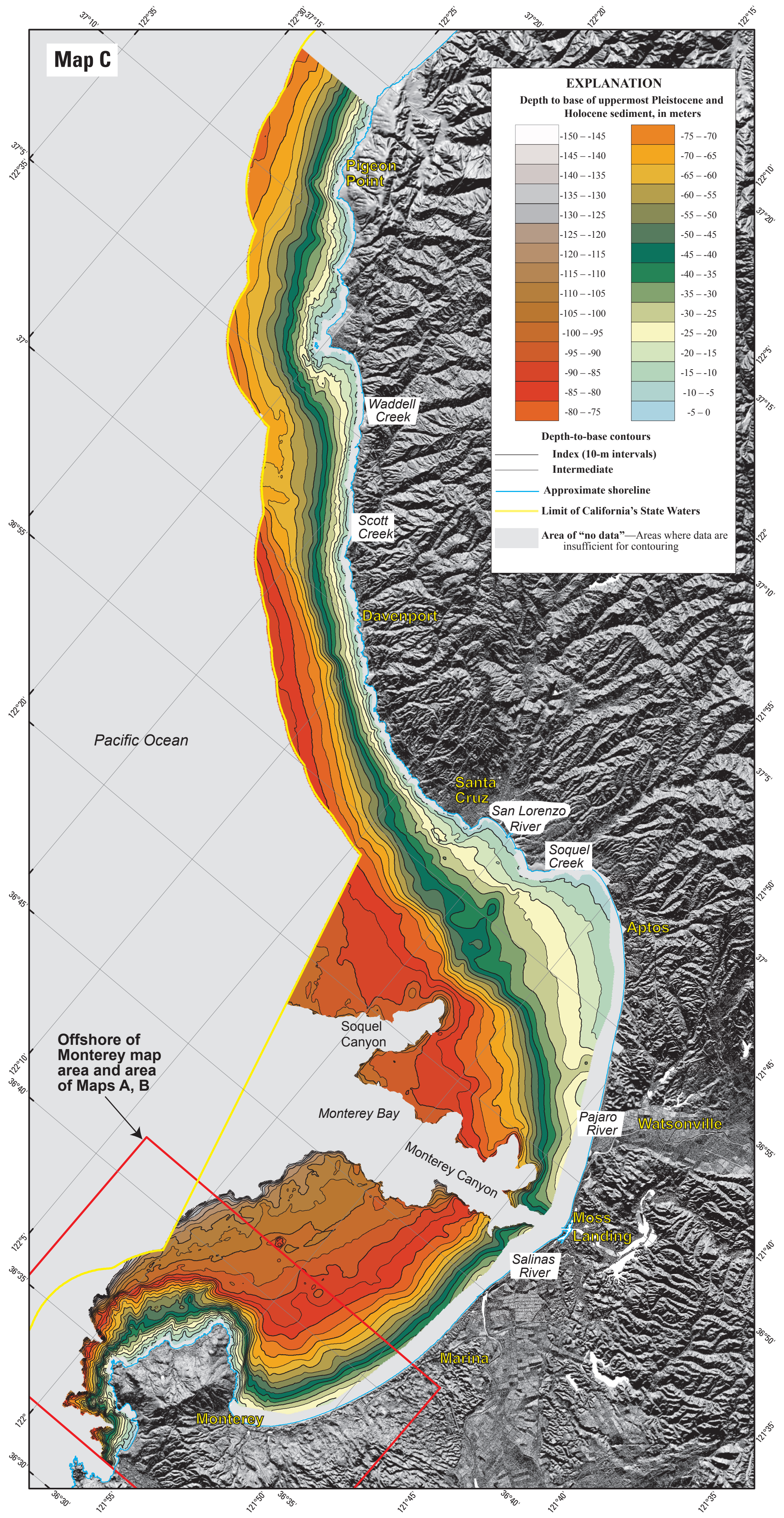
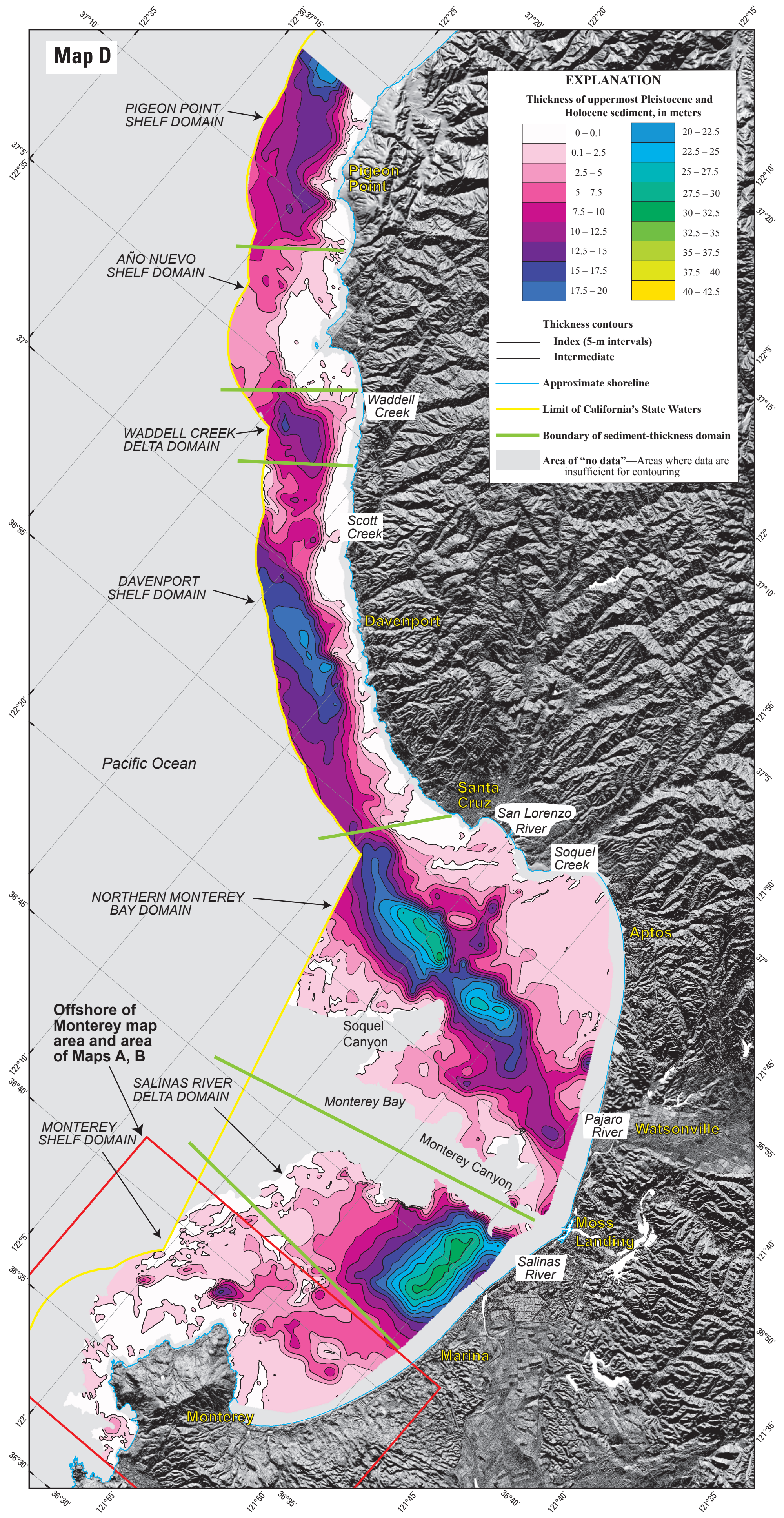


Figure 1. USGS high-resolution minisparker seismic-reflection profile SMBS–09 (collected in 2011 on cruise S–6–11–MB), which crosses shelf north and west of Monterey peninsula (see Maps A, B for location; see also, fig. 5 on sheet 8). Profile highlights massive granitic rocks, folded rocks of the upper Miocene and Pliocene Purisima Formation, and Monterey Bay Fault Zone. Dashed red lines show faults. Magenta symbol shows anticline axis. Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited in last about 21,000 years. Dashed purple lines show unconformities. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed orange lines outline Pleistocene paleochannels. Dashed yellow lines are seafloor multiples (echoes of seafloor reflector).



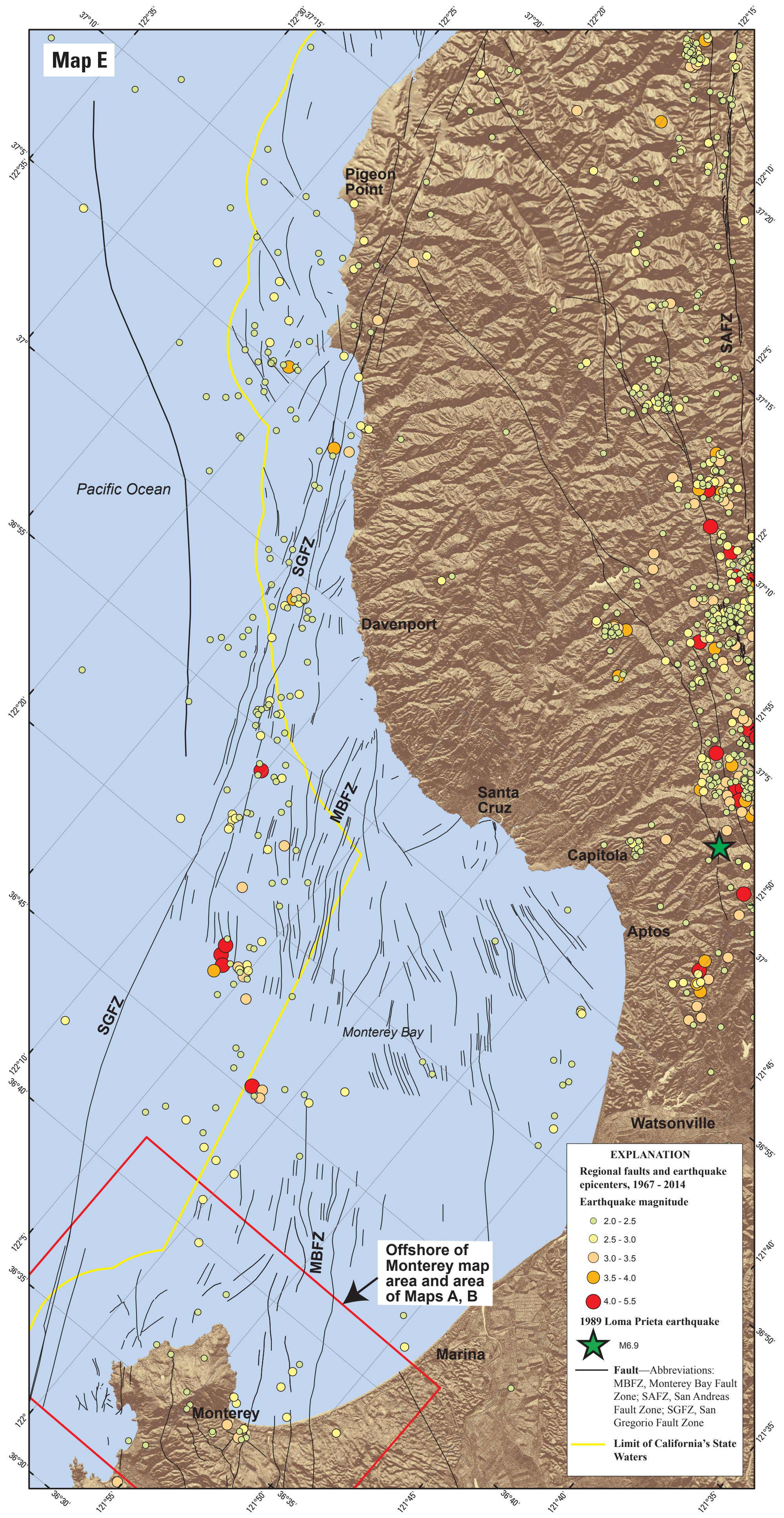


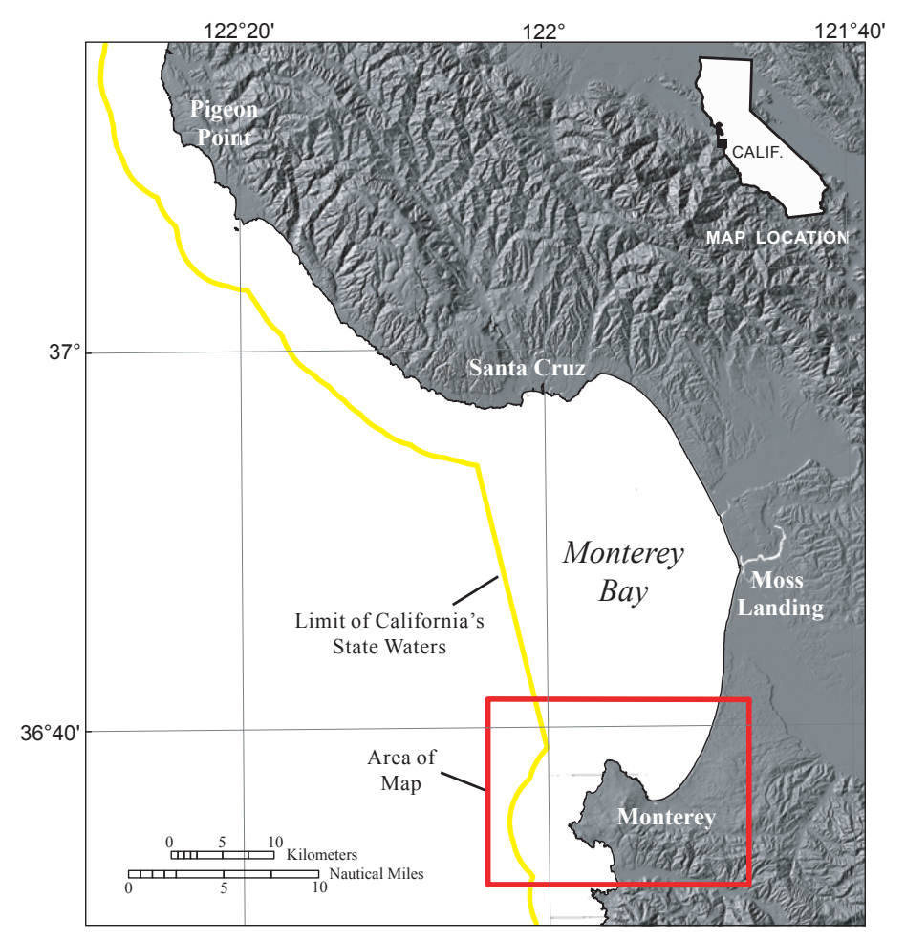
Onshore elevation data from U.S. Geological Survey's National Elevation Dataset (available at http://ned.usgs.gov/). California's State Waters limit from NOAA Office of Coast Survey

Universal Transverse Mercator projection, Zone 10N

SCALE 1:200 000

ONE MILE = 0.869 NAUTICAL MILES





Depth and thickness mapped by Samuel Y. Johnson and Stephen R. Hartwell, 2011–2012
GIS database and digital cartography by Stephen R. Hartwell
Manuscript approved for publication June 27, 2016

Local (Offshore of Monterey Map Area) and Regional (Offshore from Pigeon Point to Southern Monterey Bay) Shallow-Subsurface Geology and Structure, California

By

Samuel Y. Johnson, Stephen R. Hartwell, Janet T. Watt, Ray W. Sliter, and Katherine L. Maier

2016

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/ofr20161110

Suggested Citation: Johnson, S.Y., Hartwell, S.R., Watt, J.T., Sliter, R.W., and Maier, K.L., 2016, Local (Offshore of Monterey map area) and regional (offshore from Pigeon Point to southern Monterey Bay) shallow-subsurface geology and structure, California, *sheet 9 in* Johnson, S.Y., Dartnell, P., Hartwell, S.R., Cochrane, G.R., Golden, N.E., Watt, J.T., Davenport, C.W., Kvitek, R.G., Erdey, M.D., Krigsman, L.M., Sliter, R.W., and Maier, K.L. (S.Y. Johnson and S.A. Cochran, eds.), California State Waters Map Series—Offshore of Monterey, California: U.S. Geological Survey Open-File Report 2016–1110, pamphlet 44 p., 10 sheets, scale 1:24,000, http://dx.doi.org/10.3133/ofr20161110.