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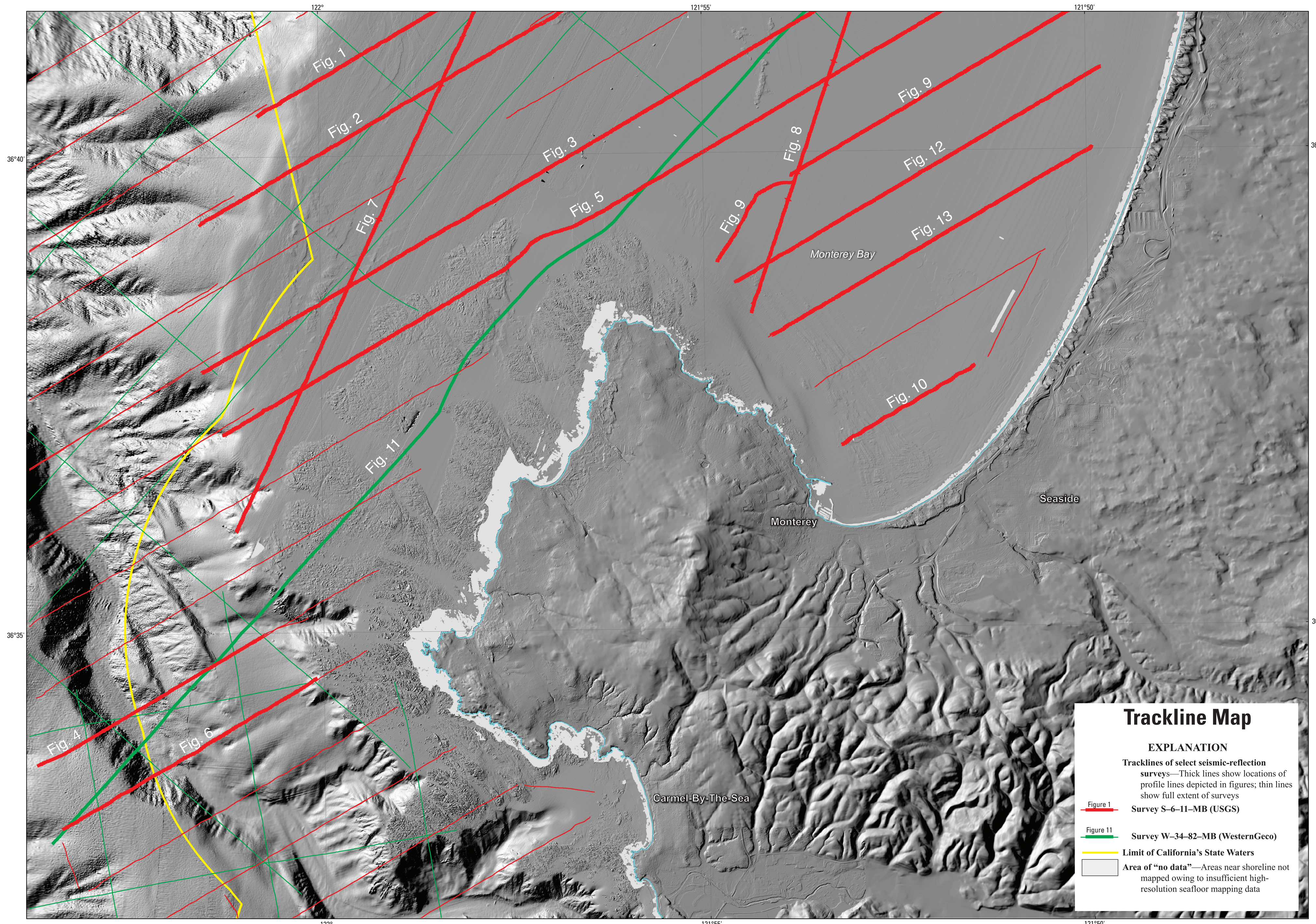
U.S. Geological Survey

Open-File Report 2016–1110
Sheet 8 of 10
Pamphlet accompanies map



Onshore elevation data from National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management's Digital Coast (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 1:50 000

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

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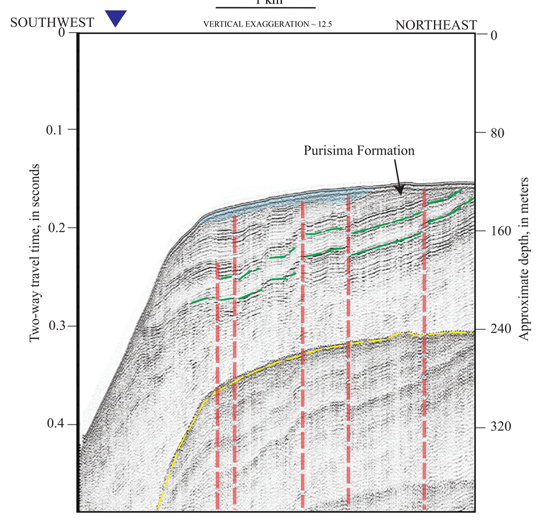


Figure 1. USGS high-resolution minisparker seismic-reflection profile SMBS–02A (collected in 2011 on cruise S–06–11–MB), which crosses outer shelf and shelf break northwest of Monterey peninsula; see trackline map for location. Profile highlights gently dipping Neogene strata of the Purisima Formation that are cut by numerous small faults of Monterey Bay Fault Zone. Bedrock was beveled during transgression that followed Last Glacial Maximum (LGM), about 21,000 years ago, and it is overlain locally by very thin post-LGM sediment layer (blue shading; see also, sheet 9). Dashed red lines show faults. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

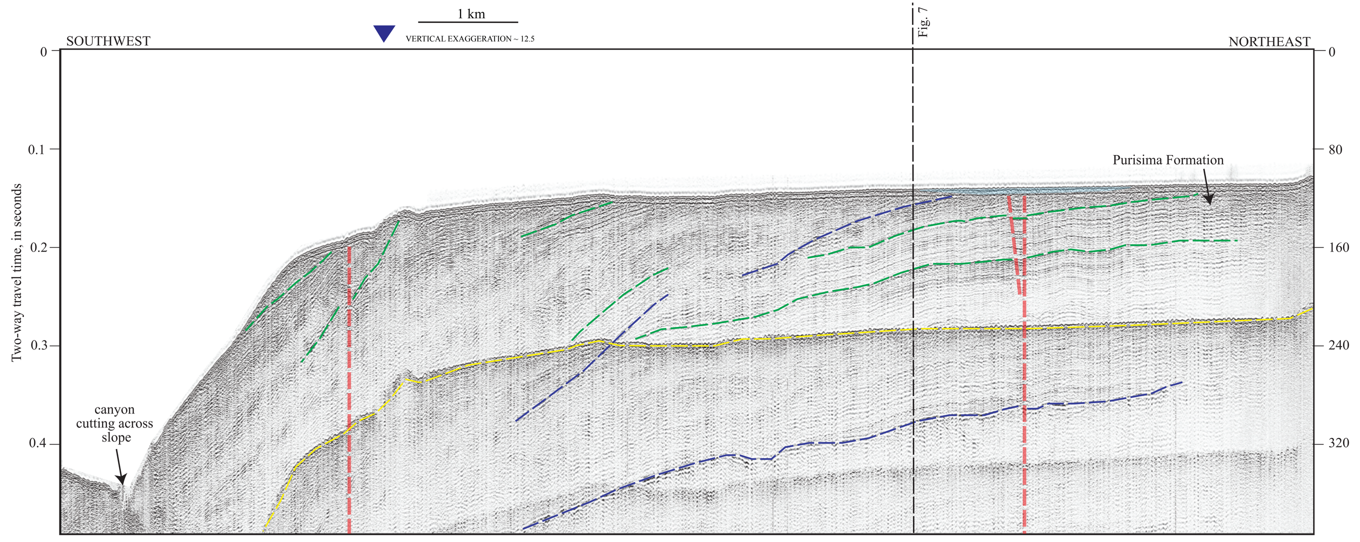


Figure 2. USGS high-resolution minisparker seismic-reflection profile SMBS–04B (collected in 2011 on cruise S–06–11–MB), which crosses outer shelf and shelf break northwest of Monterey peninsula; see trackline map for location. Profile highlights gently dipping Neogene strata of the Purisima Formation that are cut by steep faults. Southwest end of profile shows canyon cutting across slope. Bedrock was beveled during transgression that followed Last Glacial Maximum (LGM), about 21,000 years ago, and it is overlain locally by very thin post-LGM sediment layer (blue shading; see also, sheet 9). Dashed red lines show faults. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

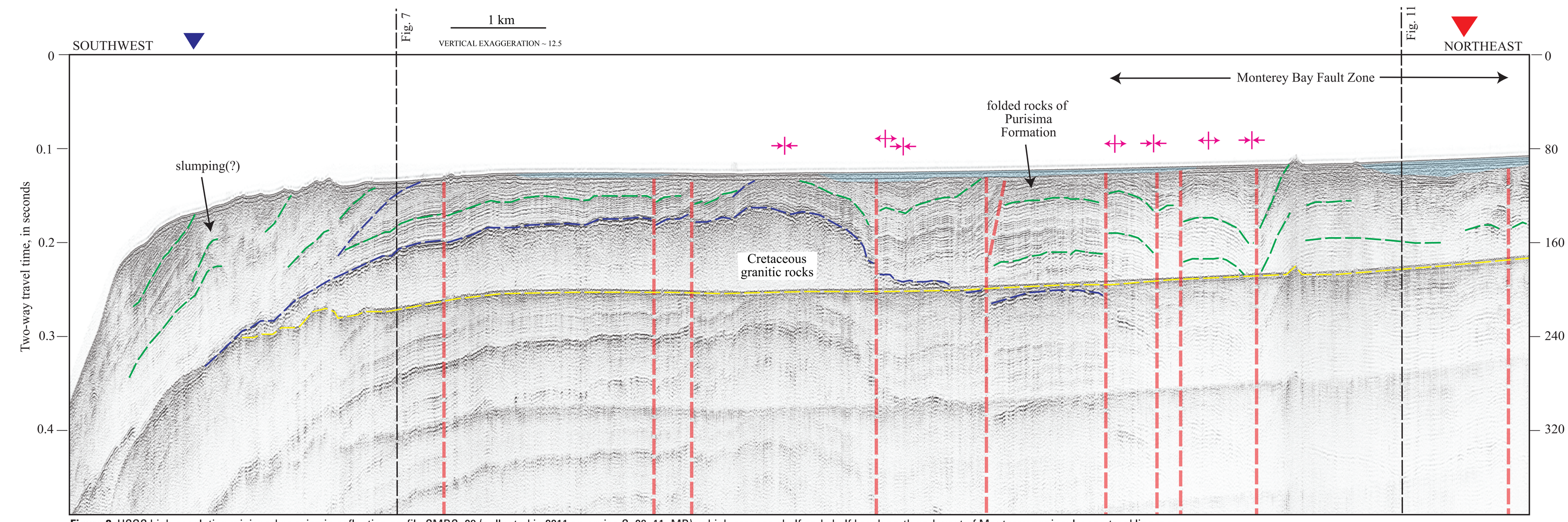
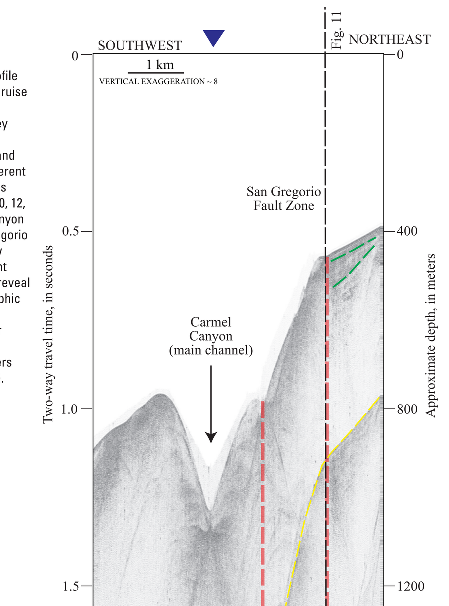


Figure 3. USGS high-resolution minisparker seismic-reflection profile SMBS–08 (collected in 2011 on cruise S–06–11–MB), which crosses shelf and shelf break north and west of Monterey peninsula; see trackline map for location. Note that profile extends beyond map area; red triangle marks north edge of map area. Profile highlights gently to moderately folded Neogene strata that overlie Cretaceous granitic rocks. Monterey Bay Fault Zone is imaged as several steep faults that cut gently dipping Neogene sedimentary strata. Erosional unconformity separates Neogene strata from sediments inferred to have been deposited following Last Glacial Maximum (LGM), about 21,000 years ago (blue shading; see also, sheet 9). Thickness of post-LGM deposits is greatest at northeast end of profile, near Salinas River delta. Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show pre-LGM unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

Figure 4. USGS high-resolution minisparker seismic-reflection profile SMBS–21B (collected in 2011 on cruise S–6–11–MB), which crosses continental slope west of Monterey peninsula; see trackline map for location. Note that vertical scale and exaggeration are significantly different than that of high-resolution profiles shown in figures 1, 2, 3, 5, 7, 8, 9, 10, 12, and 13. Profile highlights steep canyon morphology controlled by San Gregorio Fault Zone. Dashed red lines show faults. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).



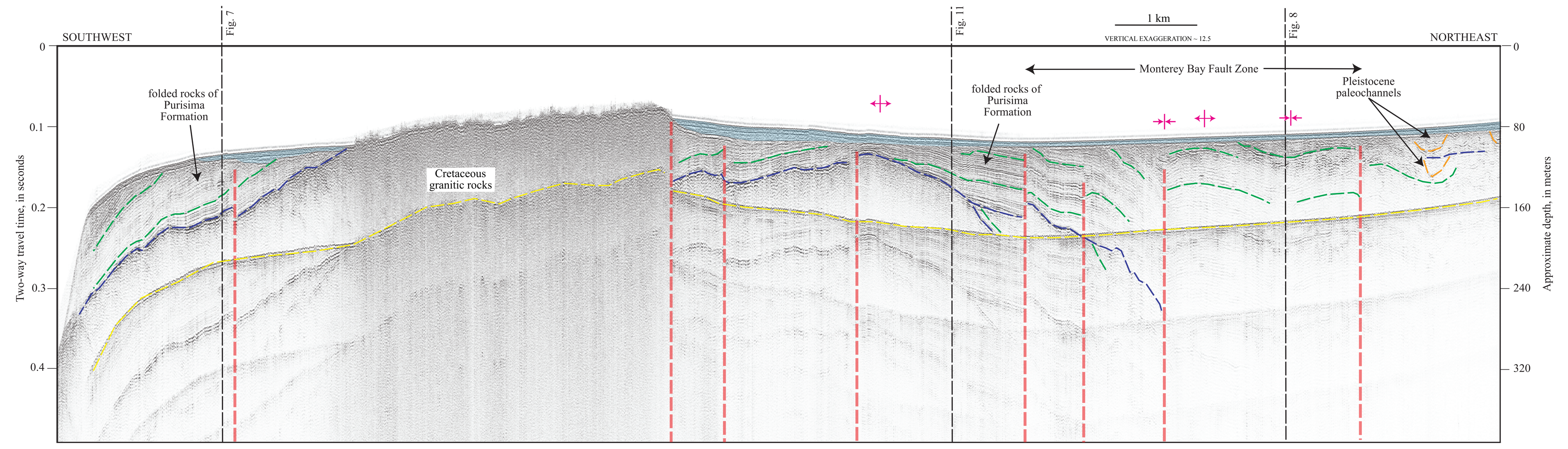


Figure 5. USGS high-resolution minisparker seismic-reflection profile SMBS–09 (collected in 2011 on cruise S–6–11–MB), which crosses shelf north and west of Monterey peninsula; see trackline map for location. Profile highlights massive Cretaceous granitic rocks, folded Neogene sedimentary rocks, and Monterey Bay Fault Zone. Dashed orange lines show Pleistocene paleochannel system near northeast end of profile, which could be associated with lowstand paleochannels of Salinas River (present-day location, about 0.6 km north of map area). Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). 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 yellow lines are seafloor multiples (echoes of seafloor reflector).

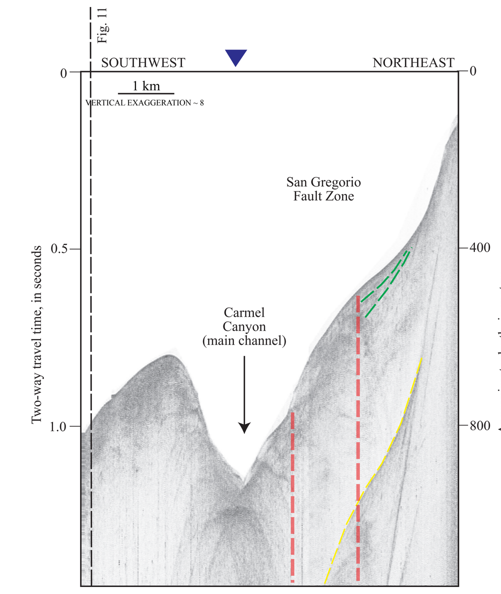


Figure 6. USGS high-resolution minisparker seismic-reflection profiles SMBS–22A and SMBS–22C (collected in 2011 on cruise S–6–11–MB), which cross continental slope west of Monterey peninsula; see trackline map for location. Note that vertical scale and exaggeration are significantly different than that of high-resolution profiles shown in figures 1, 2, 3, 5, 7, 8, 9, 10, 12, and 13. Profile highlights steep canyon morphology controlled by San Gregorio Fault Zone. Dashed red lines show faults. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

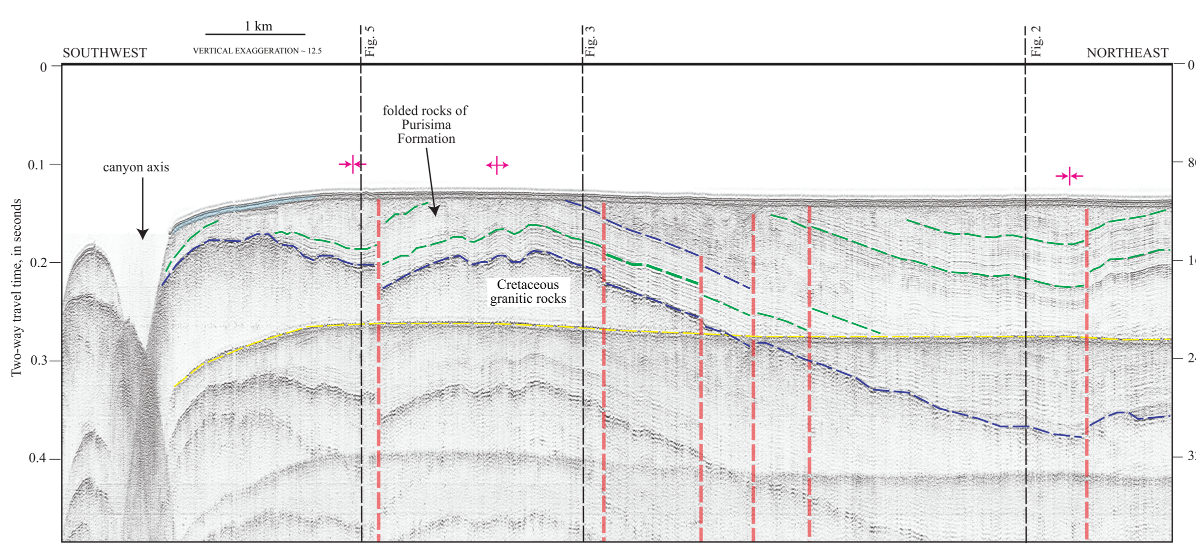


Figure 7. USGS high-resolution minisparker seismic-reflection profile SMBS–14 (collected in 2011 on cruise S–6–11–MB), which crosses shelf northwest of Monterey peninsula; see trackline map for location. Profile highlights massive Cretaceous granitic rocks and gently folded Neogene sedimentary rocks, as well as several small faults that offset Neogene strata. Bedrock was beveled during transgression that followed Last Glacial Maximum (LGM), about 21,000 years ago, and it is overlain locally by very thin post-LGM sediment layer (blue shading; see also, sheet 9). Dashed red lines show faults. Magenta symbols show fold axes (converging arrows, synclines; diverging arrows, anticline). Dashed purple lines show unconformities. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector).

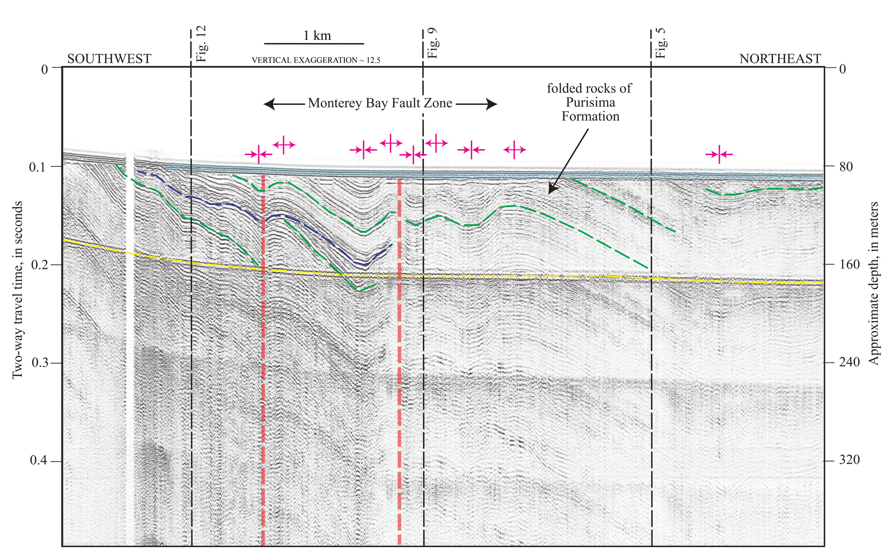
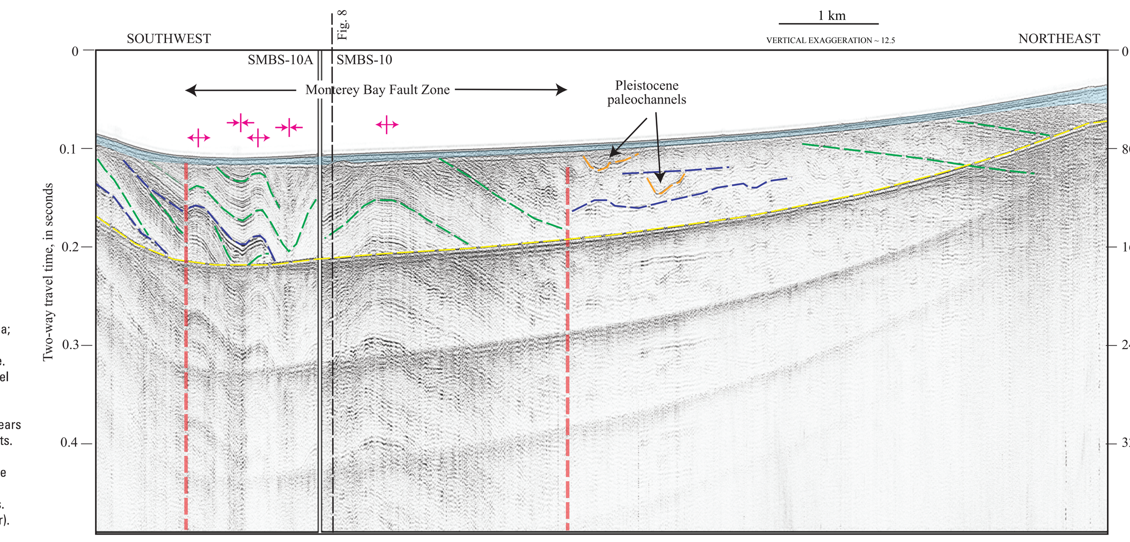


Figure 8. USGS high-resolution minisparker seismic-reflection profile SMBS–15 (collected in 2011 on cruise S–06–11–MB), which crosses shelf north-northeast of Monterey peninsula; see trackline map for location. Profile highlights gently folded Neogene strata that are cut by faults of Monterey Bay Fault Zone. Bedrock was beveled during transgression that followed Last Glacial Maximum (LGM), about 21,000 years ago, and it is overlain locally by very thin post-LGM sediment layer (blue shading; see also, sheet 9). Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector).

Figure 9. USGS high-resolution minisparker seismic-reflection profiles SMBS–10 and SMBS–10A (collected in 2011 on cruise S–06–11–MB), which cross shelf northeast of Monterey peninsula; see trackline map for location. Profile highlights gently folded Neogene strata that are cut by faults of Monterey Bay Fault Zone. Dashed orange lines show well-defined Pleistocene paleochannel system present in central part of profile. Erosional unconformity separates Neogene strata from sediments inferred to have been deposited following Last Glacial Maximum (LGM), about 21,000 years ago (blue shading; see also, sheet 9). Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector).



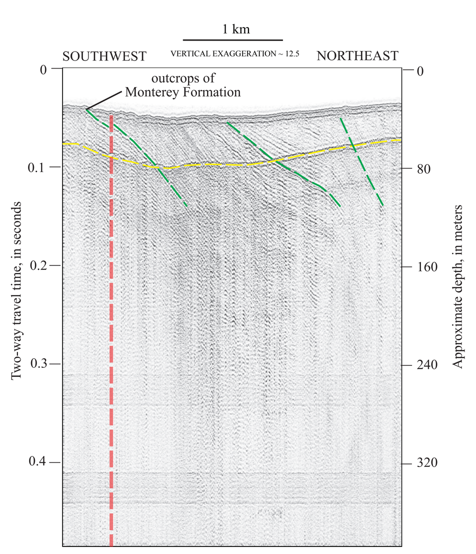


Figure 10. USGS high-resolution minisparker seismic-reflection profile SMBS–20 (collected in 2011 on cruise S–06–11–MB), which crosses shelf northeast of Monterey peninsula; see trackline map for location. Profile highlights gently dipping Neogene strata. Bedrock was beveled during transgression that followed Last Glacial Maximum (LGM), about 21,000 years ago; however, post-LGM sediment is absent along profile (see sheet 9). Dashed red line shows fault. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector).

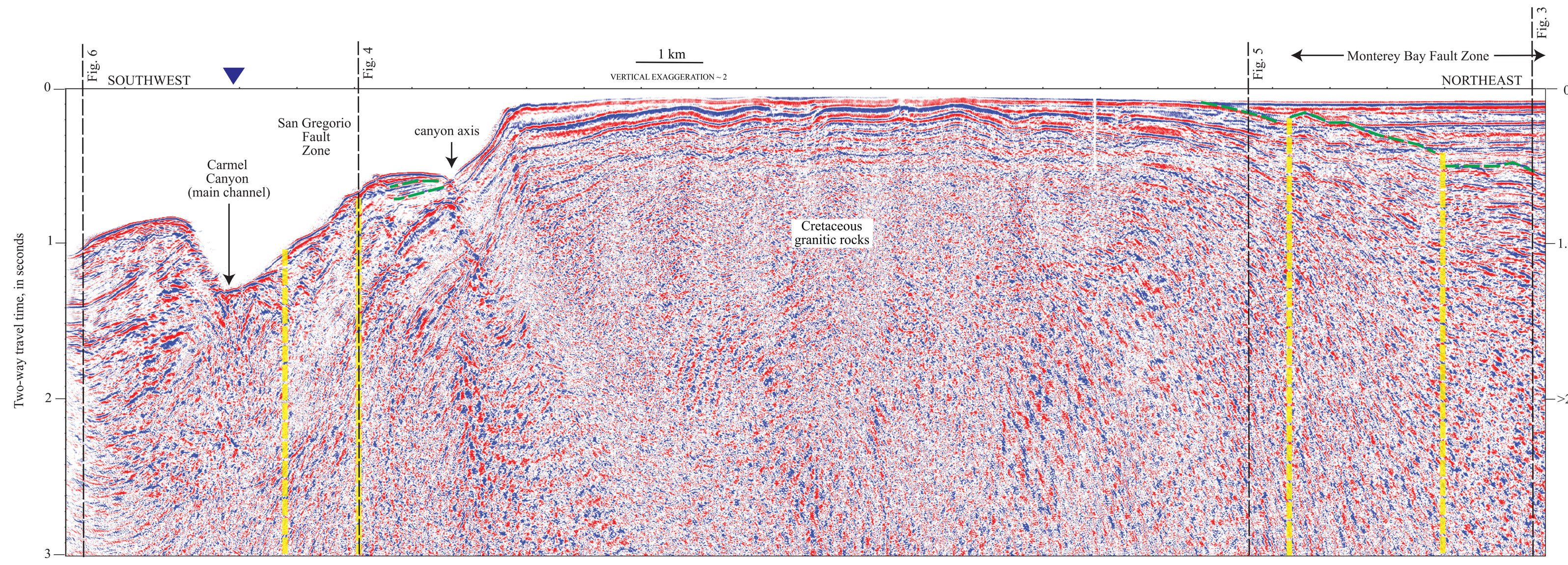


Figure 11. Migrated, deep-penetration industry, 2-D, multichannel air-gun seismic-reflection profile WS82–636 (collected in 1982 on WesternGeco survey W–34–82–MB; from USGS National Archive of Marine Seismic Surveys [Triezenberg and others, 2016]), which crosses shelf north and west of Monterey peninsula; see trackline map for location. Note that vertical scale and exaggeration are significantly different than that of high-resolution profiles shown in figures 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, and 13. Northeastern part of profile highlights granitic basement and overlying Neogene sedimentary rocks (primarily rocks of the Miocene to Pliocene Purisima Formation and also possibly older rocks) that have been faulted and folded along Monterey Bay Fault Zone. Southwestern end of profile shows where Carmel Canyon is cut by San Gregorio Fault Zone. Dashed yellow lines show faults. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

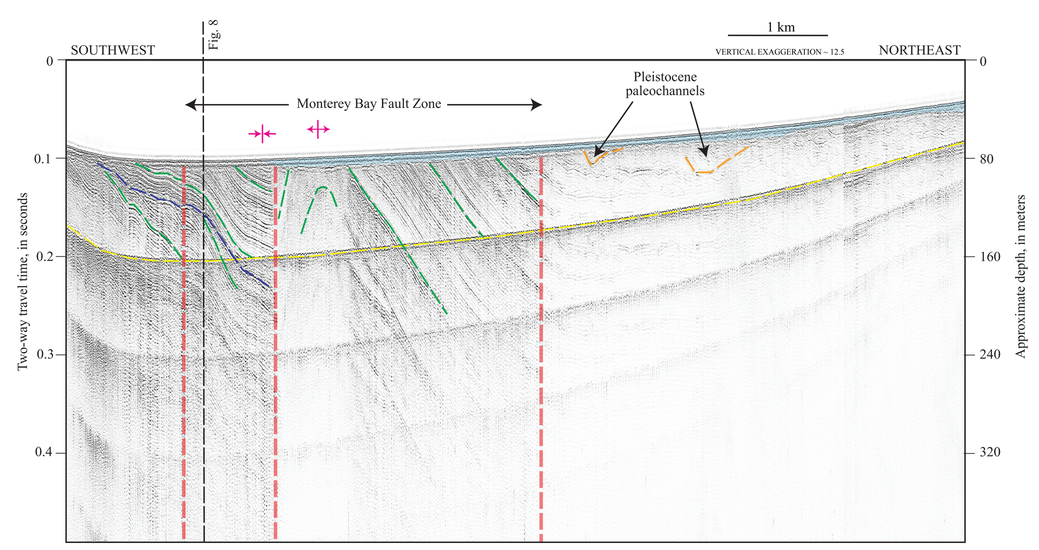


Figure 12. USGS high-resolution minisparker seismic-reflection profile SMBS–11 (collected in 2011 on cruise S–06–11–MB), which crosses shelf northeast of Monterey peninsula; see trackline map for location. Profile highlights gently folded Neogene strata that are cut by faults of Monterey Bay Fault Zone. Dashed orange lines show paleochannels that could be associated with lowstand paleochannels of Salinas River (present-day location, about 0.6 km north of map area). Erosional unconformity separates Neogene strata from sediments inferred to have been deposited following Last Glacial Maximum (LGM), about 21,000 years ago (blue shading; see also, sheet 9). Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector).

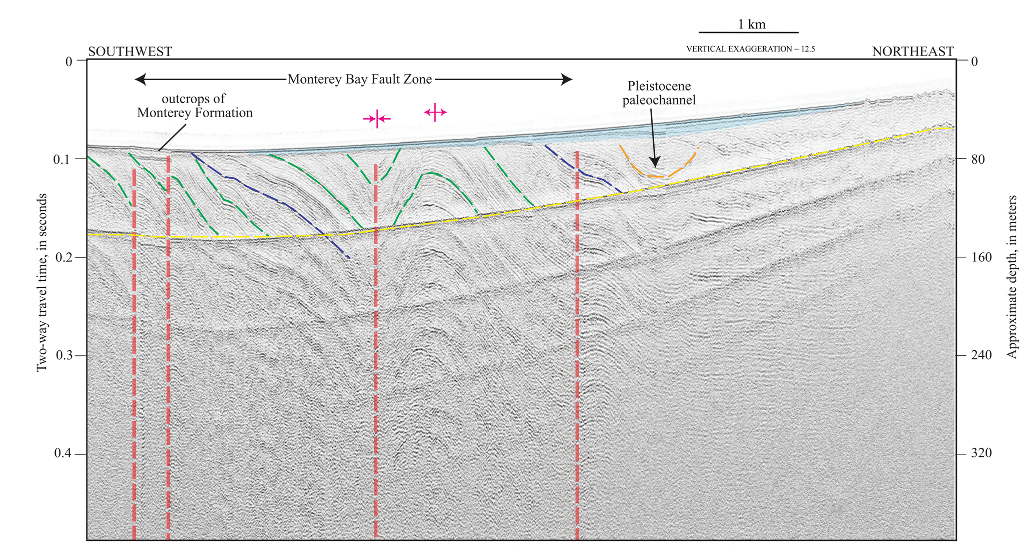
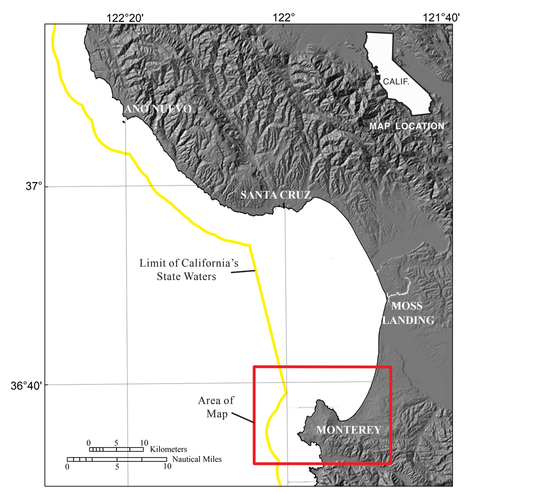


Figure 13. USGS high-resolution minisparker seismic-reflection profile SMBS–12 (collected in 2011 on cruise S–06–11–MB), which crosses shelf northeast of Monterey peninsula; see trackline map for location. Profile highlights gently folded Neogene strata that are cut by faults of Monterey Bay Fault Zone. Dashed orange lines show paleochannel of probable Pleistocene age. Erosional unconformity separates Neogene strata from sediments inferred to have been deposited following Last Glacial Maximum (LGM), about 21,000 years ago (blue shading; see also, sheet 9). Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple lines show unconformities. Dashed yellow line is seafloor multiple (echo of seafloor reflector).



DISCUSSION

This map sheet shows seismic-reflection profiles from two different surveys of the Offshore of Monterey map area, providing imagery of the subsurface geology in southern Monterey Bay and on the flanks of the Monterey peninsula. The continental shelf in the map area extends from the shoreline to water depths of about 100 to 120 m. Shelf slope ranges from as little as 0.5° offshore of Marina to as much as 3.8° offshore of the west flank of the Monterey peninsula. To the north and west, the shelf is incised by the Monterey Canyon system and its tributaries, including Carmel Canyon (sheets 1, 2). The seismic-reflection profiles provide the data for interpreting the subbottom stratigraphy, sediment thickness, and geologic structure (see sheets 9, 10) of this diverse area.

Most profiles displayed on this sheet (figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13) were collected in 2011 on U.S. Geological Survey (USGS) cruise S–6–11–MB (Sliter and others, 2013). The single-channel seismic-reflection data were acquired using a SIG 2Mille minisparker system that used a 500-J high-voltage electrical discharge fired 2 times per second, which, at normal survey speeds of 4 to 4.5 nautical miles per hour, gives a data trace every 1.0 to 1.5 m of lateral distance covered. The data were digitally recorded in standard SEG-Y 32-bit floating-point format using Triton SubBottom Logger (SBL) software that merges seismic-reflection data with differential GPS-navigation data. After the survey, a short-window (20 ms) automatic gain control algorithm was applied to the data, along with a 160- to 1,200-Hz bandpass filter and a heave correction that uses an automatic seafloor-detection window (averaged over 30 m of lateral distance covered). These data can resolve geologic features a few meters thick (and, hence, are considered "high-resolution"), down to subbottom depths of as much as 400 m.

Figure 11 shows a migrated, deep-penetration, multichannel seismic-reflection profile collected in 1982 by WesternGeco on cruise W–34–82–MB. This profile and other similar data were collected in many areas offshore of California in the 1970s and 1980s when these areas were considered a frontier for oil and gas exploration. Much of these data have been publicly released and are now archived at the USGS National Archive of Marine Seismic Surveys (Triezenberg and others, 2016). These data were acquired using a large-volume air-gun source that has a frequency range of 3 to 40 Hz and recorded with a multichannel hydrophone streamer about 2 km long. Shot spacing was about 30 m. These data can resolve geologic features that are 20 to 30 m thick, down to subbottom depths of as much as 4 km.

The continental shelf in the Offshore of Monterey map area is underlain by Cretaceous granitic basement rocks, Tertiary sedimentary rocks, and uppermost Pleistocene to Holocene sediments (see sheet 10). Granitic basement rocks are characterized as massive, reflection-free zones (see, for example, figs. 3, 5, 6). Tertiary sedimentary rocks, which predominantly consist of the Miocene Monterey Formation and the Miocene and Pliocene Purisima Formation, are characterized on high-resolution and multichannel seismic-reflection profiles (for example, figs. 1, 2, 3, 5, 7, 8, 9) by parallel to subparallel, continuous, variable-amplitude, high-frequency reflections (terminology from Mitchum and others, 1977). The seismic-reflection profiles reveal that these rocks typically are flat lying to gently folded and are cut by high-angle faults.

Eustasy was an important control on latest Pleistocene to Holocene shelf deposition in the Offshore of Monterey map area. Surficial and shallow sediments were deposited on the shelf in the last about 21,000 years during the sea-level rise that followed the last major lowstand and the Last Glacial Maximum (LGM) (Stanford and others, 2011). Sea level was about 120 to 130 m lower than present during the LGM, at which time the shelf surrounding the Monterey Canyon system was emergent. The post-LGM sea-level rise was rapid (about 9 to 11 meters per thousand years) until about 7,000 years ago, when it slowed considerably to about 1 m per thousand years (Stanford and others, 2011). The sediments deposited on the shelf during the post-LGM sea-level rise (above a transgressive surface of erosion) are shaded blue in the high-resolution seismic-reflection profiles (figs. 1, 2, 3, 5, 7, 8, 9, 12, 13), and their thicknesses are shown on sheet 9. Throughout the map area, the contact between bedrock and the overlying upper Quaternary sediments is an angular erosional unconformity that commonly is marked by minor channeling and an upward change to lower amplitude, more diffuse reflections.

Monterey Canyon and its tributaries, including Carmel Canyon, incise bedrock and sediments through the continental shelf in the Offshore of Monterey map area, creating as much as several hundreds of meters of relief on the seafloor. Although several high-resolution seismic-reflection profiles were collected across parts of Carmel Canyon, their quality and resolution is less than that of adjacent seismic-reflection data on the shelf. Reflection-free granitic rock forms much of the east wall of Carmel Canyon, and steep canyon relief creates widespread side-echoes and diffractions that significantly diminish data quality. A single deep-penetration, multichannel seismic-reflection profile crosses Carmel Canyon (fig. 11); however, this profile images reflections at a larger scale and a lower resolution than that of the high-resolution seismic-reflection profiles.

The shelf northeast and north of the Monterey peninsula is cut by the diffuse zone of northwest-striking, steeply dipping to vertical faults of the Monterey Bay Fault Zone. The fault strands are identified in seismic-reflection profiles on the basis of the abrupt truncation or warping of reflections and (or) the juxtaposition of reflection panels that have differing seismic parameters, such as amplitude, frequency, geometry, continuity, and vertical sequence. The Monterey Bay Fault Zone, originally mapped by Greene (1977, 1990), extends about 45 km across outer Monterey Bay (see Map E on sheet 10). To the south-southeast, the fault connects with the Navy, Chupines, Seaside, and Ord Terrace Faults onland (see sheet 10). Seismic-reflection profiles in the map area that traverse this diffuse zone cross as many as five faults over a width of about 4 to 5 km (see, for example, figs. 3, 5). The Monterey Bay Fault Zone lacks a continuous "master fault" along which deformation is concentrated; fault strands are as long as about 20 km (on the basis of mapping outside the map area), but most strands are only about 2 to 7 km long. Faults in this diffuse zone cut through bedrock, and they locally appear to have minimally disrupted the overlying inferred Quaternary sediments. The presence of warped reflections along some fault strands suggests that both vertical and strike-slip offset may have occurred.

West of the Monterey peninsula, the northwest-striking San Gregorio Fault Zone extends roughly parallel to the axis of Carmel Canyon. The San Gregorio Fault Zone is an important structure in the distributed transform boundary between the North American and Pacific plates (see, for example, Dickinson and others, 2005). It is part of the San Gregorio–Hosgri Fault system, which is present predominantly in the offshore for about 400 km, from Point Conception in the south (where it is known as the Hosgri Fault; Johnson and Watt, 2012) to Bolinas and Point Reyes in the north (Bruns and others, 2002; Ryan and others, 2008). The San Gregorio Fault Zone in the map area is part of a 90-km-long offshore segment that extends northward from Point Sur (about 25 km south of the map area), across outer Monterey Bay to Point Año Nuevo (about 50 km north of the map area) (see sheet 9; see also, Brabb and others, 1998; Wagner and others, 2002). The San Gregorio Fault Zone is not well imaged in the map area, on either high-resolution (see, for example, fig. 12) or deep-penetration (fig. 11) seismic-reflection profiles because of its location in steep-sided Carmel Canyon and also because it cuts through reflection-free granitic basement rocks along the east wall of the canyon. Accordingly, we have mapped the 1,000- to 1,300-m-wide fault zone largely on the basis of the presence of prominent, lengthy geomorphic lineaments (see sheets 1, 2), as well as the geomorphic and lithologic contrasts across the fault (see sheet 10).

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Seismic-Reflection Profiles, Offshore of Monterey Map Area, California

By

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2016