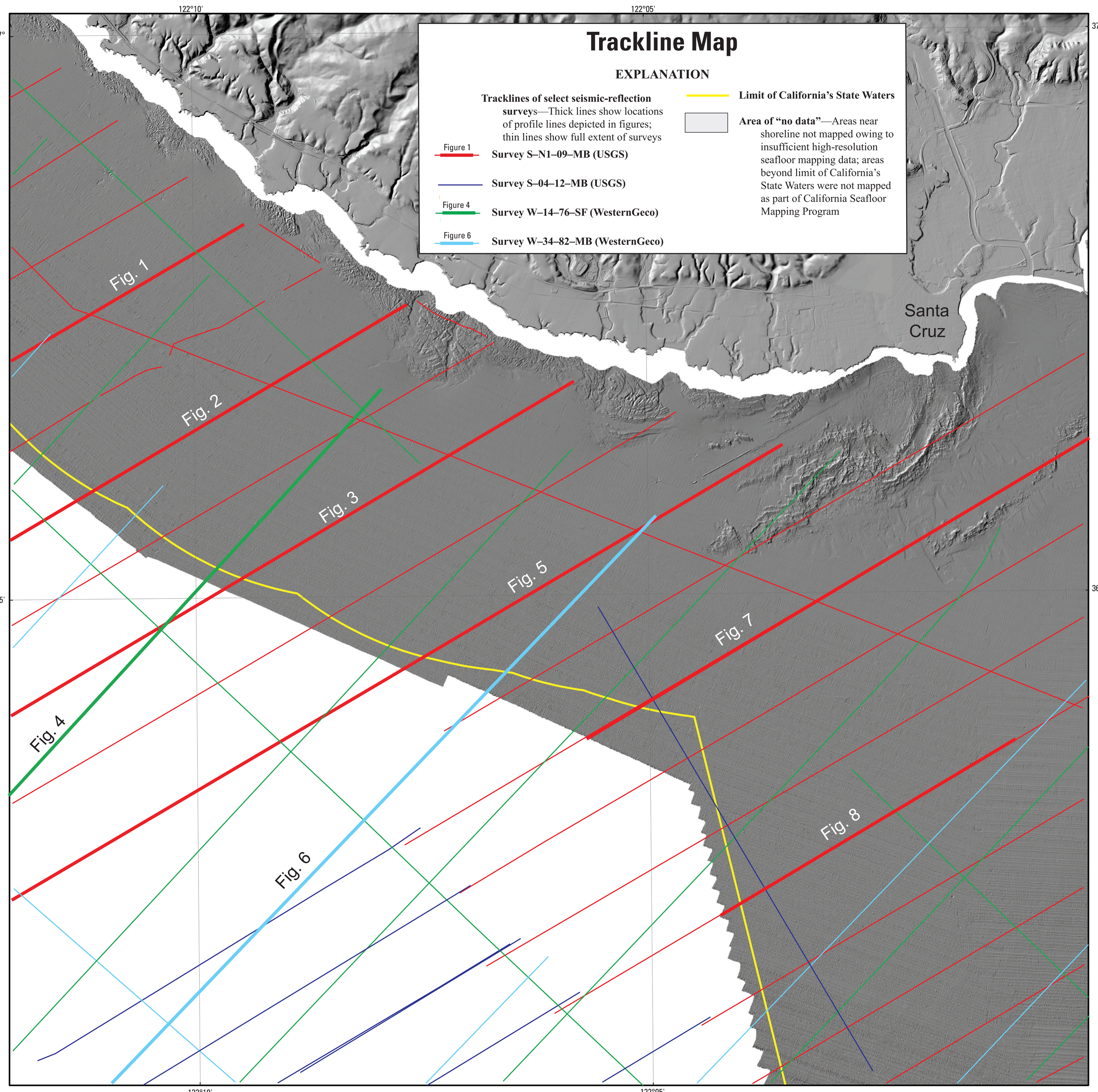


Onshore elevation data from National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management's Digital Coast (available at http://www.csc.noaa.gov/digitalcoast/data/coastallidar/) and from U.S. Geological Survey's National Elevation Dataset (available at http://ned.usgs.gov/). Offshore 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

APPROXIMATE MEAN DECLINATION, 2016

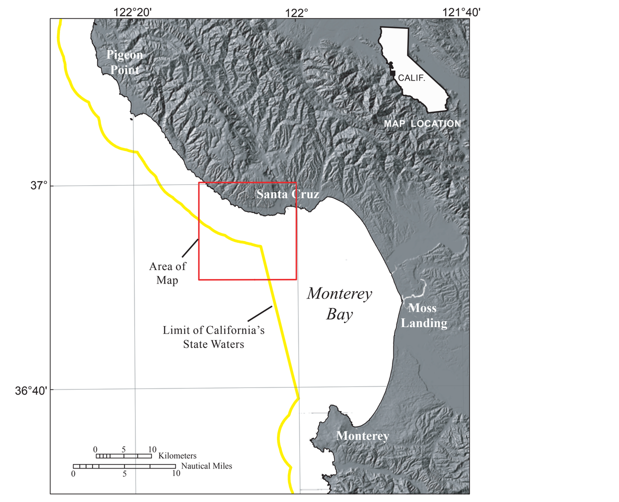
SCALE 1:50 000

ONE MILE = 0.869 NAUTICAL MILES

MAP LOCATION

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

Manuscript approved for publication February 18, 2016



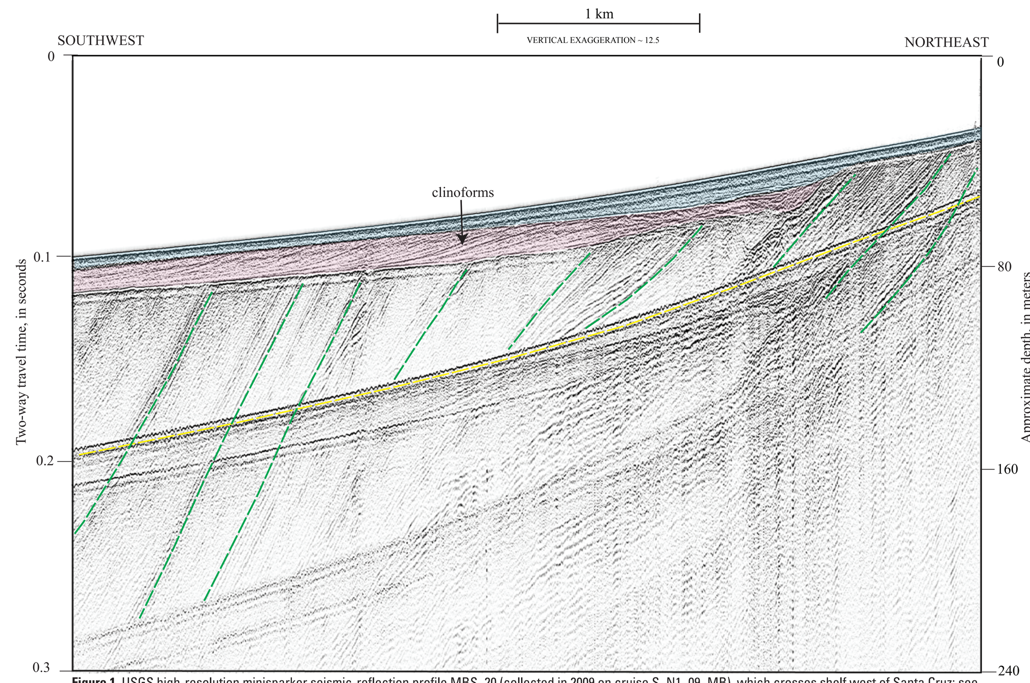


Figure 1. USGS high-resolution minisparker seismic-reflection profile MBS–20 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf west of Santa Cruz; see trackline map for location. Profile highlights west-dipping strata beneath continental shelf. Blue and pink shading shows inferred uppermost Pleistocene and Holocene strata, deposited in about last 30,000 years during final stages of sea-level fall and subsequent sea-level rise. Underlying southwest-dipping reflectors are of Neogene age. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector).

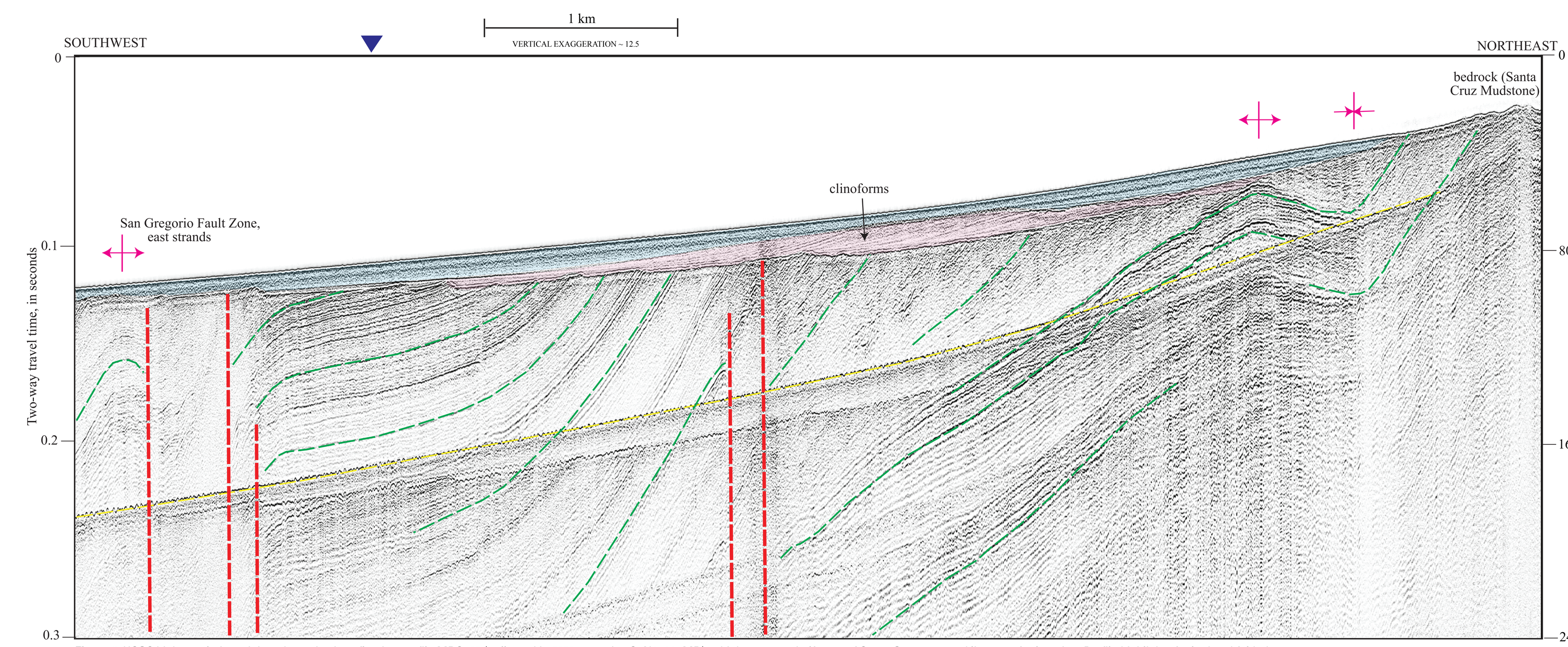


Figure 2. USGS high-resolution minisparker seismic-reflection profile MBS–06 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf west of Santa Cruz; see trackline map for location. Profile highlights faulted and folded strata beneath continental shelf, including east strands of San Gregorio Fault Zone. Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, syncline). Blue and pink shading shows inferred uppermost Pleistocene and Holocene strata, deposited in about last 30,000 years during final stages of sea-level fall and subsequent sea-level rise. Underlying southwest-dipping reflectors are of Neogene age. 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).

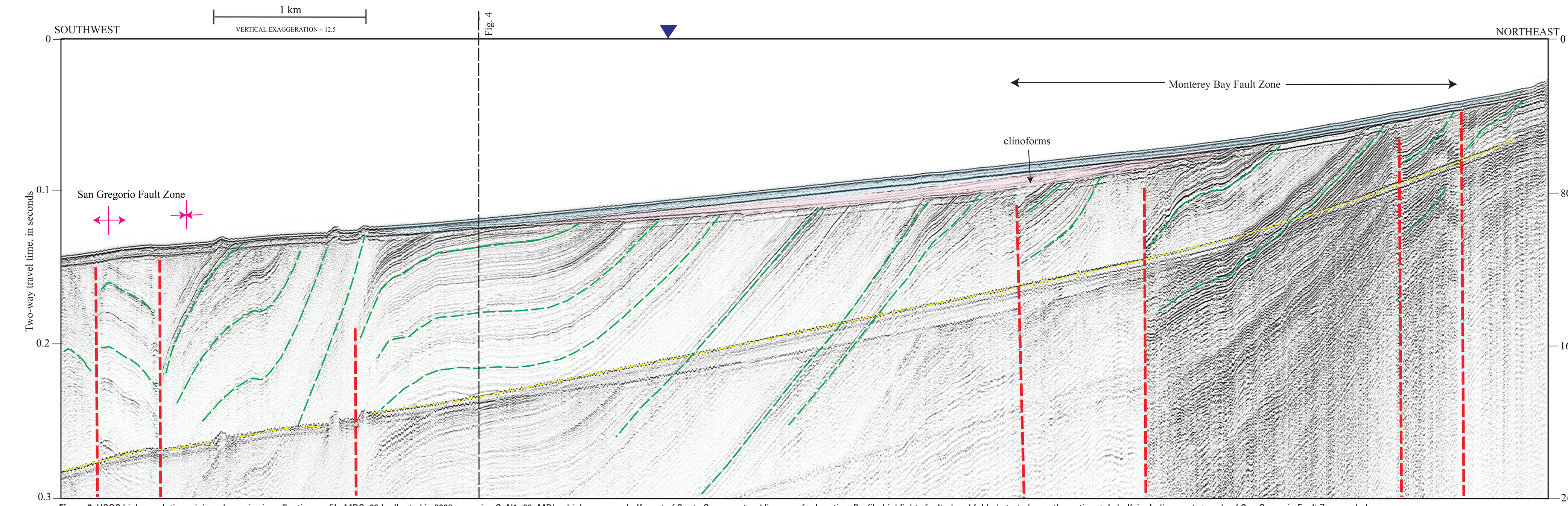


Figure 3. USGS high-resolution minisparker seismic-reflection profile MBS–03 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf west of Santa Cruz; see trackline map for location. Profile highlights faulted and folded strata beneath continental shelf, including east strands of San Gregorio Fault Zone and also Monterey Bay Fault Zone. Dashed red lines show faults. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Blue and pink shading shows inferred uppermost Pleistocene and Holocene strata, deposited in about last 30,000 years during final stages of sea-level fall and subsequent sea-level rise. Underlying southwest-dipping reflectors are of Neogene age. 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).

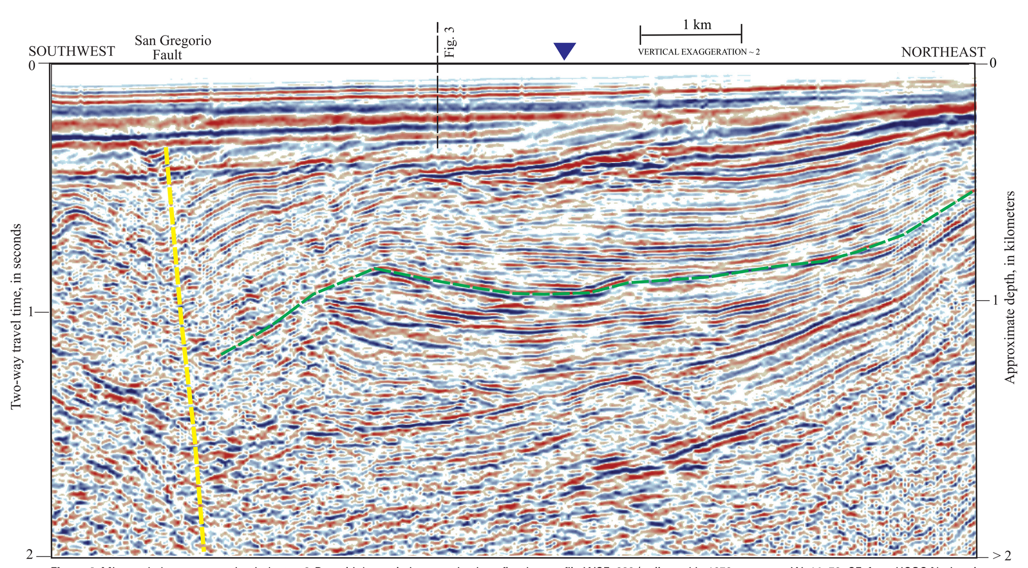


Figure 4. Migrated, deep-penetration industry, 2-D, multichannel air-gun seismic-reflection profile WSF–020 (collected in 1976 on survey W–14–76–SF; from USGS National Archive of Marine Seismic Surveys [U.S. Geological Survey, 2009]), which crosses shelf west-southwest of Santa Cruz; see trackline map for location. Note that vertical scale and exaggeration are significantly different than that of high-resolution seismic-reflection profiles shown in figures 1, 2, 3, 5, 7, and 8. Profile highlights San Gregorio Fault (dashed yellow line) and gently dipping strata beneath continental shelf. Dashed green line highlights stratigraphic surface that changes (from northeast to southwest [right to left]) from conformity to angular unconformity (compare to profile in fig. 6). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

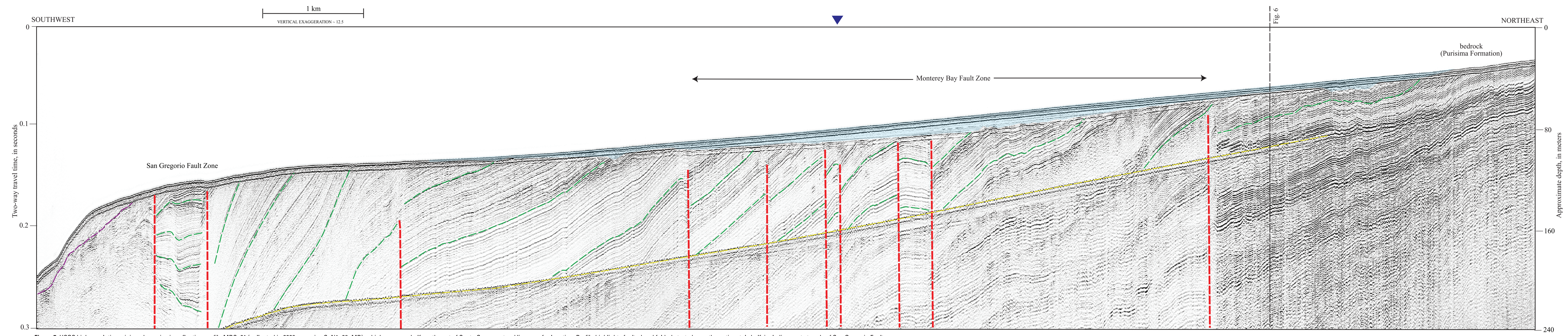


Figure 5. USGS high-resolution minisparker seismic-reflection profile MBS–01 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf southwest of Santa Cruz; see trackline map for location. Profile highlights faulted and folded strata beneath continental shelf, including east strands of San Gregorio Fault Zone and also Monterey Bay Fault Zone. Dashed red lines show faults. Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited during sea-level rise in about last 21,000 years. Underlying reflectors are of inferred Neogene age. Dashed green lines highlight some continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed purple line shows unconformity. 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).

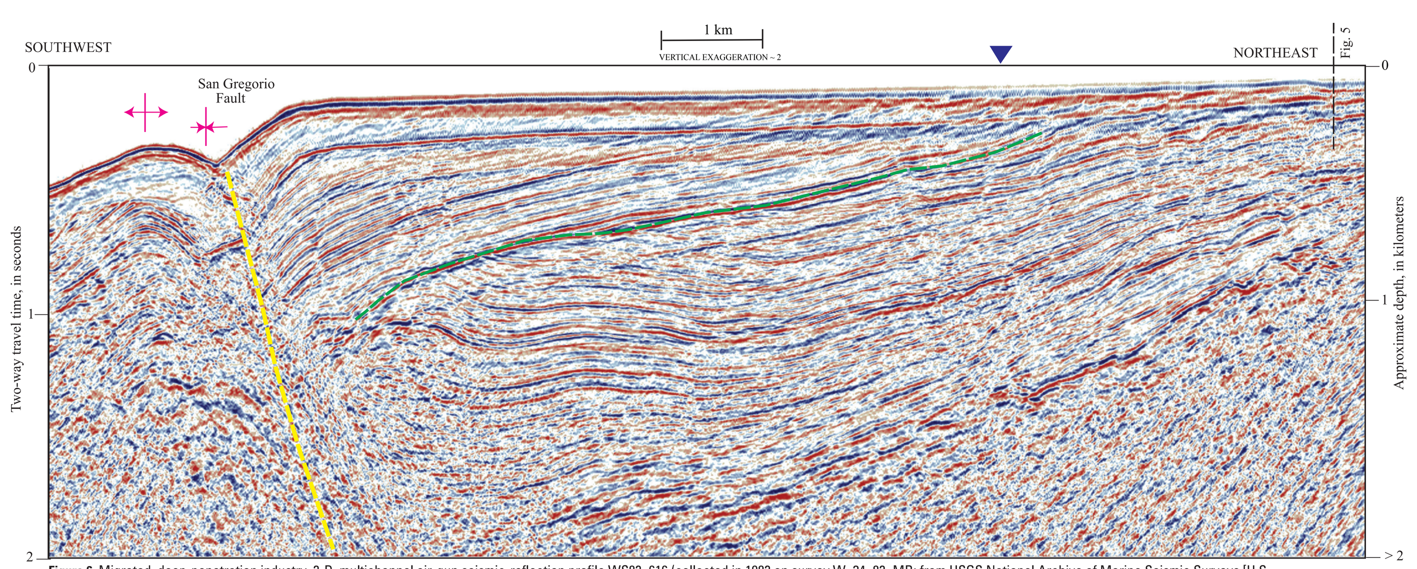


Figure 6. Migrated, deep-penetration industry, 2-D, multichannel air-gun seismic-reflection profile WS82–616 (collected in 1982 on survey W–34–82–MB; from USGS National Archive of Marine Seismic Surveys [U.S. Geological Survey, 2009]), which crosses shelf southwest of Santa Cruz; see trackline map for location. Note that vertical scale and exaggeration are significantly different than that of high-resolution seismic-reflection profiles shown in figures 1, 2, 3, 5, 7, and 8. Profile highlights gently dipping strata beneath continental shelf in northern Monterey Bay, as well as San Gregorio Fault (dashed yellow line) and associated folds west of fault (magenta symbols: diverging arrows, anticline; converging arrows, syncline). Dashed green line highlights stratigraphic surface that changes (from northeast to southwest [right to left]) from conformity to angular unconformity (compare to profile in fig. 4). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

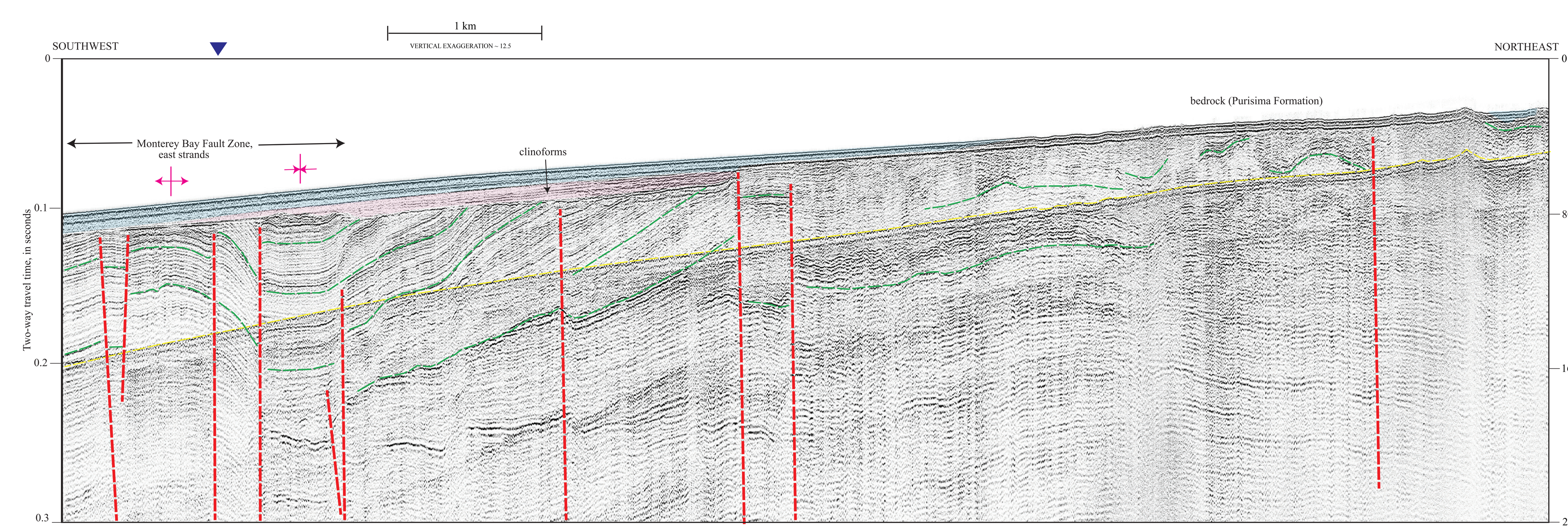


Figure 7. USGS high-resolution minisparker seismic-reflection profile MBS–09 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf south of Santa Cruz; see trackline map for location. Profile highlights faulted and gently folded strata west beneath continental shelf in northern Monterey Bay. Dashed red lines show faults, including east strands of Monterey Bay Fault Zone. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Blue and pink shading shows inferred uppermost Pleistocene and Holocene strata, deposited in about last 30,000 years during final stages of sea-level fall and subsequent sea-level rise. Underlying reflectors are of inferred Neogene age. 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).

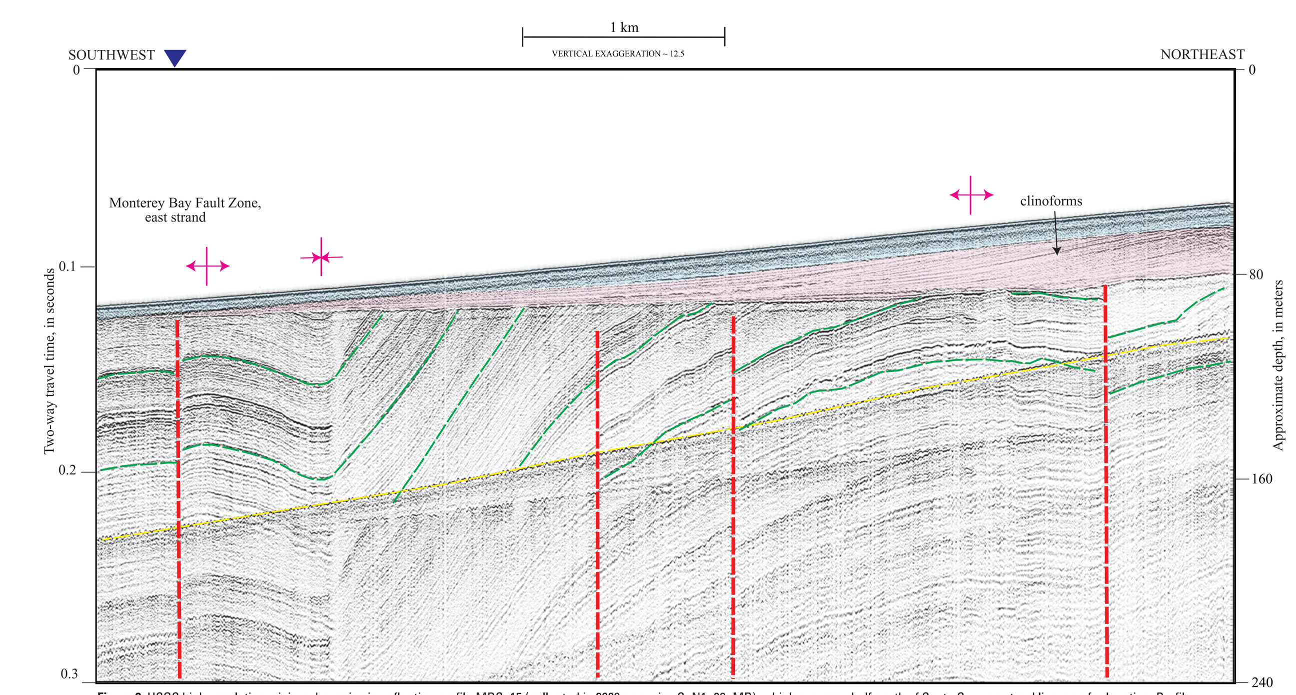


Figure 8. USGS high-resolution minisparker seismic-reflection profile MBS–15 (collected in 2009 on cruise S–N1–09–MB), which crosses shelf south of Santa Cruz; see trackline map for location. Profile highlights faulted and gently folded strata west beneath continental shelf in northern Monterey Bay. Dashed red lines show faults, including east strand of Monterey Bay Fault Zone. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, syncline). Blue and pink shading shows inferred uppermost Pleistocene and Holocene strata, deposited in about last 30,000 years during final stages of sea-level fall and subsequent sea-level rise. Underlying reflectors are of inferred Neogene age. 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).

DISCUSSION

This map sheet shows seismic-reflection profiles from three different surveys of the Offshore of Santa Cruz map area, providing imagery of the subsurface geology. This map area is characterized by a gently (about 0.7°) offshore-dipping inner shelf and midshelf area, extending to water depths of about 65 to 90 m at the limit of California's State Waters (note that the California's State Waters limit, which generally is 3 nautical miles from shore, extends farther offshore south of Santa Cruz, so that it encompasses all of Monterey Bay). Most of the shelf is underlain by flat, sandy and muddy sediment; bedrock forms moderate-relief outcrops that locally extend from the shoreline out to water depths of as much as 45 m (see sheet 10), most prominently south of Santa Cruz. The seismic-reflection profiles provide the data for interpreting subbottom stratigraphy, sediment thickness, and geologic structure (see sheets 9, 10).

Most profiles displayed on this sheet (figs. 1, 2, 3, 5, 7, 8) were collected in 2009 on U.S. Geological Survey (USGS) cruise S–N1–09–MB. The single-channel seismic-reflection data were acquired using a SIG 2Mille minisparker system that used a 500-J high-voltage electrical discharge fired 1 to 4 times per second, which, at normal survey speeds of 4 to 4.5 nautical miles per hour, gives a data trace every 0.5 to 2.0 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 (hence, are considered "high-resolution"), down to subbottom depths of about 400 m.

Figures 4 and 6 show migrated, deep-penetration, multichannel seismic-reflection profiles collected in 1976 and 1982 by WesternGeco on cruises W–14–76–SF and W–34–82–MB, respectively. These profiles 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 (U.S. Geological Survey, 2009). 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 about 4 km.

The offshore part of the map area is cut by two significant fault zones, 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 differences in seismic parameters, such as amplitude, frequency, geometry, continuity, and vertical sequence. The north-northwest-striking, right-lateral San Gregorio Fault Zone cuts through the Offshore of Santa Cruz map area outside California's State Waters, forming a steeply dipping shear zone (figs. 2, 3, 4, 5, 6). This fault zone is part of a regional system that 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 (Dickinson and others, 2005). 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 60 km south of the map area), across outer Monterey Bay to Point Año Nuevo (17 km north of the map area) on the north (see sheet 9; see also, Weber and Lajoie, 1980; Brabb and others, 1998; Wagner and others, 2002). Cumulative lateral slip on this fault zone is thought to range from 4 to 10 mm/yr in this area (Weber, 1994).

The Monterey Bay Fault Zone (Greene, 1990; see figs. 3, 5, 7, 8) is a distributed, about 5-km-wide, steeply dipping to vertical fault zone that lies east of, and subparallel to, the San Gregorio Fault Zone. Seismic-reflection profiles reveal that this fault zone can include as many as ten or more strands, most of which can be mapped for only a few kilometers (see sheets 9, 10). Faults in this zone do not appear to offset Quaternary deposits.

The high-resolution seismic-reflection profiles (figs. 1, 2, 3, 5, 7, 8) image a lower unit made up of deformed Neogene bedrock and one or two upper units (pink and blue shading) consisting of upper Quaternary sediments. Bedrock is characterized by folded and faulted, moderate- to high-amplitude, variably continuous, parallel to subparallel reflections. On the seafloor west and northwest of Santa Cruz, shallow bedrock imaged in seismic-reflection profiles is inferred to consist of the upper Miocene Santa Cruz Mudstone, as is continuous with coastal outcrops. Deeper seismic-reflection profiles (figs. 4, 6) image an unconformity that may represent the contact between the Santa Cruz Mudstone and the middle and upper Miocene Monterey Formation. South of Santa Cruz, shallow bedrock imaged in seismic-reflection profiles is inferred to consist of the Santa Cruz Mudstone and the upper Miocene and Pliocene Purisima Formation.

Throughout the map area, the contact between Neogene bedrock and the overlying upper Quaternary sediments is an angular unconformity. Two upper Quaternary units are recognized. The lower unit (pink shading) of the two overlying sedimentary units is present in the northwestern (figs. 1, 2, 3) and southeastern (figs. 7, 8) parts of the map area but appears to be absent in the central part (fig. 5). This unit notably includes low-amplitude, low-angle (1° to 3°), offshore-dipping clinoforms (Catuneanu, 2006) that are as thick as 20 m. The upper unit (blue shading) of the two units typically is characterized by low-amplitude, continuous to moderately continuous, diffuse, subparallel reflections, and it has a maximum thickness of about 13 m. Our preferred hypothesis is that the clinoforms in the lower unit (pink shading) represent a progradational shoreface and deltaic sequence that formed between about 30,000 and 21,000 years ago during the sea-level regression of marine-isotope stage 2 (Waelbroeck and others, 2002). The upper unit (blue shading) represents shelf deposits that formed during the sea-level transgression of the last about 21,000 years (Stanford and others, 2011). In this interpretation, the contact between the upper and lower units is a transgressive surface of erosion that formed as the shoreline migrated landward. Because these two upper Quaternary units each consist of unconsolidated sediments overlying a prominent angular unconformity with bedrock, we have combined their thicknesses on the thickness maps (Maps B, D) on sheet 9.

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Seismic-Reflection Profiles, Offshore of Santa Cruz Map Area, California

by

Samuel Y. Johnson, Stephen R. Hartwell, and Ray W. Sliter

2016

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