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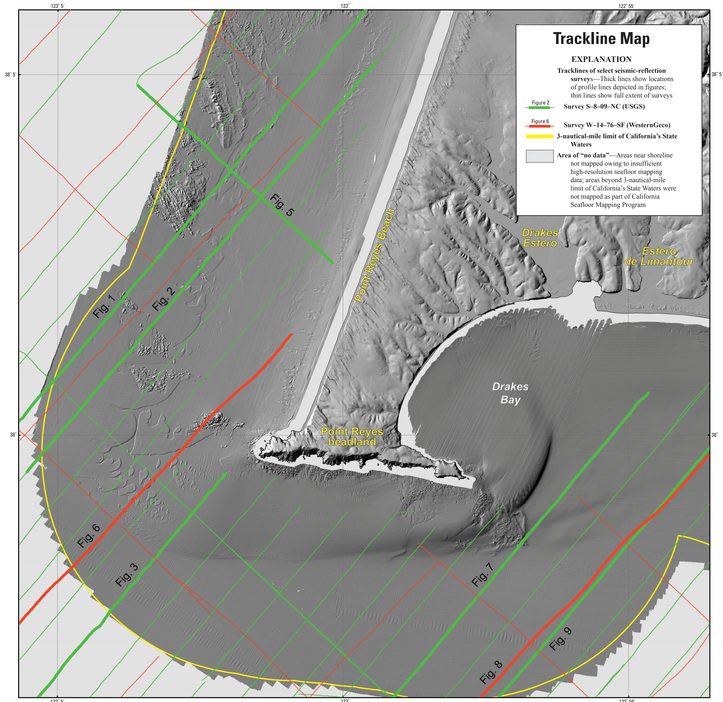
U.S. Geological Survey

Open-File Report 2015–1114
Sheet 8 of 10
Pamphlet accompanies map



Onshore elevation data from NOAA Coastal Service Center's Digital Coast (available at http://coast.noaa.gov/digitalcoast/) and from U.S. Geological Survey's National Elevation Dataset (available at http://ned.usgs.gov/). Offshore elevation and 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
2 0 2 MILES
7000 3500 0 7000 FEET
0.5 0 1 KILOMETER
ONE MILE = 0.869 NAUTICAL MILES

APPROXIMATE MEAN DECLINATION, 2015

MAP LOCATION

GIS database and digital cartography by Janet T. Watt, Stephen R. Hartwell, and Peter Dartnell
Manuscript approved for publication June 8, 2015

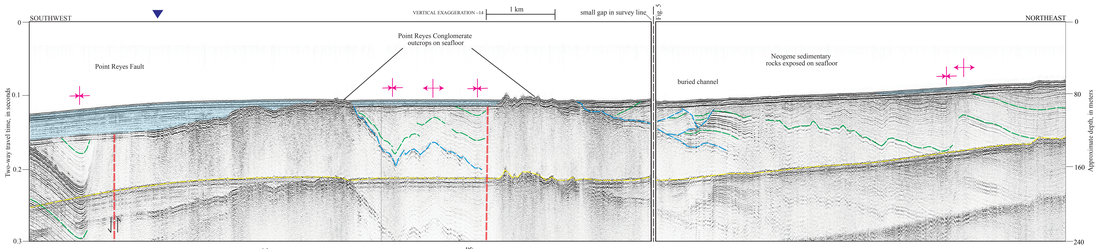


Figure 1. USGS high-resolution minisparker seismic-reflection profile PR–58 (collected in 2009 on survey S–8–09–NC), which crosses shelf west of Point Reyes peninsula; see trackline map for location. Profile shows Point Reyes Fault near southwest end of profile as acoustically transparent zone that separates nonreflective Upper Cretaceous and Paleogene rocks to northeast from highly reflective, folded Tertiary and Quaternary strata to southwest. Gently folded Neogene strata northeast of Point Reyes Fault, which lie unconformably on the lower Eocene Point Reyes Conglomerate, are highly reflective. Erosional unconformity separates Neogene strata from inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. Dashed red lines shows faults; black arrows on fault show relative motion. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed blue lines show erosional unconformities. Dashed green lines highlight 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).

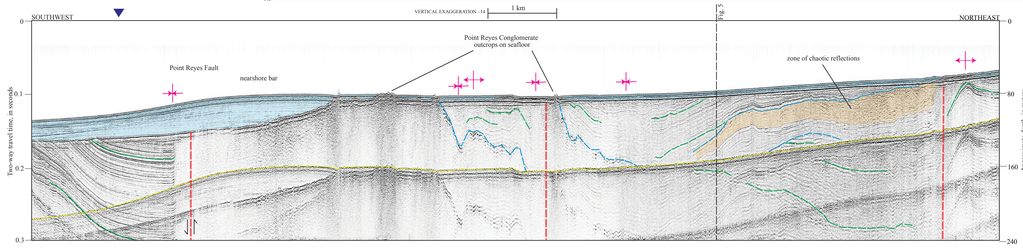


Figure 2. USGS high-resolution minisparker seismic-reflection profile PR–56A (collected in 2009 on survey S–8–09–NC), which crosses shelf west of Point Reyes peninsula; see trackline map for location. Profile shows Point Reyes Fault as acoustically transparent zone that separates nonreflective Upper Cretaceous and Paleogene rocks to northeast from folded Tertiary and Quaternary strata to southwest. The lower Eocene Point Reyes Conglomerate, exposed on seafloor, is overlain by gently folded Neogene strata. Zone of chaotic reflections (orange shading), which underlies erosional unconformity within Neogene section, is inferred to be the Santa Margarita Sandstone. Erosional unconformity separates gently folded Neogene strata from inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. Uppermost Pleistocene and Holocene shelf strata include nearshore-bar deposits, which are characterized by shingled, prograding clinoforms that overlie relatively flat lying, parallel reflectors. Dashed red lines show faults; black arrows on fault show relative motion. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed green lines highlight 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).

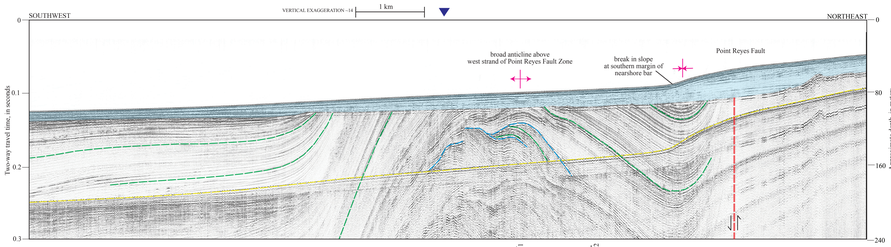


Figure 3. USGS high-resolution minisparker seismic-reflection profile PR–48 (collected in 2009 on survey S–8–09–NC), which crosses shelf southwest of Point Reyes headland; see trackline map for location. Profile shows Point Reyes Fault as acoustically transparent zone that separates Late Cretaceous granitic rocks and Paleogene sedimentary rocks to northeast from mildly folded Tertiary and Quaternary strata to southwest. West strand of Point Reyes Fault Zone (see fig. 6) is expressed near surface as broad anticline in upper Miocene to Pleistocene strata. Erosional unconformity separates folded strata from inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. Uppermost Pleistocene and Holocene shelf strata include nearshore-bar deposits, which are characterized by shingled, prograding clinoforms that overlie relatively flat lying, parallel reflectors. Thickness of uppermost Pleistocene and Holocene (post-LGM) strata is greatest (more than 30 m) within nearshore-bar deposits. Dashed red line shows fault; black arrows on fault show relative motion. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed blue lines show erosional unconformities. Dashed green lines highlight 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 PR–70 (collected in 2009 on survey S–8–09–NC), which crosses shelf west of Point Reyes Beach; see trackline map for location. Profile shows dipping reflectors within Neogene strata within Point Reyes Syncline. Syncline is bounded to northwest by the (reflection-free) lower Eocene Point Reyes Conglomerate, which is exposed on seafloor. Erosional unconformity separates Tertiary strata from thin layer of inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. Magenta symbol shows syncline axis. Dashed blue lines show erosional unconformities. Dashed green lines highlight 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).

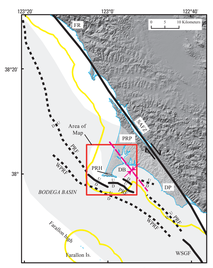


Figure 4. Map showing important structures of Point Reyes Fault Zone offshore of Point Reyes peninsula. Fault structures are based on interpretation of both deep-penetration multichannel and USGS shallow minisparker seismic-reflection data. Faults are shown by thick black lines: solid lines show buried faults that are imaged in shallow minisparker data; dashed lines indicate buried faults that show no visible offset in shallow minisparker data; U, upthrown block; D, downthrown block; paired arrows indicate relative motion on strike-slip fault. Dashed magenta line shows approximate axis of Point Reyes Syncline. Gray shading shows late Tertiary Bodega Basin (modified from McCulloch, 1987). Red box shows Offshore of Point Reyes map area. Yellow line shows limit of California's State Waters. Abbreviations: DB, Drakes Bay; DP, Double Point; FR, Fort Ross; PRF, Point Reyes Fault Zone; PRH, Point Reyes headland; PRP, Point Reyes peninsula; SAFZ, San Andreas Fault Zone; WPRF, west strand of Point Reyes Fault Zone; WSGF, west strand of San Gregorio Fault Zone.

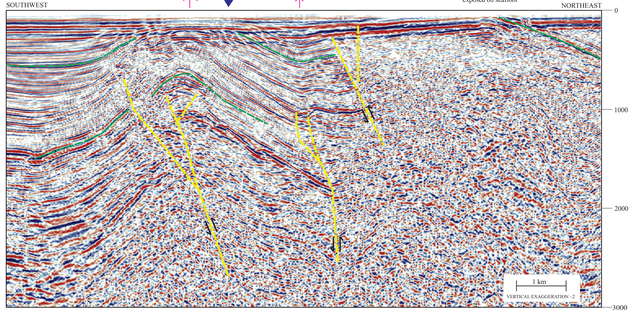


Figure 6 (left). Depth-converted, deep-penetration industry, 2-D, multichannel air-gun seismic-reflection profile WSF–090 (collected in 1976 on survey W–14–76–SF; from USGS National Archive of Marine Seismic Surveys [U.S. Geological Survey, 2009]), which crosses shelf west-southwest of Point Reyes headline; see trackline map for location. Profile shows Point Reyes Fault Zone as multiple structures, which include Point Reyes Fault and west strand of Point Reyes Fault Zone. Point Reyes Fault imaged as steeply dipping structure that has northeast-side-up vertical displacement. West strand of Point Reyes Fault Zone, which is also northeast dipping, forms broad anticline in Tertiary strata. Dashed yellow lines show faults; black arrows on faults show relative motion. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed green lines highlight continuous reflections that reveal structure (not distinctive stratigraphic markers). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

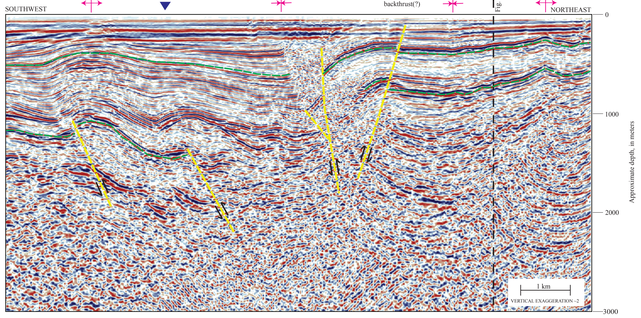


Figure 8 (left). Depth-converted, deep-penetration industry, 2-D, multichannel air-gun seismic-reflection profile WSF–090 (collected in 1976 on survey W–14–76–SF; from USGS National Archive of Marine Seismic Surveys [U.S. Geological Survey, 2009]), which crosses shelf south and east of Point Reyes headland; see trackline map for location. Profile shows Point Reyes Fault Zone as multiple structures, which include Point Reyes Fault and west strand of Point Reyes Fault Zone. Point Reyes Fault is imaged as steeply dipping structure that has northeast-side-up vertical displacement. West strand of Point Reyes Fault Zone is shown as multiple northeast-dipping structures that form broad anticline in Tertiary strata. Southwest-dipping structure near center of profile may be backthrust that is related to Point Reyes Fault. Dashed yellow lines show faults; black arrows on faults show relative motion. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Dashed green lines highlight continuous reflections that reveal structure (not distinctive stratigraphic markers). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

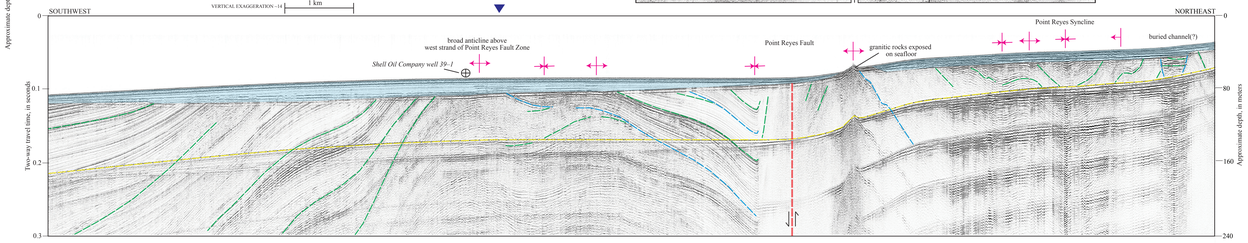


Figure 7. USGS high-resolution minisparker seismic-reflection profile PR–19 (collected in 2009 on survey S–8–09–NC), which crosses shelf south and east of Point Reyes headland; see trackline map for location. Profile shows southwest-dipping reflectors in upper Miocene to Pleistocene strata that form southwest limb of anticline above west strand of Point Reyes Fault Zone (see also, figs. 4, 8). Point Reyes Fault shown as acoustically transparent zone that separates Late Cretaceous granitic rocks and the lower Eocene Point Reyes Conglomerate to northeast from Tertiary and Quaternary strata to southwest. Granitic basement rocks crop out on seafloor just northeast of Point Reyes Fault. Folded Tertiary strata, including the upper Miocene and Pliocene Purisima Formation, form Point Reyes Syncline (see also, fig. 8). Erosional unconformity separates folded strata from 2- to 18–m-thick layer of inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. At base of uppermost Pleistocene and Holocene shelf strata, distinct sediment sequences, which are characterized by channeling and various progradational patterns, likely represent deposition within estuarine environment similar to that in nearby Drakes Estero and Estero de Limantour (see also, fig. 9). Dashed red line shows fault; black arrows on fault show relative motion. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines) and sharp flexure (single arrow shows direction of increasing dip). Dashed blue lines show erosional unconformities. Dashed green lines highlight 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).

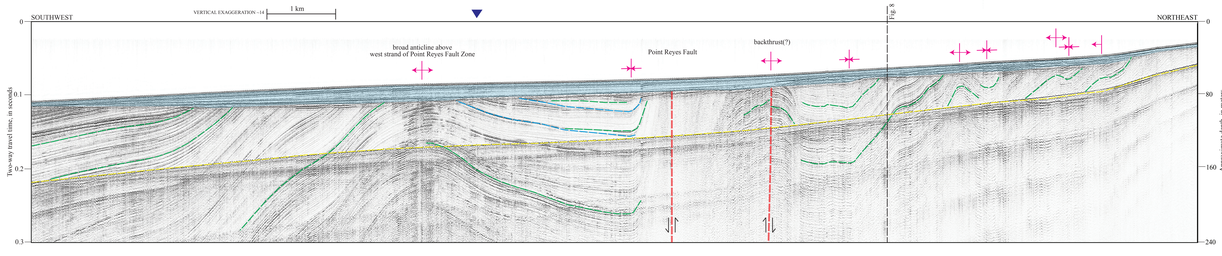


Figure 9 (right). USGS high-resolution minisparker seismic-reflection profile PR–40 (collected in 2009 on survey S–8–09–NC), which crosses shelf south and east of Point Reyes headland; see trackline map for location. Profile shows Point Reyes Fault shown as acoustically transparent zone that separates folded Tertiary strata to northeast from mildly folded Tertiary and Quaternary strata to southwest. West strand of Point Reyes Fault Zone (see also, fig. 8) is expressed near surface as broad anticline in upper Miocene to Pleistocene strata. Erosional unconformity separates folded strata from 2- to 18–m-thick layer of inferred uppermost Pleistocene and Holocene shelf strata (blue shading), which were deposited since last sea-level lowstand about 21,000 years ago. At base of uppermost Pleistocene and Holocene shelf strata, distinct sediment sequences, which are characterized by channeling and various progradational patterns, likely represent deposition within estuarine environment similar to that in nearby Drakes Estero and Estero de Limantour (see also, fig. 7). Dashed red lines show faults; black arrows on faults show relative motion. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines) and sharp flexure (single arrow shows direction of increasing dip). Dashed blue lines show erosional unconformities. Dashed green lines highlight 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).

Seismic-Reflection Profiles, Offshore of Point Reyes Map Area, California

By

Janet T. Watt, Samuel Y. Johnson, John L. Chin, and Ray W. Sliter

2015

DISCUSSION

This map sheet shows seismic-reflection profiles from surveys of the Offshore of Point Reyes map area, providing imagery of the subsurface geology. The seismic-reflection profiles provide the data for interpreting subbottom stratigraphy, sediment thickness, and geologic structure (see sheets 9, 10 of this report).

The Offshore of Point Reyes map area is characterized by granitic and metamorphic basement rocks of the Salinian block and overlying Tertiary marine sedimentary rocks of the Bodega Basin (McCulloch, 1987) and the Point Reyes Syncline (Weaver, 1949), all of which have been uplifted and deformed along the Point Reyes Fault Zone, forming the present-day Point Reyes peninsula. These different rock types can be mapped on the seafloor (see sheet 10 of this report) on the basis of their distinctive surface morphologies. Granitic seafloor outcrops are characterized by their massive, bulbous texture, and they are cut by a dense network of fractures and small faults. In contrast, the overlying folded Tertiary sedimentary rocks are characterized by a "ribbed" seafloor morphology that results from the variable resistance to erosion of different beds (lithologies) within the sedimentary sections. Offshore of Point Reyes Beach, in the northwestern part of the map area, the sedimentary rocks are less "ribbed," owing to their shallower dips (see sheet 10).

On seismic-reflection data, the Late Cretaceous granitic rocks and the early Eocene (Clark and Brabb, 1997) Point Reyes Conglomerate of Galloway (1977) are nonreflective. The overlying Neogene section (mapped as the undivided sedimentary rocks unit [Tu] and the Purisima Formation [Tp] on sheet 10) is characterized by continuous, parallel to subparallel, variable amplitude, high-frequency reflections (terminology from Mitchum and others, 1977), except for a zone of chaotic low-amplitude reflections (fig. 2). This zone of chaotic reflections may represent more massive (that is, lacking bedding) rocks within either the Monterey Formation or the Santa Cruz Mudstone, or it may represent the Santa Margarita Sandstone.

Surficial and shallow sediments were deposited in the last about 21,000 years during the sea-level rise that followed the last major lowstand associated with the Last Glacial Maximum (LGM) (Lambeck and Chappell, 2001; Peltier and Fairbanks, 2006). Sea level was about 125 m lower during the LGM, at which time the Offshore of Point Reyes map area was emergent. The post-LGM sea-level rise was rapid (about 9 to 11 m per thousand years) until about 7,000 years ago, when it slowed considerably to about 1 m per thousand years (Peltier and Fairbanks, 2006; Stanford and others, 2011).

The sediments deposited during the post-LGM sea-level rise (the rapid transgression and highstand) are shaded blue in the high-resolution seismic-reflection profiles (figs. 1, 2, 3, 5, 7, 9), and their thickness is shown on sheet 9 (Maps B, D). Two distinct sediment sequences are present within the post-LGM unit: (1) West and southwest of the Point Reyes headland, low-amplitude, prograding clinoforms overlie parallel, gently dipping reflectors that are visible in high-resolution seismic-reflection profiles (figs. 1, 2, 3); the clinoforms are interpreted to represent the nearshore bar that wraps around the Point Reyes headland and into Drakes Bay. The bar is continuous except offshore of the east end of the Point Reyes headland, where granitic rocks are exposed on the seafloor. The limit of the bar is denoted by a break in slope that is visible both on multibeam imagery (see sheet 1) and on high-resolution seismic-reflection profiles (sheet 8). The bar is located south of the east-west-trending Point Reyes headland, which once was emergent when sea level was lower but now is partly submerged. Deposition of the bar likely began as sea level was rising, and the bar migrated eastward as sea level rose and the west end of that bedrock ridge was submerged below wave base. (2) At the base of the uppermost Pleistocene and Holocene unit are inferred transgressive-systems-tract deposits (Catuneanu, 2006), which are characterized by channeling and various progradational patterns (figs. 6, 8). These deposits likely represent deposition within an estuarine environment, similar to that in the nearby Drakes Estero and Estero de Limantour.

Faults in the offshore part of the Offshore of Point Reyes map area are identified on 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 reflection presence, amplitude, frequency, geometry, continuity, and vertical sequence. The Point Reyes Fault Zone, which runs through the map area in the offshore, is a curvilinear reverse fault zone that has predominantly north-side-up motion (Hoskins and Griffiths, 1971; McCulloch, 1987; Heck and others, 1990; Shostak, 2012); this fault likely connects at depth with the west strand of the San Gregorio Fault Zone south of the map area (Ryan and others, 2008), which means that it is part of the San Andreas Fault system. The Point Reyes Fault Zone is characterized by a 5- to 11-km-wide zone of deformation in the shallow subsurface that is associated with two main fault structures, which are imaged with deep-penetration industry multichannel seismic data: the Point Reyes Fault, and also a west strand mapped offshore of the Point Reyes peninsula (see fig. 4). Near the Point Reyes headland, vertical displacement of granitic basement rocks across the Point Reyes Fault is at least 1.4 km (McCulloch, 1987). The west strand of the Point Reyes Fault Zone is defined by a broad anticlinal structure, which is visible in both industry and high-resolution seismic data (see figs. 3, 6). The west strand exhibits the same sense of vergence (north side up) as that of the Point Reyes Fault. In the map area, the cumulative (since late Miocene) slip rate on the Point Reyes Fault Zone is poorly constrained, but it is estimated to be 0.3 mm/yr on the basis of vertical offset of granitic basement rocks (McCulloch, 1987; Wills and others, 2008).

A distinct unconformity (or acoustic-impedance contrast) between the upper Miocene and Pliocene Purisima Formation and younger sediments is otherwise lacking in the map area, making the distribution of upper Pliocene and Pleistocene strata difficult to ascertain from seismic-reflection data. However, lithological and paleontological data from Shell Oil Company offshore well 39–1, which was drilled into the crest of the anticline above the west strand of the Point Reyes Fault Zone (see fig. 7), suggest that about 220 m of upper Pliocene to Pleistocene sediments overlie the Purisima Formation (Webster and Yenne, 1987; Heck and others, 1990) and that the upper 80 m is interpreted as being of Quaternary age (Webster and Yenne, 1987). If this is the case, then a significant amount of post–Purisima Formation strata is present on the shelf south of the Point Reyes headland that has been deformed within the Point Reyes Fault Zone. Lack of clear deformation within the post-LGM unit suggests that activity along the Point Reyes Fault Zone has diminished or slowed since about 21,000 years ago.

Except for the profiles in figures 6 and 8, all profiles displayed on this map sheet were collected in 2009 on U.S. Geological Survey (USGS) cruise S–8–09–NC. The single-channel seismic-reflection data were acquired using the SIG 2Mille minisparker, which 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 meters. The data were digitally recorded in standard SEG-Y 32-bit floating-point format, using PC-based 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).

Figures 6 and 8 show deep-penetration, depth-converted, multichannel seismic-reflection profiles collected in 1976 by WesternGeco on cruise W–14–76–SF. 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.

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