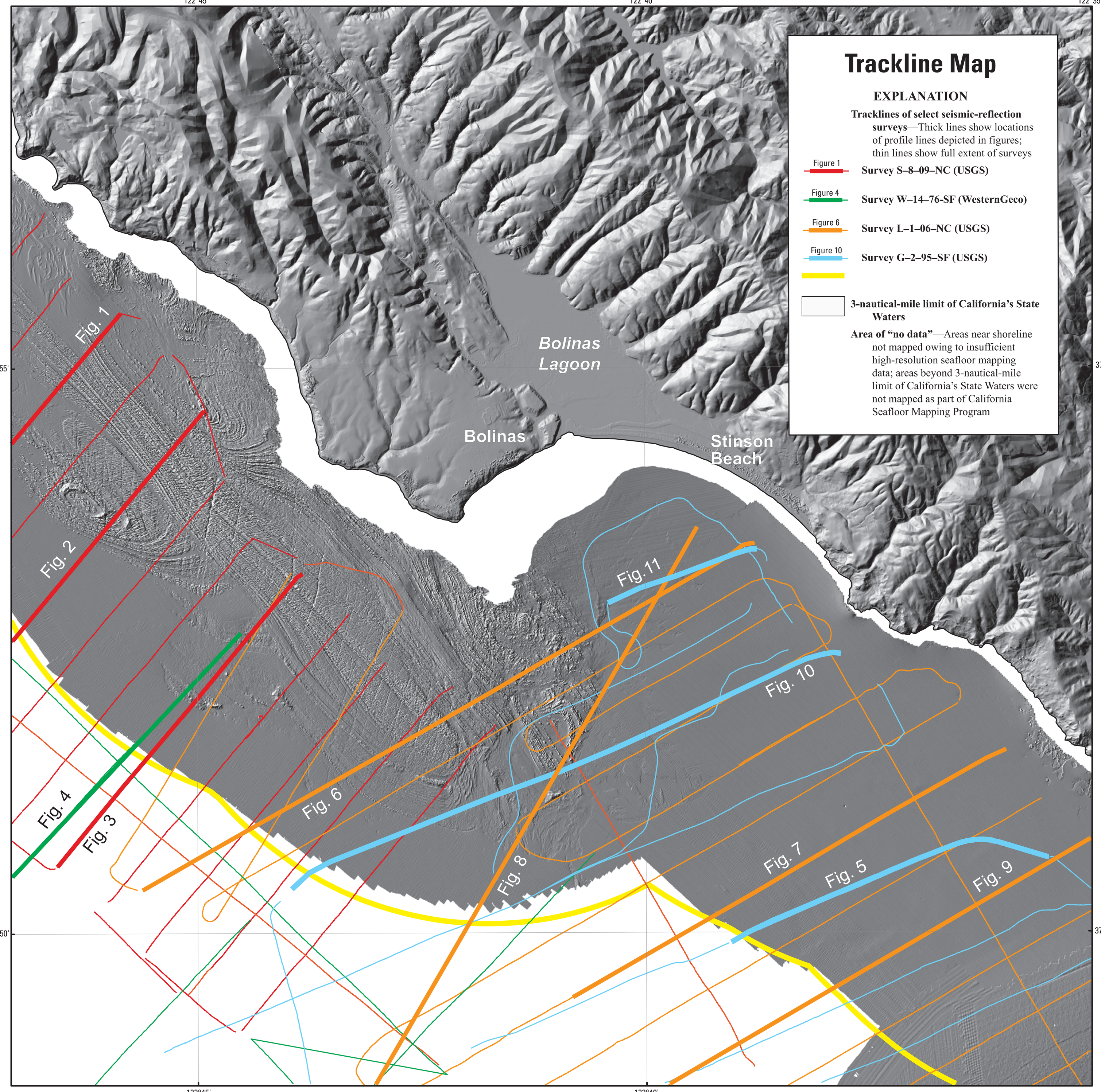


Onshore elevation data collected by Earth Eye in 2010 for San Francisco State University and U.S. Geological Survey (available at http://egsc.usgs.gov/). Offshore shaded-relief bathymetry from map on sheet 2, this report. California State Waters limit from NOAA Office of Coast Survey
Universal Transverse Mercator projection, Zone 10N

NOT INTENDED FOR NAVIGATIONAL USE

SCALE 1:50 000

ONE MILE = 0.869 NAUTICAL MILES

APPROXIMATE MEAN DECLINATION, 2015

MAP LOCATION

GIS database and digital cartography by Eleyne L. Phillips and Florence L. Wong
Manuscript approved for publication July 21, 2015

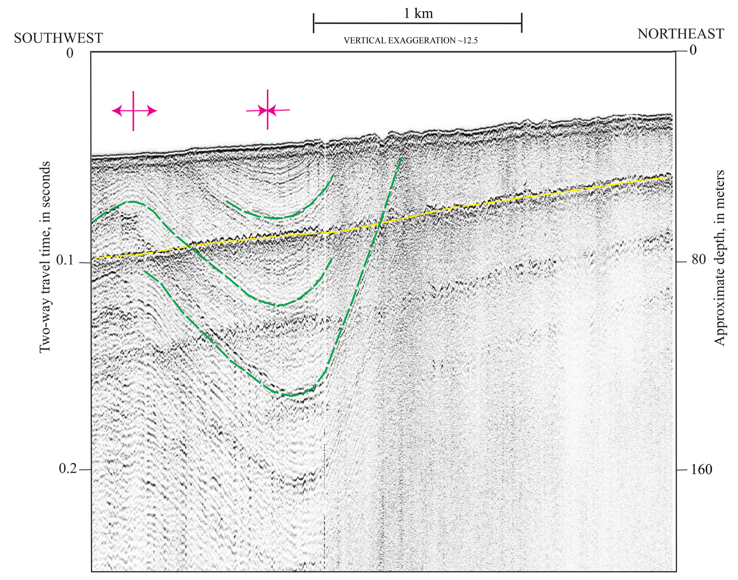


Figure 1. USGS high-resolution minisparker seismic-reflection profile PR–27 (collected in 2009 on survey S–8–09–NC), which crosses shelf northwest of Bolinas; see trackline map for location. Profile shows folding west of east strand of San Gregorio Fault Zone. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed green lines highlight continuous reflections that reveal structure (not distinctive stratigraphic markers). Dashed yellow line is seafloor multiple (echo of seafloor reflector).

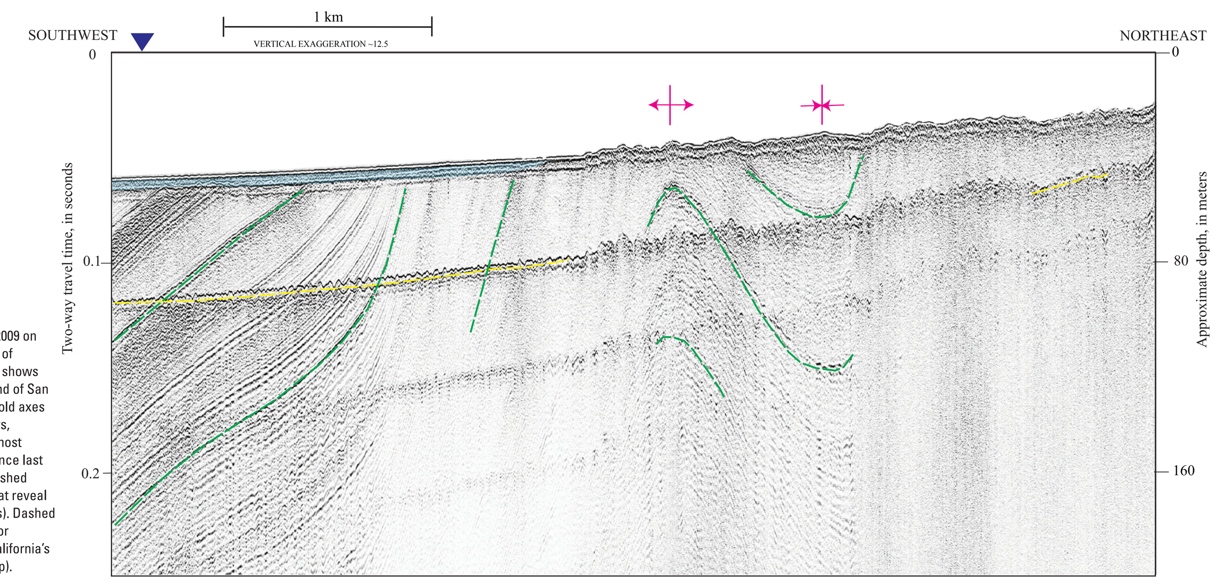


Figure 2. USGS high-resolution minisparker seismic-reflection profile PR–26 (collected in 2009 on survey S–8–09–NC), which crosses shelf west of Bolinas; see trackline map for location. Profile shows folding and shallow bedrock west of east strand of San Gregorio Fault Zone. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. 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).

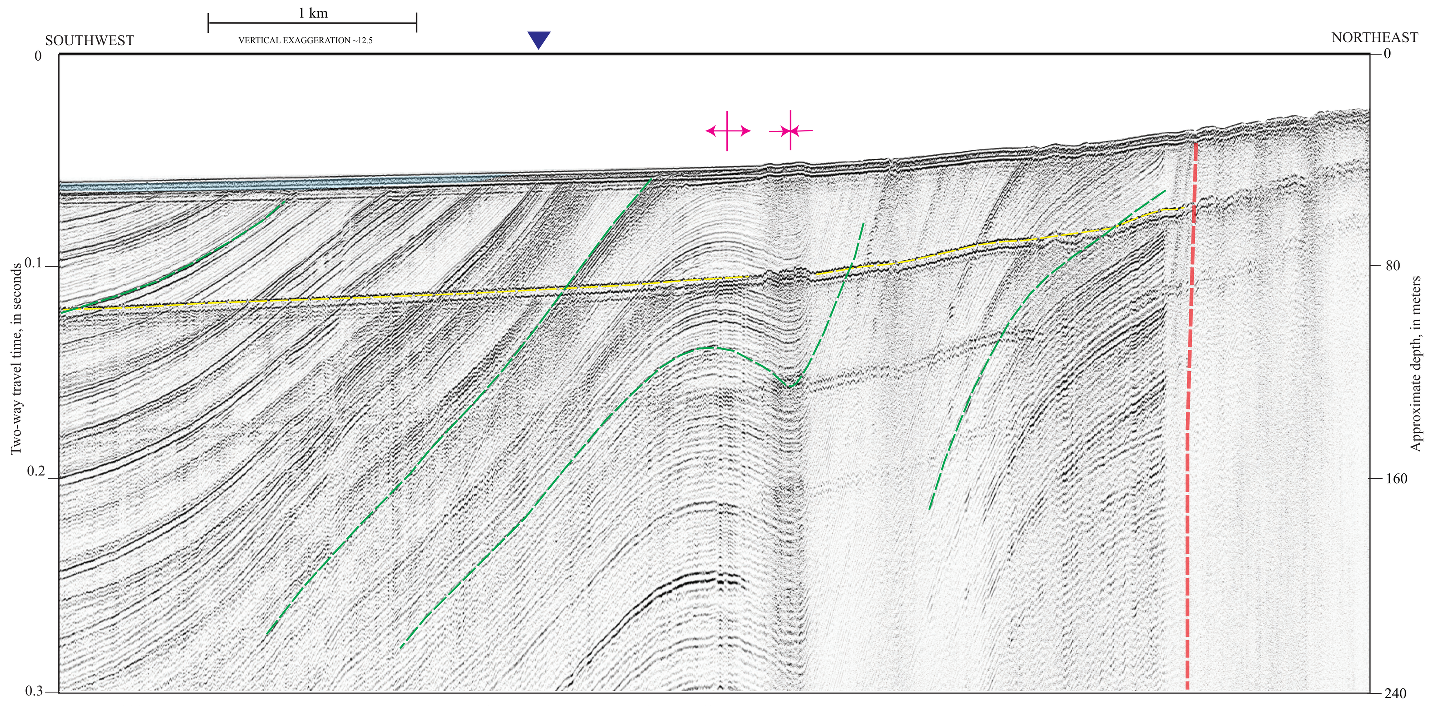


Figure 3. USGS high-resolution minisparker seismic-reflection profile PR–14 (collected in 2009 on survey S–8–09–NC), which crosses shelf southwest of Bolinas; see trackline map for location. Profile shows folding west of east strand of San Gregorio Fault Zone. Dashed red line shows local fault (not part of San Gregorio Fault Zone). Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. 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).

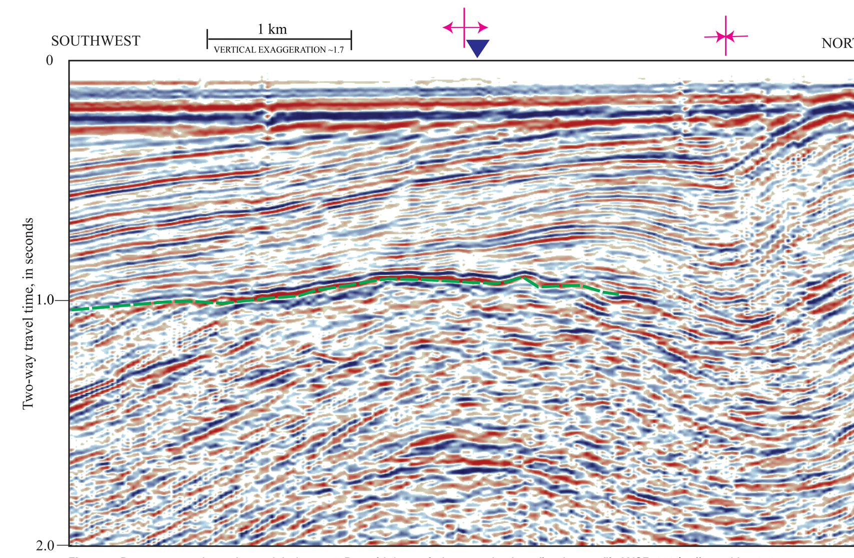


Figure 4. Deep-penetration, migrated, industry, 2-D, multichannel air-gun seismic-reflection profile WSF–080 (collected in 1976 on survey W–14–76–SF; from USGS National Archive of Marine Seismic Surveys [U.S. Geological Survey, 2009]), which crosses shelf southwest of Bolinas; see trackline map for location. Note that vertical scale and exaggeration are significantly different than for high-resolution profiles shown in figures 1, 2, 3, 6, 7, 8, and 9. Profile highlights folding west of east strand of San Gregorio Fault Zone. Magenta symbols show fold axes (diverging arrows, anticline; converging arrows, syncline). Dashed green line shows angular unconformity above axis and west limb of anticline; surface becomes conformable within syncline to northeast. Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

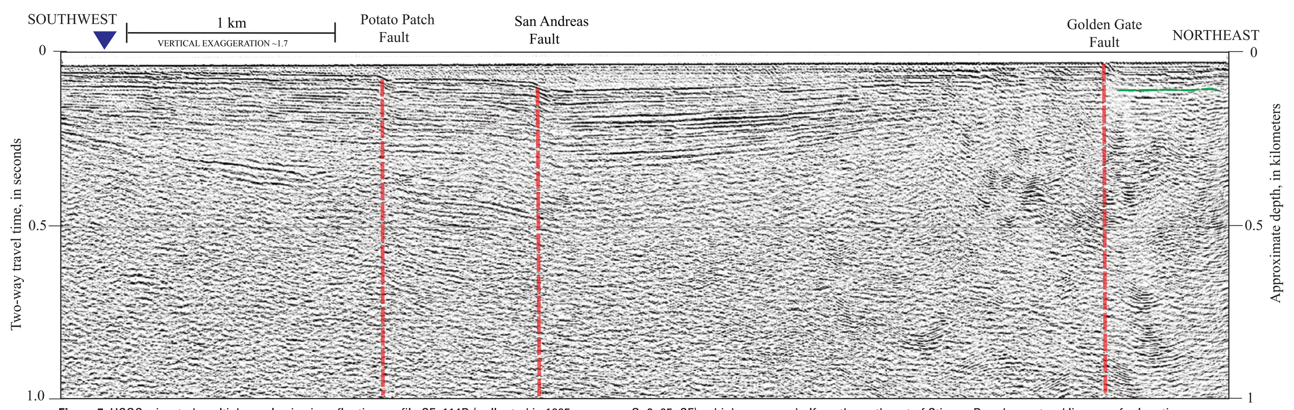


Figure 5. USGS migrated, multichannel seismic-reflection profile SF–114B (collected in 1995 on survey G–2–95–SF), which crosses shelf south-southeast of Stinson Beach; see trackline map for location. Dashed red lines show faults as described by Bruns and others (2002) and Ryan and others (2008). Minimal vertical exaggeration in profile highlights gently dipping character of strata in shallow subsurface (upper 1,000 m). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

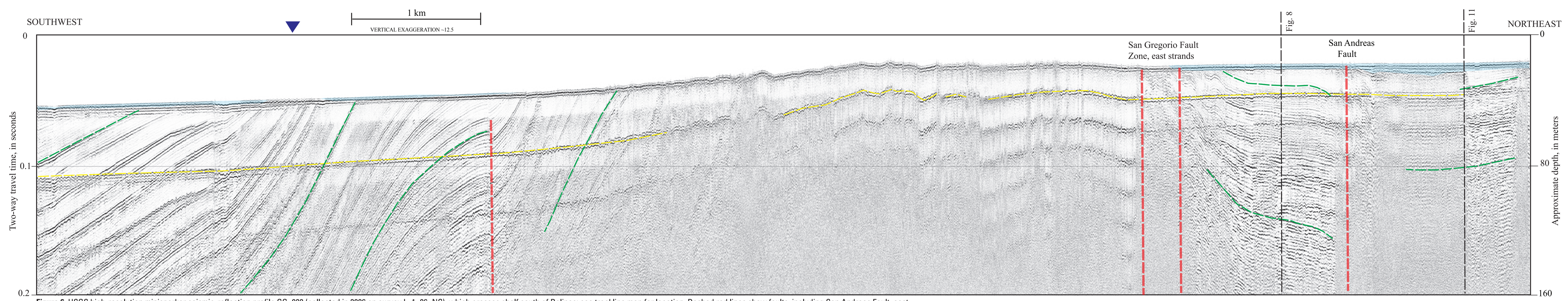


Figure 6. USGS high-resolution minisparker seismic-reflection profile GG–022 (collected in 2006 on survey L–1–06–NC), which crosses shelf south of Bolinas; see trackline map for location. Dashed red lines show faults, including San Andreas Fault, east strand(s) of San Gregorio Fault Zone, and local structure farther west. Note that deep, late Quaternary sedimentary basin (San Andreas graben) bounded by these faults (see sheet 9, figs. 7, 9; see also, Bruns and others, 2002; Ryan and others, 2008) has shallowed and, thus, is not prominent feature on this profile. Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. 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).

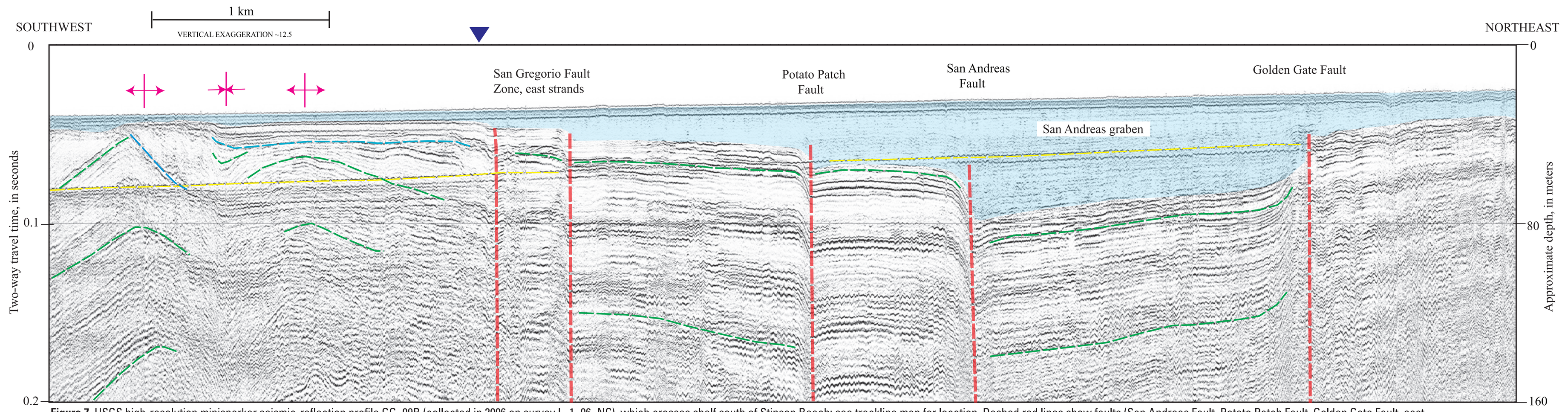


Figure 7. USGS high-resolution minisparker seismic-reflection profile GG–09B (collected in 2006 on survey L–1–06–NC), which crosses shelf south of Stinson Beach; see trackline map for location. Dashed red lines show faults (San Andreas Fault, Potato Patch Fault, Golden Gate Fault, east strands of San Gregorio Fault Zone) that cut through and (or) form structural boundaries of San Andreas graben (Cooper, 1973; Bruns and others, 2002; Ryan and others, 2008). Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, syncline). Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. Dashed blue lines in southwestern part of profile show significant 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).

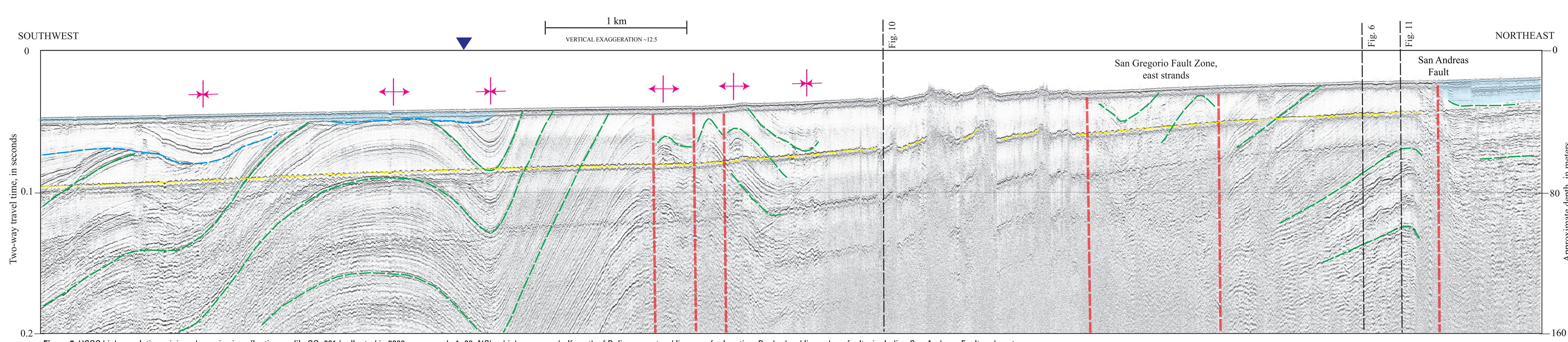


Figure 8. USGS high-resolution minisparker seismic-reflection profile GG–021 (collected in 2006 on survey L–1–06–NC), which crosses shelf south of Bolinas; see trackline map for location. Dashed red lines show faults, including San Andreas Fault and east strands of San Gregorio Fault Zone. San Andreas Fault forms eastern boundary of late Quaternary basin (close to shoreline; see Maps A, B on sheet 9) that is north of, and is shallower than, San Andreas graben. Magenta symbols show fold axes (diverging arrows, anticlines; converging arrows, synclines). Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. Dashed blue lines show significant 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).

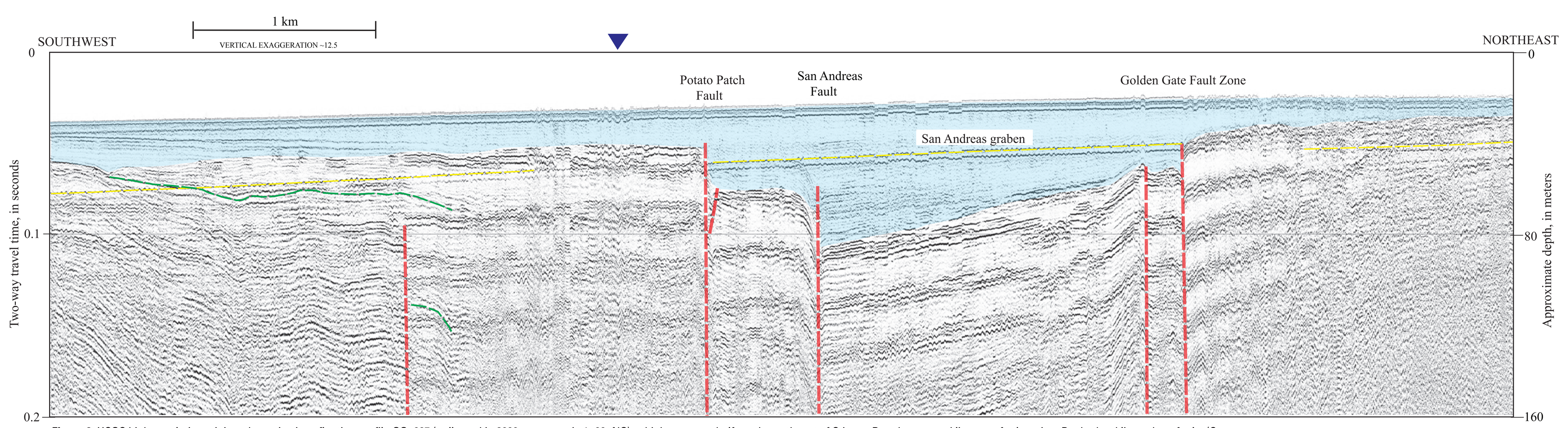


Figure 9. USGS high-resolution minisparker seismic-reflection profile GG–007 (collected in 2006 on survey L–1–06–NC); which crosses shelf south-southeast of Stinson Beach; see trackline map for location. Dashed red lines show faults (San Andreas Fault, Potato Patch Fault, and Golden Gate Fault Zone) that form boundaries of San Andreas graben (Cooper, 1973; Bruns and others, 2002; Ryan and others, 2008). Blue shading shows inferred uppermost Pleistocene and Holocene strata, deposited since last sea-level lowstand about 21,000 years ago. 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).

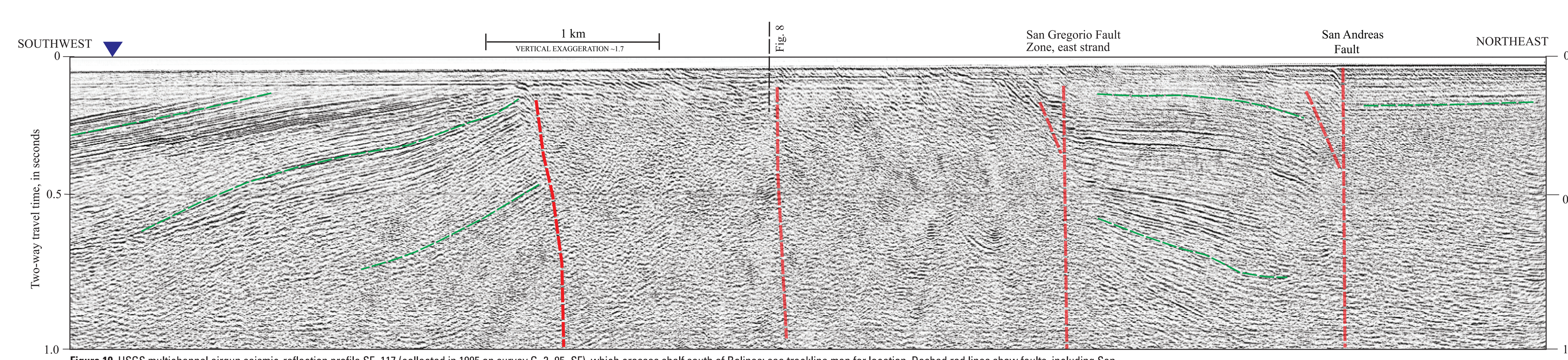
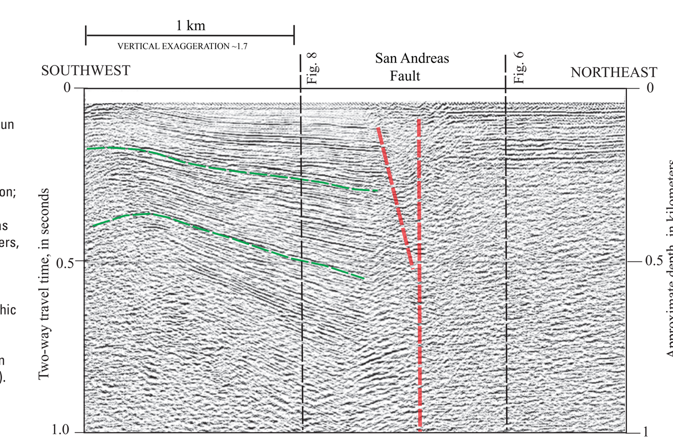
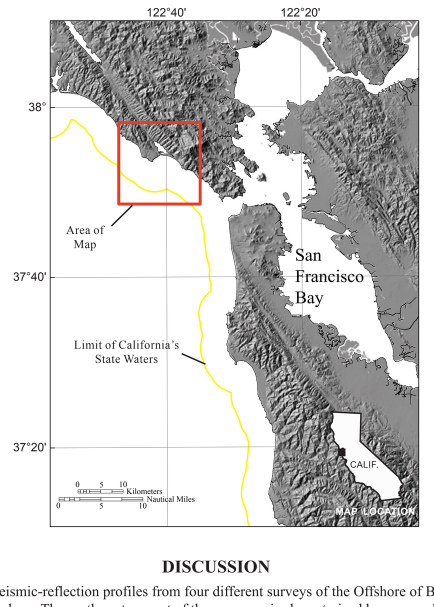


Figure 10. USGS multichannel airgun seismic-reflection profile SF–117 (collected in 1995 on survey G–2–95–SF), which crosses shelf south of Bolinas; see trackline map for location. Dashed red lines show faults, including San Andreas Fault and east strand of San Gregorio Fault Zone (modified from Bruns and others, 2002, their fig. 21; Ryan and others, 2008). Dashed green lines highlight continuous reflections that reveal structure (not distinctive stratigraphic markers). Minimal vertical exaggeration in profile highlights flat-lying to gently dipping character of strata in shallow subsurface (upper 1,000 m). Purple triangle shows location of California's State Waters limit (yellow line on trackline map).

Figure 11. USGS multichannel air-gun seismic-reflection profile SF–120A (collected in 1995 on survey G–2–95–SF), which crosses shelf about 2.5 km south of Bolinas Lagoon; see trackline map for location. Dashed red line shows San Andreas Fault (modified from Bruns and others, 2002, their fig. 22; Ryan and others, 2008). Dashed green lines highlight continuous reflections that reveal structure (not distinctive stratigraphic markers). Minimal vertical exaggeration in profile highlights gently dipping character of strata in shallow subsurface (upper 1,000 m).





DISCUSSION

This map sheet shows seismic-reflection profiles from four different surveys of the Offshore of Bolinas map area, providing imagery of the subsurface geology. The northwestern part of the map area is characterized by a rugged bedrock shelf, whereas the southeastern part features a shallow, flat, sediment-covered shelf and the northern part of the San Francisco ebb-tidal delta. 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 Bolinas map area, which straddles the right-lateral transform boundary between the North American and Pacific plates, is cut by several active faults that cumulatively form a distributed shear zone; these active faults include the San Andreas Fault, the east strand of the San Gregorio Fault Zone, the Golden Gate Fault, and the Potato Patch Fault (see sheets 9, 10; see also, Jachens and Zoback, 1999; Zoback and others, 1999; Bruns and others, 2002; Parsons and others, 2005; Ryan and others, 2008). The offshore parts of these faults 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 San Andreas Fault (figs. 5 through 11), which is the dominant plate-boundary structure, extends northwest through the southern part of the map area before moving onshore at Bolinas Lagoon. In this area, the San Andreas Fault has an estimated slip rate of 17 to 24 mm/yr (U.S. Geological Survey and California Geological Survey, 2010), and the devastating great 1906 California earthquake (M7.8) is thought to have nucleated on the San Andreas Fault offshore San Francisco (Bolt, 1968; Lomax, 2005), a few kilometers south of the map area.

The San Gregorio Fault Zone, another major strike-slip fault system within the distributed transform plate boundary, extends predominantly in the offshore for about 400 km. Cumulative lateral slip is estimated to be about 4 to 10 mm/yr (U.S. Geological Survey and California Geological Survey, 2010) near San Francisco. Slip on the San Gregorio Fault Zone is divided between an east strand (figs. 6, 7, 8, 10), which converges with the San Andreas Fault in the map area and also moves onshore at Bolinas Lagoon (see sheets 9, 10), and a west strand, which lies southwest of the map area and may merge with the northwest-striking, northeast-dipping Point Reyes Fault Zone (Bruns and others, 2002; Ryan and others, 2008). The Potato Patch Fault (figs. 5, 7, 9), which lies between the San Andreas Fault and the east strand of the San Gregorio Fault Zone between Pacifica and Bolinas, also converges northward with the San Andreas Fault south of Bolinas Lagoon (see sheets 9, 10). The Golden Gate Fault (figs. 5, 7, 9) lies east of, and is parallel to, the San Andreas Fault between San Francisco and Bolinas.

Zoback and others (1999) and Ryan and others (2008) noted a northward bend in the strike (from about 325° to 330°) of both the San Andreas and San Gregorio Faults offshore of San Francisco, resulting in a local change from contractional to extensional crustal deformation. The inferred extensional setting is consistent with subsidence of the San Francisco ebb-tidal delta and development of the prominent San Andreas graben (figs. 7, 9; see Maps A, B, D on sheet 9; see also, Cooper, 1973; Bruns and others, 2002; Ryan and others, 2008). This basin, which is about 7 km long and 2.5 km wide, is bounded on the southwest by the east strand of the San Gregorio Fault Zone (and the Bolinas shelf) and on the northeast by the Golden Gate Fault (and the Marin shelf). The basin floor dips gently westward toward the San Andreas Fault, along which the basin is deepest and the basin fill is thickest. The abrupt northern margin of the basin (see Maps A, B, D on sheet 9) could have formed either as an extensional, en echelon normal fault or as a gentle northwest-striking restraining bend in the Golden Gate Fault as it converges with the San Andreas Fault to the north. The southern margin of the basin, whose slope appears to be more gradual, lies offshore of San Francisco within a sea-level-lowstand paleovalley.

Several high-resolution seismic profiles show an upper unit (blue shading in profiles; figs. 2, 3, 6, 7, 8, 9) that is inferred to have been deposited in about the last 21,000 years during the latest Pleistocene and Holocene post–Last Glacial Maximum sea-level rise. These deposits typically are characterized either by "acoustic transparency" or by parallel, low-amplitude, low- to high-frequency, continuous to moderately continuous, diffuse reflections (terminology from Mitchum and others, 1977). The contact with underlying units is a transgressive surface of erosion that is commonly marked by angularity, channeling, or a distinct upward change to lower amplitude, more diffuse reflections. The maximum thickness of the unit is found in the San Andreas graben, where the uppermost Pleistocene and Holocene section is as much as 57 m thick. In contrast, the uppermost Pleistocene to Holocene section is quite thin (0 to 5 m) beneath the bedrock platform west of the east strand of the San Gregorio Fault. It is emphasized that the base of this unit is an interpretation that is somewhat hindered in areas of greater thickness by the absence of a strong basal reflector (possibly related to a uniform sediment grain size and, hence, the lack of acoustic-impedance contrasts), as well as by "acoustic masking" associated with interstitial gas (Fader, 1997; Ryan and others, 2008).

Data for the seismic-reflection profiles shown in figures 1, 2, and 3 were collected in 2009 on U.S. Geological Survey (USGS) cruise S–8–09–NC, and data for the profiles shown in figures 6, 7, 8 and 9 were collected in 2006 on USGS cruise L–1–06–NC. Both cruises deployed the SIG 2Mille minisparker system, which used a 500-J high-voltage electrical-discharge source fired 1 to 4 times per second. At normal survey speeds of 4 to 4.5 nautical miles per hour, this yields 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 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, a 160- to 1,200-Hz bandpass filter, and a heave correction were applied to the minisparker data.

Data for the seismic-reflection profiles shown in figures 5, 10, and 11 were collected in 1995 on USGS cruise G–2–95–SF (Childs and others, 2000; Bruns and others, 2002). Two 0.65-L air guns fired at 12.5-m intervals provided the seismic source, and data were digitally recorded on a 24-channel, 150-m-long streamer merged with GPS navigation data. Data-processing steps included deconvolution, stacking, and migration.

Figure 4 shows a deep-penetration, migrated, multichannel seismic-reflection profile collected in 1976 by WesternGeco on cruise W–14–76–SF. 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 (U.S. Geological Survey, 2009). These data were acquired with 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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Seismic-Reflection Profiles, Offshore of Bolinas Map Area, California

by

Samuel Y. Johnson, Ray W. Sliter, Terry R. Bruns, and John L. Chin

2015

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

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