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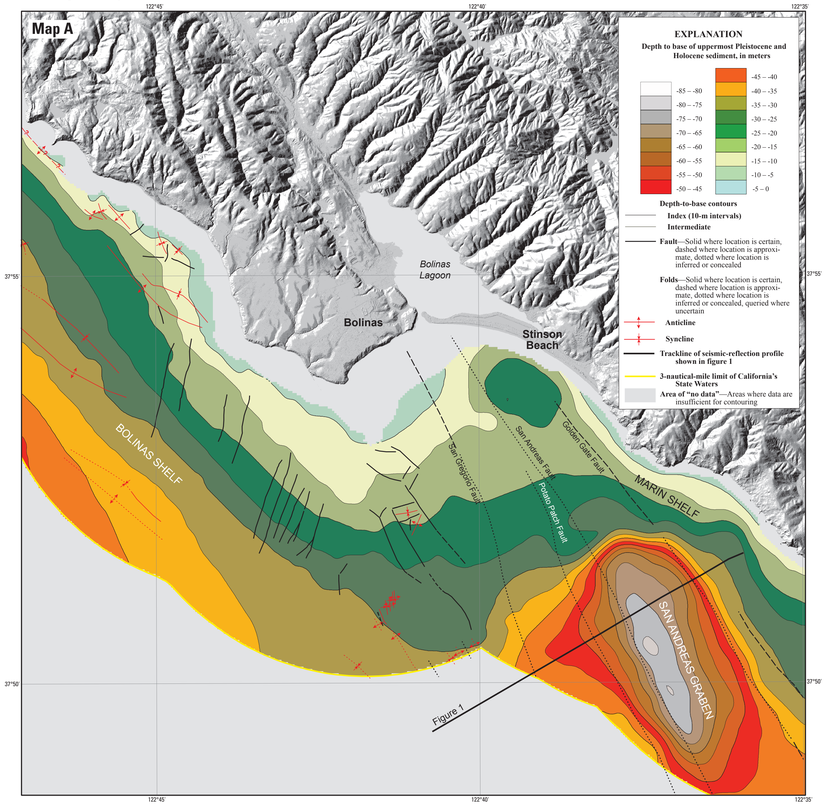
U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2015–1135
Sheet 9 of 10
Pamphlet accompanies map



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 Bolinas map area (Maps A, B), as well as for a larger area that extends about 91 km along the coast from Bolinas to Pescadero (Maps C, D) to establish a regional context. This uppermost stratigraphic unit (blue shading in seismic-reflection profile of fig. 1; see also, figs. 2, 3, 6, 7, 8, 9 on sheet 8) is inferred to have been deposited during the post-Last Glacial Maximum (LGM) sea-level rise in the last about 21,000 years (see, for example, Peltier and Fairbanks, 2006; Stanford and others, 2011). The unit commonly is 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 acoustic transparency can be caused by extensive wave winnowing, which results in a uniform sediment grain size and the consequent lack of acoustic-impedance contrasts needed to produce seismic reflections. On the continental shelf, the contact with underlying units is a transgressive surface of erosion commonly marked by angularity, channeling, or a distinct upward change to lower amplitude, more diffuse reflections. Within rapidly subsiding shelf basins such as the San Andreas graben (fig. 1), the contact can be parallel with underlying units, and it is inferred largely based on contrasts in reflection amplitude.

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 in 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 data points are dense along tracklines (about 1 m apart) and sparse between tracklines (1 km apart), resulting in minor contouring artifacts. To incorporate the effect of a few rapid thickness changes along faults, to remove irregularities from interpolation, and to reflect other geologic information and complexity, minor manual editing of the preliminary thickness contours was undertaken. Contour modifications and regridding were repeated several times to produce the final sediment-thickness maps. Information for the depth to base of the post-LGM unit (Maps A, C) was generated by adding the sediment-thickness data to water depths determined by multibeam bathymetry (see sheet 1).

The thickness of the post-LGM unit in the Offshore of Bolinas map area ranges from 0 to 57 m (Map B), and the depth to base of the unit ranges from less than 10 to 78 m (Map A). These large ranges in values are attributed to the area's active tectonic setting. The map area, which straddles the right-lateral transform boundary between the North American and Pacific plates, is cut by several active northwest-striking faults; these include the San Andreas Fault, the east strand of the San Gregorio Fault Zone, the Golden Gate Fault, and the Potato Patch Fault (fig. 1; see also, Jachens and Zoback, 1999; Zoback and others, 1999; Bruns and others, 2002; Ryan and others, 2008). Sediment cover is thin or absent west of the east strand of the San Gregorio Fault Zone, where uplift has brought bedrock to the surface or near to the surface. Sediment is thickest in the fault-bounded San Andreas graben, which is inferred to have formed as a stepover basin caused by at least partial eastward transfer of lateral slip from the San Gregorio, Potato Patch, and San Andreas Faults to the Golden Gate Fault (Cooper, 1973; Jachens and Zoback, 1999; Zoback and others, 1999; Bruns and others, 2002; Ryan and others, 2008). The basin is filled with sediment and, thus, has no seafloor expression. The abrupt northern margin of the basin may have formed either (1) as an extensional normal fault that resulted from the eastward slip transfer, or (2) as a gentle, northwest-striking restraining bend in the Golden Gate Fault as its trace converges northward with the San Andreas Fault. The southern margin of the basin, which is more diffuse, lies offshore of San Francisco within a sea-level-lowstand paleovalley.

Five different "domains" of sediment thickness are recognized on the regional sediment-thickness map (Map D): (1) the Bolinas shelf, located west of the east strand of the San Gregorio Fault Zone, in the northwestern part of the regional map (Map D); (2) the San Andreas graben, located between the San Gregorio Fault Zone and the Golden Gate Fault, east-southeast of the Bolinas shelf and both southwest and southeast of the Marin shelf; (3) the Marin shelf, located both northeast and northwest of the San Andreas graben and north of the San Francisco ebb-tidal delta paleovalley; (4) the northeast-trending San Francisco ebb-tidal delta paleovalley, located outside the Golden Gate at the mouth of San Francisco Bay, between the Marin shelf and San Andreas graben on the north and the Pacifica-Pescadero shelf on the south; and (5) the Pacifica-Pescadero shelf, which is located south of the San Francisco ebb-tidal delta paleovalley and which extends south all the way to Pescadero Point.

The five sediment-thickness domains have distinct geologic controls. The Bolinas and Pacifica-Pescadero shelves are uplifting and are relatively sediment poor (mean sediment thicknesses of 0.8 and 3.6 m, respectively). Thicker sediment accumulations (as much as 20 m) on the western margins of the Pacifica-Pescadero shelf (within California's State Waters) are associated with west-side-down slip on the west strand of the San Gregorio Fault Zone and with deposition on the outboard, west-dipping Pigeon Point block (McCulloch, 1987) farther south, offshore of Pescadero Point. The San Andreas graben is a rapidly subsiding, fault-controlled sedimentary basin (Cooper, 1973; Ryan and others, 2008) that has sediment thicknesses of as much as 57 m; the Marin shelf forms the uplifted northeastern and northwestern margins of this basin. The San Francisco ebb-tidal delta is filling a paleovalley that formed during the last sea-level lowstand, with sediment thicknesses of as much as 32 m along the trough axis.

Although the southern part of the San Andreas graben may extend into the paleovalley, the north flank of the paleovalley is used here as the boundary when calculating sediment volumes for the five sediment-thickness domains (see table 7–1 in accompanying pamphlet). Subsidence in the San Francisco ebb-tidal delta paleovalley and the San Andreas graben can be partly attributed to the northward change in strike of both the San Andreas and San Gregorio Fault Zones offshore of San Francisco, which has resulted in the local change from contractional deformation to extensional deformation (Zoback and others, 1999).

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) 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. Map E also shows the inferred location of the devastating great 1906 California earthquake (M7.8, 4/18/1906), thought to have nucleated on the San Andreas Fault offshore of San Francisco (see, for example, Bolt, 1968; Lomax, 2005). Map E clearly shows that the largest number of earthquakes in the region occur within the broad San Andreas Fault Zone between Pacifica and Bolinas; events west of the east strand of the San Gregorio Fault Zone and east of the Golden Gate Fault are much less common.

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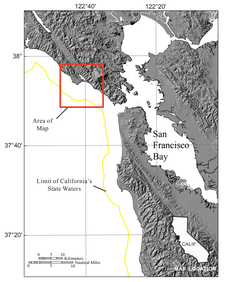


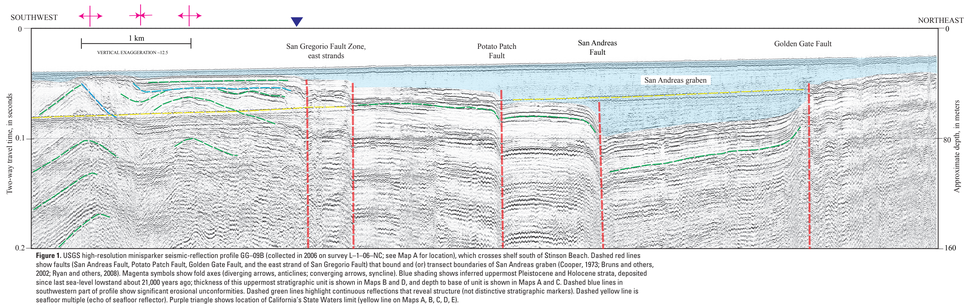
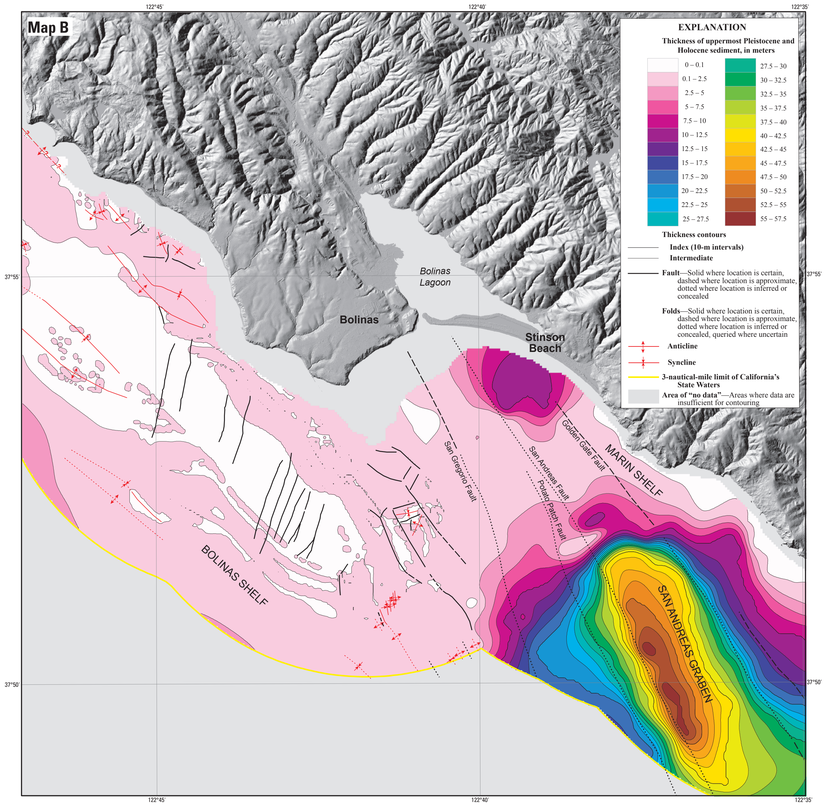


Figure 1. USGS high-resolution minisparker seismic-reflection profile GG–09B (collected in 2006 on survey L–1–06–NC; see Map A for location), which crosses shelf south of Stinson Beach. Dashed red lines show faults (San Andreas Fault, Potato Patch Fault, Golden Gate Fault, and the east strand of San Gregorio Fault) that bound and (or) transect 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; thickness of this uppermost stratigraphic unit is shown in Maps B and D, and depth to base of unit is shown in Maps A and C. 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 Maps A, B, C, D, E).



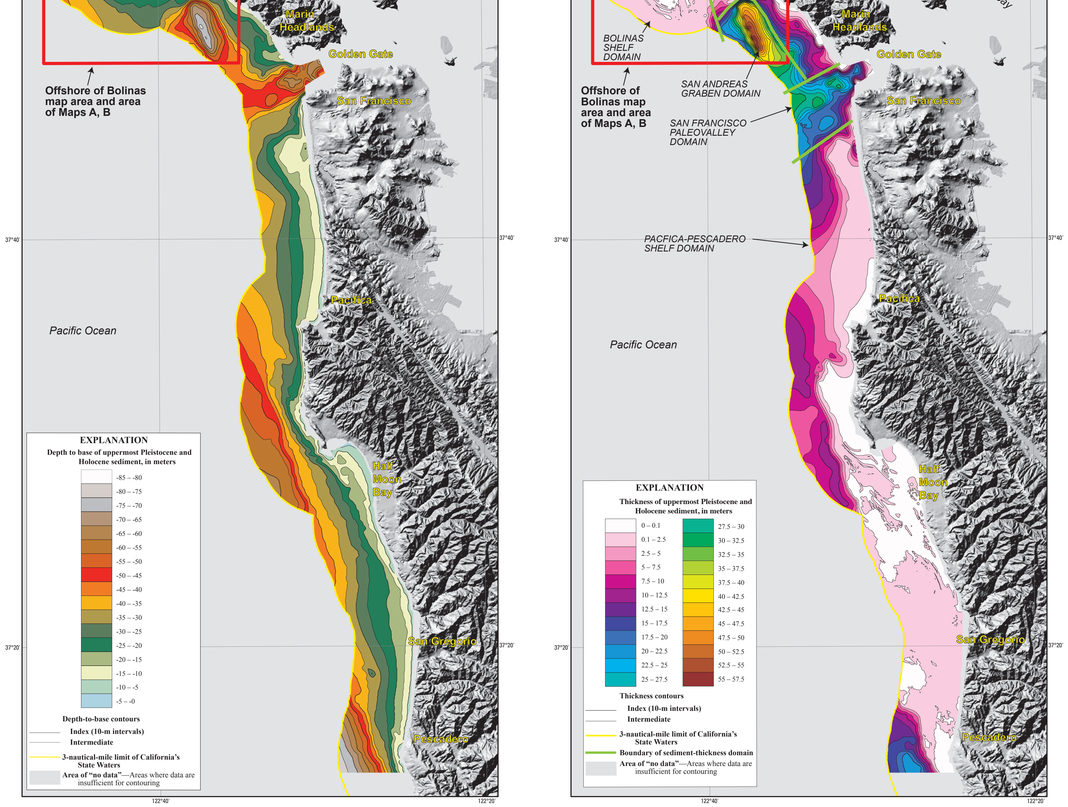
Onshore elevation data collected by Earth Eye in 2010 for San Francisco State University and U.S. Geological Survey (available at http://red.usgs.gov/). California's State Waters limit from NOAA Office of Coast Survey
Universal Transverse Mercator projection, Zone 10N

14°
APPROXIMATE MEAN DECLINATION, 2015

SCALE 1:50 000
2 0 2 MILES
7000 3500 0 7000 FEET
2.5 0 1 KILOMETER
ONE MILE = 0.869 NAUTICAL MILES

CALIF.
MAP LOCATION

Depth and thickness mapped by Samuel Y. Johnson and Steven R. Hartwell, 2011–2012
GIS database and digital cartography by Stephen R. Hartwell



Onshore elevation data from U.S. Geological Survey (2012) National Elevation dataset (available at http://red.usgs.gov/). California's State Waters limit from NOAA Office of Coast Survey
Universal Transverse Mercator projection, Zone 10N

14°
APPROXIMATE MEAN DECLINATION, 2015

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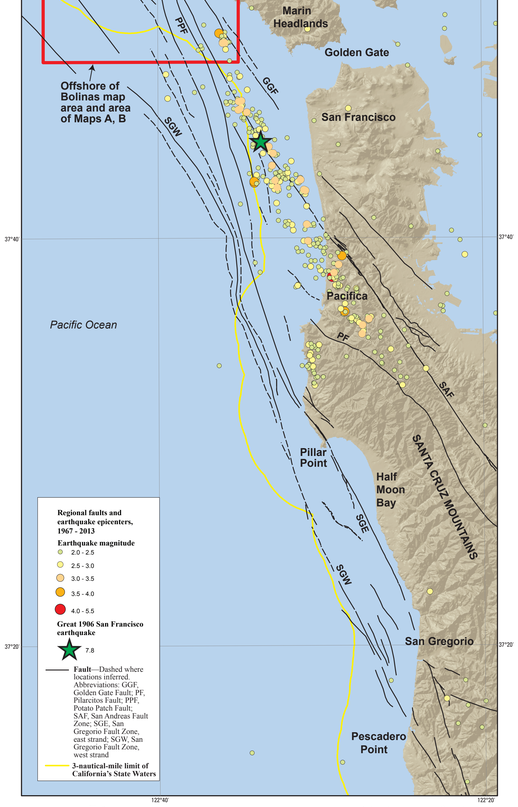
10 5 0 10 KILOMETERS
ONE MILE = 0.869 NAUTICAL MILES



CALIF.
MAP LOCATION

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 July 21, 2015

Local (Offshore of Bolinas Map Area) and Regional (Offshore from Bolinas to Pescadero) Shallow-Subsurface Geology and Structure, California

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