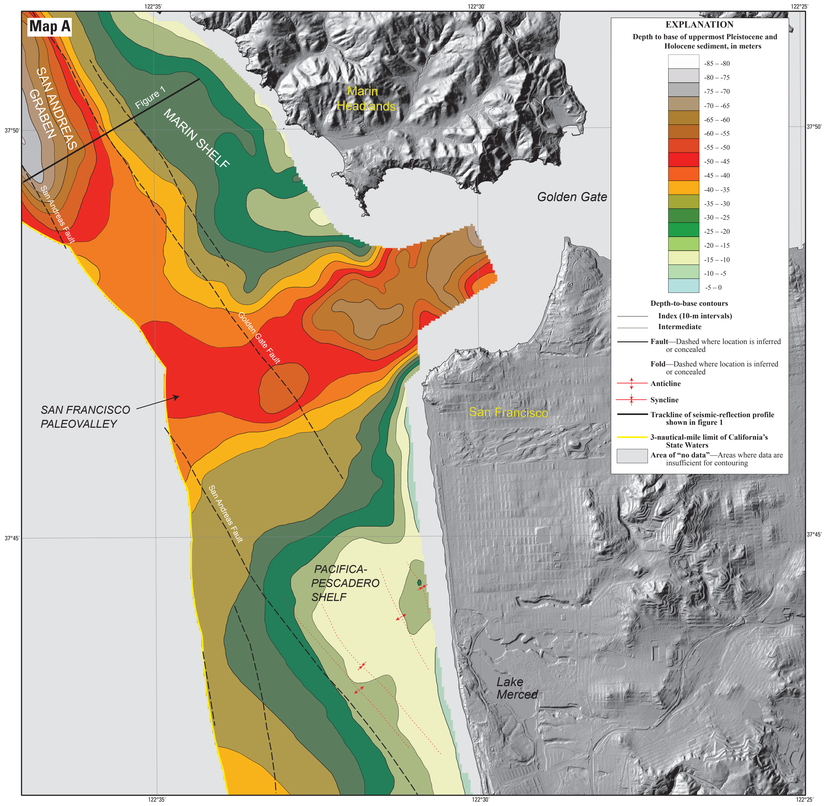

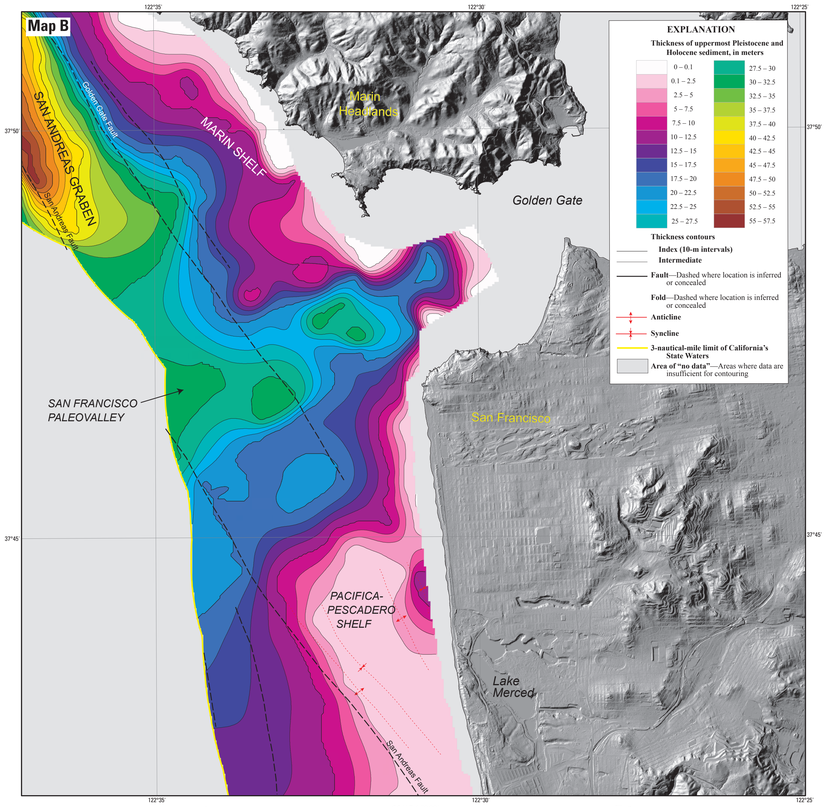

Onshore elevation data collected by Earth Eye in 2010 for San Francisco State University and the U.S. Geological Survey. California's State Waters limit from NOAA Office of Coast Survey
Universal Transverse Mercator projection, Zone 10N

SCALE 1:50 000

Depth and thickness mapped by Samuel Y. Johnson and Stephen R. Hartwell, 2011-2012
GIS database and digital cartography by Stephen R. Hartwell, Eleyne L. Phillips, and Florence L. Wong

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 San Francisco 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. 1, 2, 3, 9, 10, 11 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 and 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 San Francisco map area ranges from 0 to 57 m (Map B), and the depth to the base of the unit ranges from 10 to 78 m (Map A). These large ranges are attributed to late Quaternary sea-level history and active tectonics. Sea level was approximately 125 m lower than present during the Last Glacial Maximum, at which time the shoreline was more than 45 km west of San Francisco near the Farallon Islands. The Offshore of San Francisco map area was emergent and formed part of a large alluvial plain connected to a drainage basin that included much of California's Central Valley (Atwater and others, 1977). The river system flowed westward through the present narrows at the Golden Gate, constrained to an alluvial valley that was bounded on the north and south by bedrock highlands including what is now the Pacifica-Pescadero and Bolinas shelves. The axis of this fluvial system is represented on Maps A and B by the linear zone of sediment thickness and increased depth-to-base of sediment that extends west-southwest from the Golden Gate. Within California's State Waters, the San Francisco ebb-tidal delta is now largely confined to this lowstand alluvial valley.

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, including the San Andreas Fault and the Golden Gate Fault. These two faults merge northward with the Potato Patch Fault and the San Gregorio Fault (which lie farther west) south of Bolinas (Map E; Zoback and others, 1999; Bruns and others, 2002; Ryan and others, 2008). In the Offshore of San Francisco map area, sediment is thickest in the fault-bounded San Andreas graben inferred to have formed as a stepover basin caused by at least partial transfer of slip from the San Gregorio Fault, Potato Patch Fault, and San Andreas Fault eastward on to the Golden Gate Fault (Cooper, 1973; Jachens and Zoback, 1999; Zoback and others, 1999; Bruns and others, 2002; Ryan and others, 2008). Only the southeastern part of this fault-bounded basin is present in the Offshore of San Francisco map area (Maps A, B); the entire basin is shown on the regional maps (Maps C, D). The basin is bounded on the west and east by the San Gregorio Fault and Golden Gate Fault (fig. 1), respectively. The southern basin margin is more diffuse and lies offshore of San Francisco, within the lowstand paleovalley described above.

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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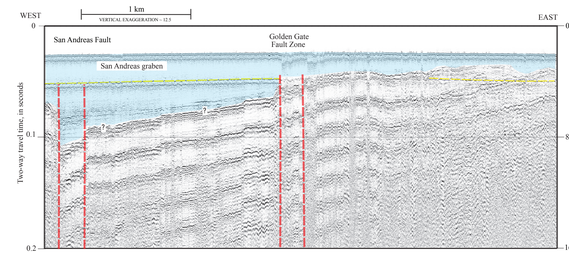
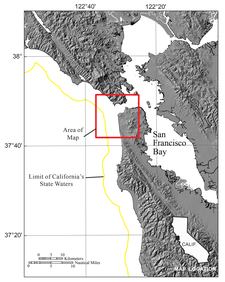
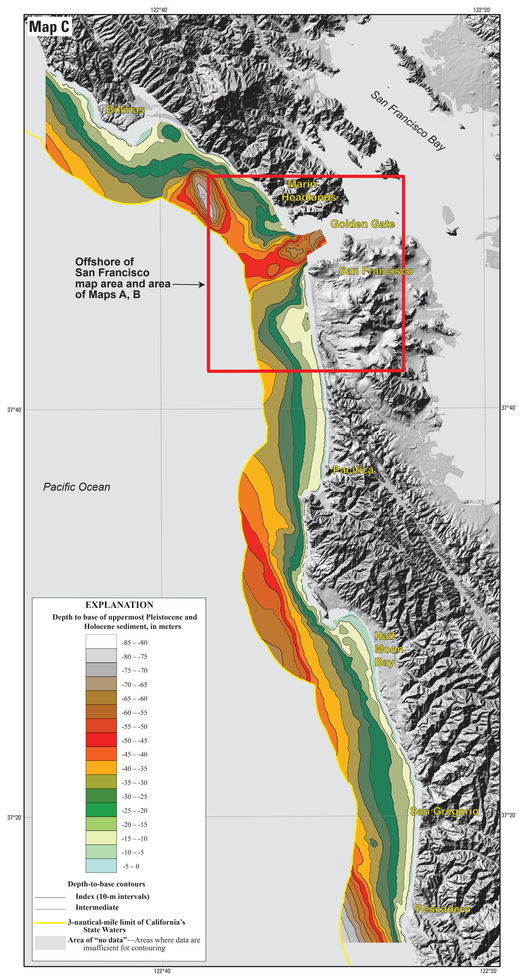
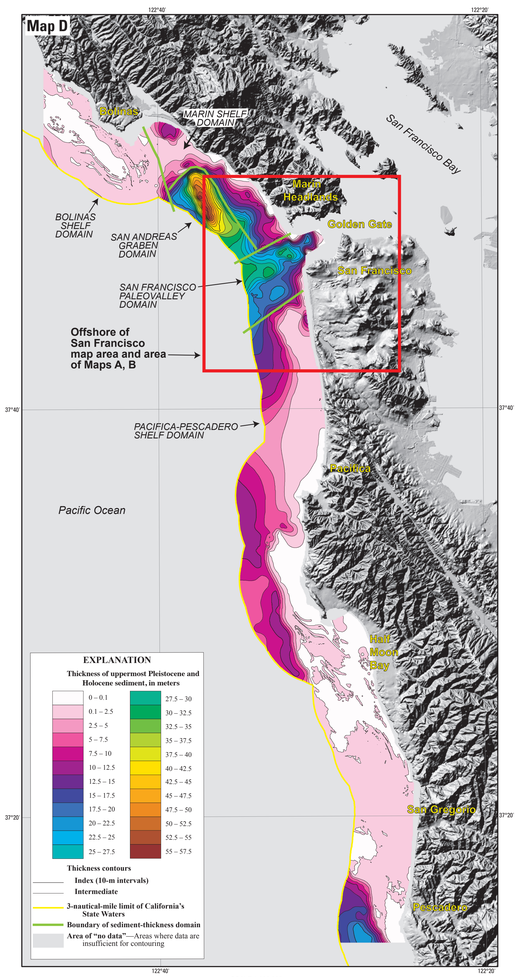


Figure 1 (left). USGS high-resolution minisparker seismic-reflection profile GG–004 (collected in 2006 on survey L–1–06–NC). Dashed red lines show San Andreas Fault and Golden Gate Fault, within and on eastern margin of San Andreas graben (Cooper, 1973; Bruns and others, 2002; Ryan and others, 2008). 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).





Onshore topography from the the U.S. Geological Survey (2012) National Elevation dataset
Universal Transverse Mercator projection, Zone 10N



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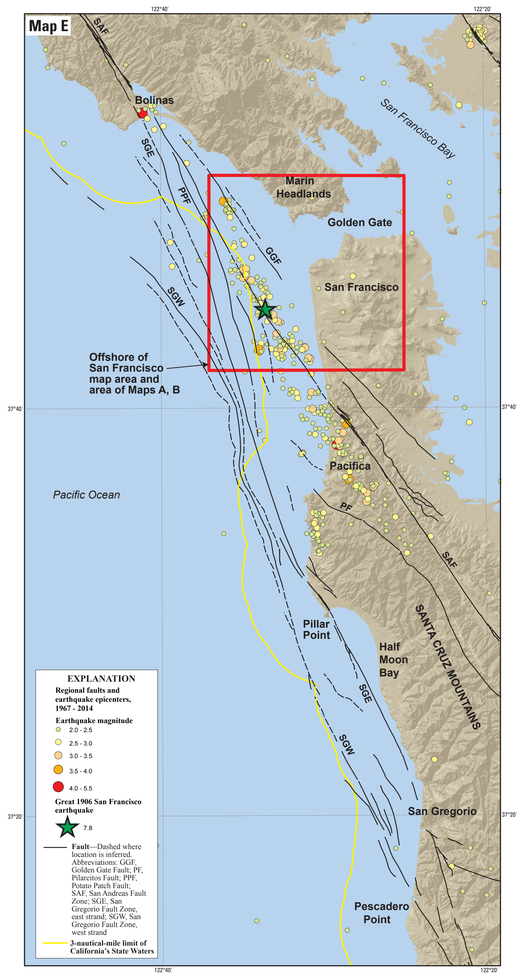

Depth and thickness mapped by Samuel Y. Johnson and Stephen R. Hartwell, 2011-2012
GIS database and digital cartography by Stephen R. Hartwell, Eleyne L. Phillips, and Florence L. Wong
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Local (Offshore of San Francisco Map Area) and Regional (Offshore from Bolinas to Pescadero) Shallow-Subsurface Geology and Structure, California

By
Samuel Y. Johnson, Stephen R. Hartwell, Ray W. Sliter, Janet T. Watt, Eleyne L. Phillips, Stephanie L. Ross, and John L. Chin
2015

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