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Compilation of Existing Data for Sand Resource Studies in Federal and California State Waters of the San Francisco, Oceanside, and Silver Strand Littoral Cell Study Areas along the Continental Shelf of California—Strategy for Field Studies and Sand Resource Assessment

Open-File Report 2022–1094

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

Cover: Photograph of San Francisco by James Conrad, U.S. Geological Survey.

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During the first two years of the project, an expert panel was established to provide expertise in designing the geographic bounds of the study area and goals of the study. This panel included Chris Potter (OPC), Clif Davenport (California Geological Survey), Heather Schlosser (U.S. Army Corps of Engineers), Leslie Ewing (California Coastal Commission), and Jeffrey Waldner (BOEM), whom we thank for their time and contributions.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m3)	0.0002642	million gallons (Mgal)
cubic kilometer (km3)	0.2399	cubic mile (mi^3)
	Energy	
joule (J)	0.0000002	kilowatthour (kWh)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Abbreviations

BOEM	Bureau of Ocean Energy Management
CSMW	Coastal Sediment Management Workgroup
GIS	geographic information system
GPS	global positioning system
Hz	hertz
kHz	kilohertz
OCS	outer continental shelf
OPC	California Ocean Protection Council
SBL	subbottom logger
TWT	two-way travel time
USGS	U.S. Geological Survey

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Executive Summary

The Sand Resources Project was established through collaborative agreements between the U.S. Geological Survey (USGS), the Bureau of Ocean Energy Management (BOEM), and the California Ocean Protection Council (OPC) with the purpose of evaluating sand and gravel resources in Federal and California State Waters for potential use in future beach-nourishment projects. Project partners worked in collaboration with California Coastal Sediment Management Workgroup (CSMW) members to define priority study areas for this work based on the potential for finding sand within the broader region and the needs for this sand as shown by beach erosion areas of concern in the adjacent littoral cells. The final study areas were defined to be (1) the San Francisco Littoral Cell, (2) the Oceanside Littoral Cell, and (3) the Silver Strand Littoral Cell.

A two-stage approach was used to assess the study areas. This report addresses the initial stage, which is a synthesis of the existing geophysical and sediment-sampling data in each area. This allowed for evaluations of the data availability, data gaps, and general patterns of sediment thickness and grain size. This report provides a description of the methods and results of this synthesis. The findings from this work were used to refine study area boundaries and develop sampling plans for stage two of the project.

Stage two of the project, the results of which will be published separately, will be the collection, processing, and synthesis of new data, including high-resolution geophysical surveys and sediment cores within the three study areas. The data collected will provide new information about the three study areas including sediment thickness, grain-size distributions, and total organic carbon. The description and results of stage two of the work is included in another USGS report (Warrick and others, 2022).

Introduction

The Sand Resources Project was established through partnerships between the U.S. Geological Survey (USGS), the Bureau of Ocean Energy Management (BOEM), and the California Ocean Protection Council (OPC) with the purpose of evaluating sand and gravel resources in Federal and California State Waters for potential use in future beach-nourishment projects. This collaborative project was conducted under interagency agreements between the USGS, BOEM, and OPC and focused on the collection and evaluation of both existing and new data.

The interests of the Sand Resources Project partners reflect the jurisdictions and missions of each agency. The State of California has jurisdiction over marine resources within California State Waters, which extend from the shoreline to Federal Waters, which begin generally about 5.6 kilometers (km; 3 nautical miles, nmi) offshore of the shoreline. The Federal Government has jurisdiction within an area referred to the outer continental shelf (OCS), which is an area of marine seabed, or submerged land that extends from the California State Waters limit to 370 km (200 nmi) offshore. BOEM has jurisdiction over mineral leases within the OCS. For potential OCS leases of sand resources for beach restoration or coastal protection, BOEM requires geophysical and geotechnical studies to identify and evaluate offshore sand resources. Although evaluating OCS mineral resources was the primary goal of this Sand Resources Project, OPC was interested in extending these investigations into California State Waters to ensure continuity and consistency in data collection and scientific understanding. Thus, data were collected and analyzed across the OCS and into California State Waters. Lastly, the USGS is a science agency of the U.S. Department of the Interior, whose mission statement says, in part, “to deliver actionable intelligence at scales and timeframes relevant to decision makers” (see https://www.usgs.gov/about/about-us/who-we-are). The USGS led all data collection and synthesis efforts for the Sand Resources Project, including sole authoring of this report.

The Sand Resources Project focused on three study areas selected in a collaborative exercise between project partners (USGS, BOEM, and OPC) and members of the California Coastal Sediment Management Workgroup (CSMW). Several constraints on study areas were defined during this process. For example, study areas could extend only to maximum water depths of 60 meters (m), owing to expected limitations of dredging technology in the future (current dredging technology in the United States can access depths of 30 m, but future technologies may significantly extend this limit). Sand resources also must be at water depths greater than the “depth of closure,” which is the seaward boundary of the active beach profile (compare with Nicholls and others, 1998), so that future uses of these resources will not negatively impact littoral cell sediment budgets. It is generally understood that the depth of closure for California beaches is approximately 10 m (Moffatt & Nichol, 2009). Additionally, the areas were required to be within 48 kilometers (km) of CSMW Beach Erosional Concern Areas to ensure that future dredging and transport of sand resources would be cost effective. Lastly, a significant part of each area was required to lie within Federal Waters to meet the project partners’ goal of focusing on the OCS.

Study Areas

On July 7, 2016, a group that consisted of 12 members from USGS, BOEM, OPC, and CSMW used these criteria, along with their professional experience and knowledge of the California coast, to address the goal of defining priority study areas for this study. Consensus was achieved, and the following three Sand Resources Project study areas were defined (fig. 1; detailed maps of each study area are provided in figures 2, 3, and 4):

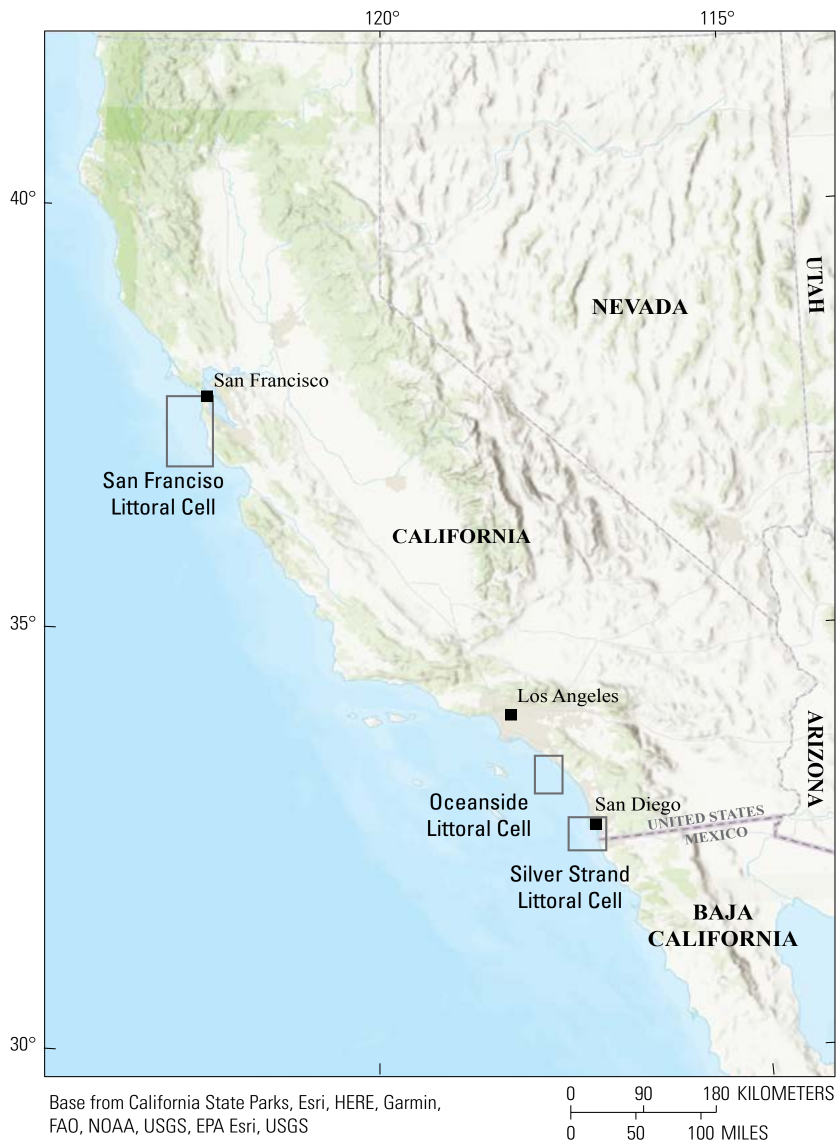
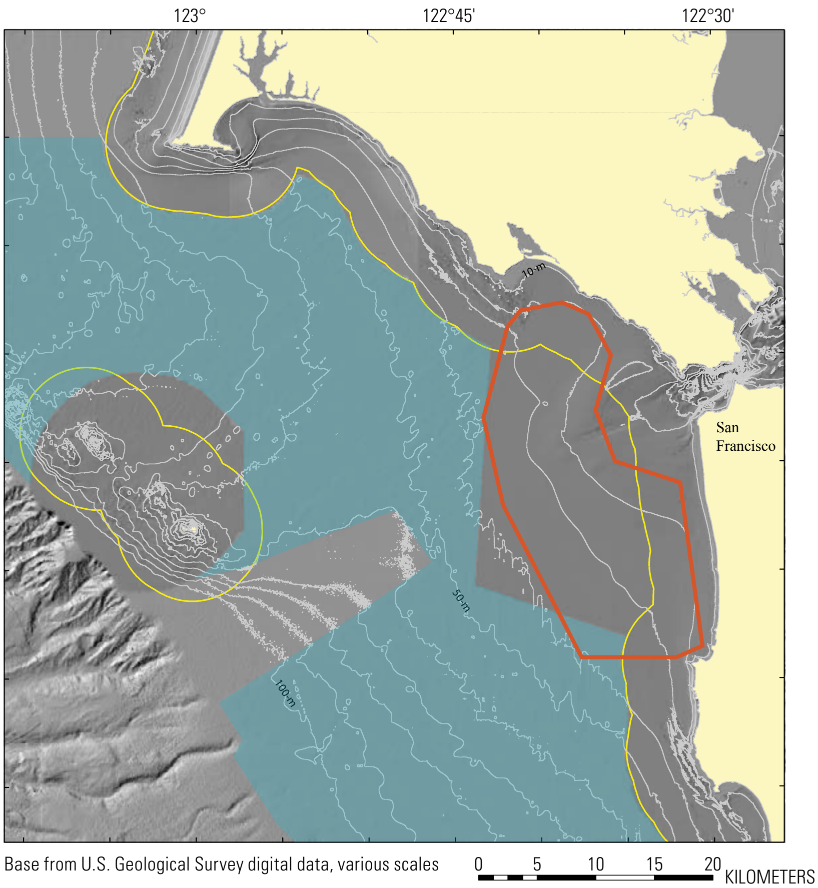


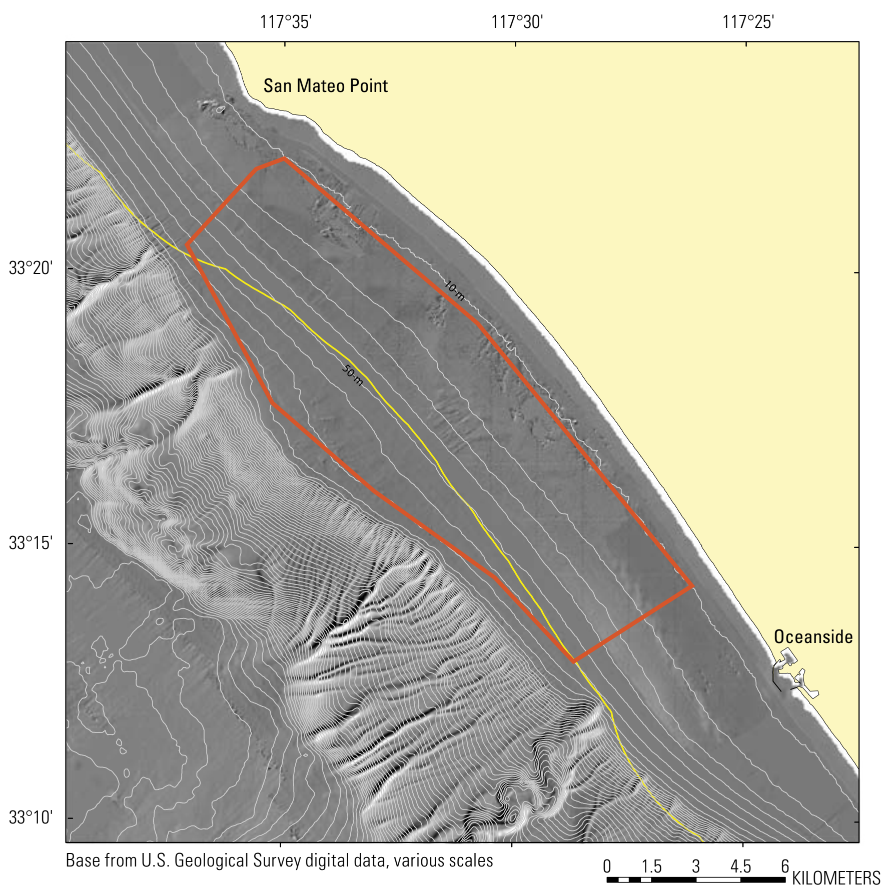
Figure 1. Shaded-relief map of California, showing locations of San Francisco, Oceanside, and Silver Strand Littoral Cell study areas (gray boxes) in Sand Resources Project.



EXPLANATION

- Area without High-Resolution Bathymetry
- Onshore area
- Study area
- Limit of California State Waters
- Bathymetric Contour lines—Interval 10 meters relative to Mean High Water

Figure 2. Shaded-relief bathymetry map of San Francisco Littoral Cell study area.



EXPLANATION

- Onshore area
- Study area
- Limit of California State Waters
- Bathymetric Contour lines—Interval 10 meters relative to Mean High Water

Figure 3. Shaded-relief bathymetry map of Oceanside Littoral Cell study area.

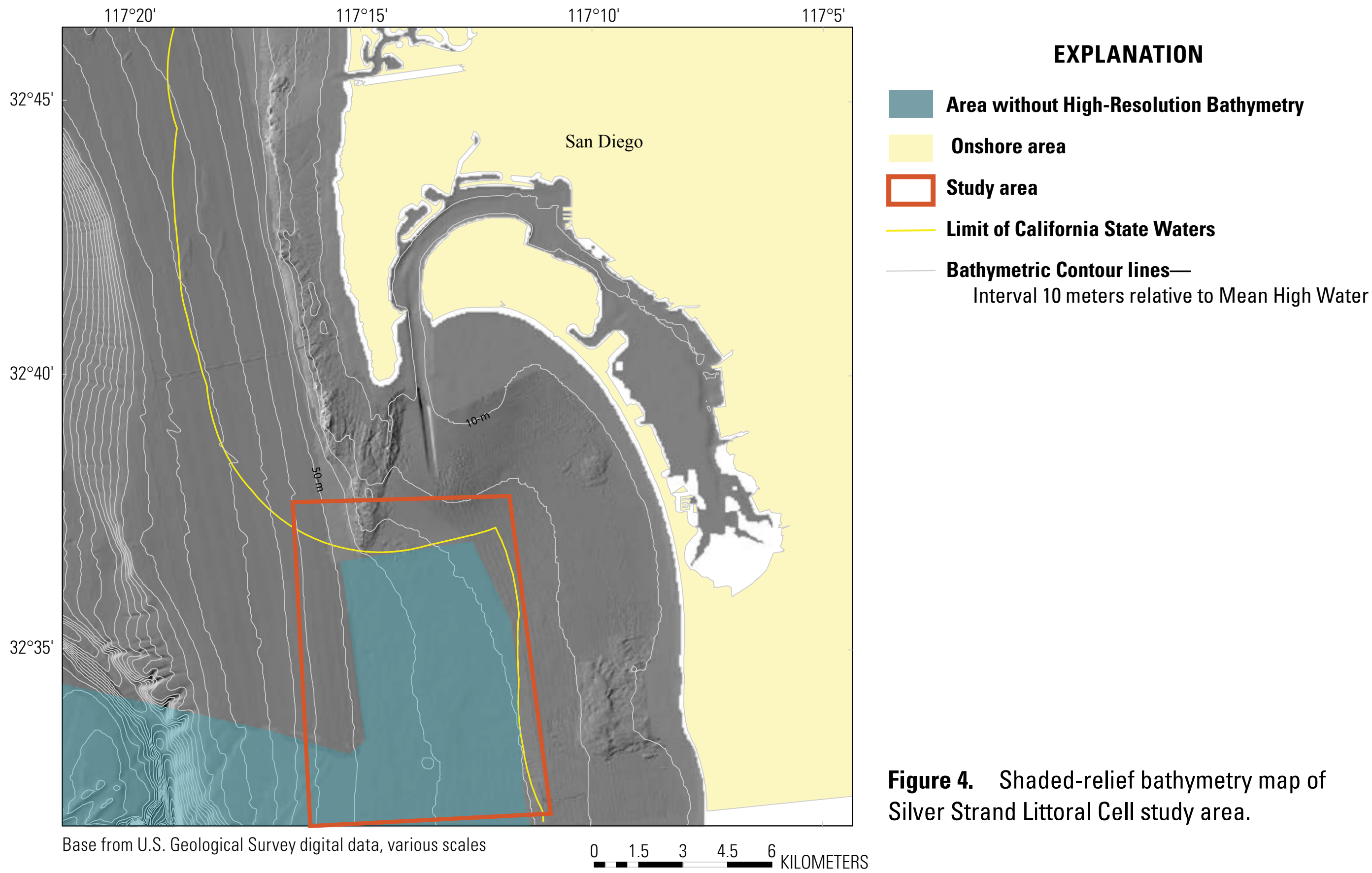


Figure 4. Shaded-relief bathymetry map of Silver Strand Littoral Cell study area.

1. San Francisco Littoral Cell,
2. Oceanside Littoral Cell, and
3. Silver Strand Littoral Cell.

Two of the three study areas, the San Francisco and Silver Strand Littoral Cells, did not have complete high-resolution bathymetry coverage across the areas of interest in Federal Waters (figs. 2, 4). High-resolution bathymetry data are important for sediment investigations and management because they provide information about the seafloor geometry, depth, and surface characteristics. Given the cost of collecting new high-resolution bathymetry, it was not possible to fill the bathymetric coverage gaps in the study areas during the Sand Resources Project. Although not complete, existing high-resolution bathymetry data coverage for the San Francisco Littoral Cell extends 10 to 15 km into Federal Waters and into areas that have the potential to contain significant sand resources (fig. 2). The bathymetry data coverage for the Silver Strand Littoral Cell, in contrast, does not extend into Federal Waters (fig. 4), thus limiting our assessment of sand resources in this study area.

Study Design

For this part of the Sand Resources Project, the USGS reviewed and synthesized existing geological data in the San Francisco, Oceanside, and Silver Strand Littoral Cells to assess sand and gravel resources in three marine settings of combined Federal and California State Waters. This work was completed in 2017–18, before the fieldwork began to collect new geophysical and vibracore data as part of the second stage of this project.

The existing data used in this synthesis focused on subbottom geophysical surveys from the USGS and other sources and sediment samples and cores in USGS, usSEABED (Reid and others, 2006), and other databases. These data were compiled and synthesized in a geographic information system (GIS) that was used to generate maps and descriptions for each study area. These products were then used to evaluate possible areas of new geophysical and sediment sampling anticipated for further field work as part of stage two of the Sand Resources Project, the results of which will be published separately (Warrick and others, 2022)

This report provides detailed descriptions of the existing data available, as well as the methods and results used to integrate these data into maps for each study area. Although the results and maps generated from these existing data may be useful for describing geologic features of the study areas, the quality of the existing data generally is low and of limited extent and detail.

Methods

Two primary data sources were used to assess sediment resources in the study areas. First, the thickness of the unconsolidated sediment on the continental shelf was estimated using historical seismic-reflection data. Second, existing measurements of these continental shelf sediments were compiled to evaluate sediment grain-size distribution information. The data sources used for each study area is included in table 1.

Existing Geophysical Data

A review of the existing geophysical data in the three study areas revealed that three types of data were available and useful for the purposes of this study—chirp, single-channel minisparker, and Geopulse boomer. A primary consideration in the data processing was that many of the historical data include data artifacts from ocean swell that need to be removed using new processing tools. Once reprocessed to remove the swell-related data artifacts, the geophysical data were easier to interpret. An example of this reprocessing and interpretation is shown in figure 5.

Table 1. Sources of historical data used in the assessment of significant sand resources for the three study areas, the San Francisco, Oceanside, and Silver Strand Littoral Cells.

[Sources: CC, Coastal Conservancy; NOAA, National Oceanic and Atmospheric Administration; NOS, National Ocean Service; SANDAG, San Diego Association of Governments; USACE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey. Other abbreviation: n/a, not applicable]

Data type(s)	Source	Year(s)	Cruise(s)	Publication(s)
San Francisco Littoral Cell				
Bathymetry, topographic-bathymetric lidar	USACE	2014	n/a	National Oceanic and Atmospheric Administration (2017)
Bathymetry, hydrographic survey	NOAA NOS	2009	H12109, H12110, H12111, H12112, H12113	National Oceanic and Atmospheric Administration (2017)
Bathymetry, acoustic backscatter	CC (lead)	Many	Many	California State University, Monterey Bay, Seafloor Mapping Lab (2022)
Acoustic backscatter, sidescan sonar	USGS	1989	F-9-89-NC	Sweeney and others (2004)
Seismic reflection	USGS	2007	F-2-07-NC	Ross and others (2019)
Seismic reflection	USGS	2006	L-01-06-SF	Ryan and others (2019)
Seismic reflection	USGS	1997	M-4-97-MB	Wong and Eittreim (2001)
Seismic reflection	USGS	1995	M-1-95-MB	https://cmgds.marine.usgs.gov/fan_info.php?fan=M195MB
Seismic reflection	USGS	1995	G-2-95-SF	Childs and others (2000)
Seismic reflection	USGS	1989	F-2-89-NC	Maher and others (1991)
Seismic reflection	USGS	1984	F-2-84-NC	https://cmgds.marine.usgs.gov/fan_info.php?fan=F284NC
Seismic reflection	USGS	1979	S-14-79-NC	https://cmgds.er.usgs.gov/services/activity.php?id=S1479NC
Seismic reflection	USGS	1973	K-1-73-NC	McCulloch (1976)
Seafloor sediment sampling	usSEABED	Many	Many	Reid and others (2006)
Seafloor sediment sampling	USGS	2002	M-1-95-MB	Orzech and others (2001)

Table 1. Sources of historical data used in the assessment of significant sand resources for the three study areas, the San Francisco, Oceanside, and Silver Strand Littoral Cells.—Continued

Data type(s)	Source	Year(s)	Cruise(s)	Publication(s)
			Oceanside Littoral Cell	
Bathymetry, topographic-bathymetric lidar	USACE	2014	n/a	National Oceanic and Atmospheric Administration (2017)
Bathymetry, hydrographic surveys	NOAA NOS	Many	Many	National Oceanic and Atmospheric Administration (2017)
Bathymetry, acoustic backscatter	CC (lead)	Many	Many	California State University, Monterey Bay, Seafloor Mapping Lab (2022); https://walrus.wr.usgs.gov/mapping/csmp/; https://www.usgs.gov/centers/pcmsc/science/california-seafloor-mapping-program-mapping-progress
Bathymetry, acoustic backscatter	USGS (lead)	Many	Many	Dartnell and others (2014)
Seismic reflection	USGS	2012	S-12-10-SC	Sliter and others (2017b, d)
Seismic reflection	USGS	2006	S-2-06-SC	Sliter and others (2010)
Seismic reflection	USGS	2000	A-1-00-SC	Gutmacher and others (2000)
Seismic reflection	USGS	1999	O-1-99-SC	Normark and others (1999)
Seismic reflection	USGS	1979	S-2a-79-SC	https://cmgds.marine.usgs.gov/services/activity.php?id=S2A79SC
Seafloor sediment sampling	usSEABED	Many	Many	Reid and others (2006)
Sediment vibracores, shallow seismic reflection	SANDAG	1999	n/a	Sea Surveyor, Inc. (1999)
			Silver Strand Littoral Cell	
Bathymetry, topographic-bathymetric lidar	USACE	2014	n/a	National Oceanic and Atmospheric Administration (2017)
Bathymetry, hydrographic survey	NOAA NOS	Many	Many	National Oceanic and Atmospheric Administration (2017)
Bathymetry, acoustic backscatter	CC (lead)	Many	Many	California State University, Monterey Bay, Seafloor Mapping Lab (2022); https://walrus.wr.usgs.gov/mapping/csmp/; https://www.usgs.gov/centers/pcmsc/science/california-seafloor-mapping-program-mapping-progress
Bathymetry, acoustic backscatter	USGS (lead)	Many	Many	Dartnell and others (2014)
Bathymetry, acoustic backscatter	USGS	1998	A-2-98-SC	Gardner and Mayer (1998)
Seismic reflection	USGS	2008	B-1-08-SC	Sliter and others (2017c)
Seismic reflection	USGS	2000	A-1-00-SC	Gutmacher and others (2000)
Seismic reflection	USGS	1999	O-1-99-SC	Normark and others (1999)
Seafloor sediment samples	usSEABED	Many	Many	Reid and others (2006)
Sediment vibracores, shallow seismic reflection	SANDAG	1999	n/a	Sea Surveyor, Inc. (1999)
Seafloor sediment sampling	USGS	2009	Many	Warrick and others (2012)

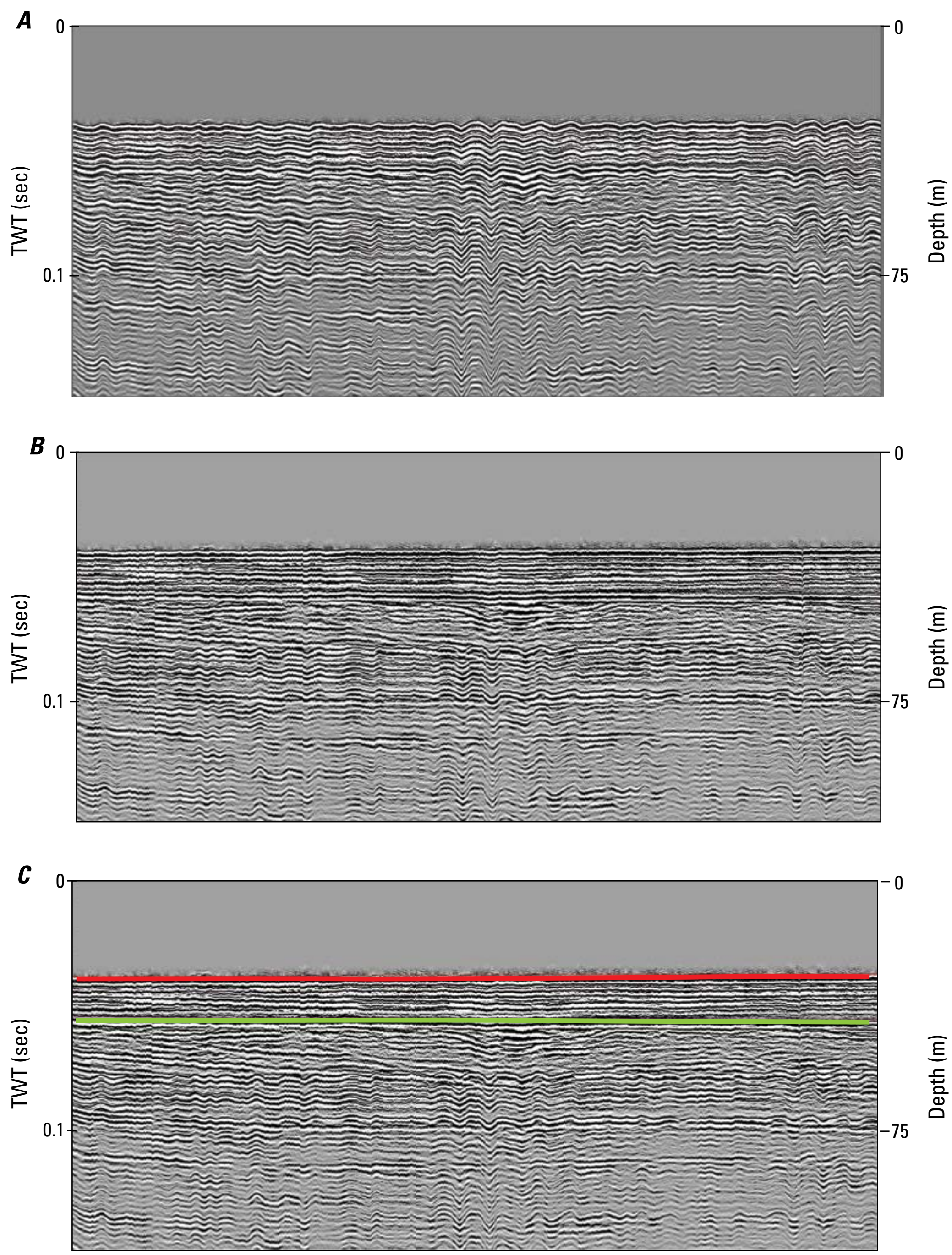


Figure 5. Example seismic-reflection profiles of original, reprocessed, and interpreted geophysical data. *A*. Original data. *B*. Reprocessed data, after correction for swell-induced effects in original data. *C*. Interpreted data, showing seafloor (red line) and base of unconsolidated sediment (green line). Abbreviations: m, meter; sec, second; TWT, two-way travel time.

Chirp Data

Chirp high-resolution seismic-reflection data were provided from collections using an Edgetech 512 Chirp subbottom profiling system. This system consists of a source transducer and an array of receiving hydrophones housed in a 500-pound “fish” towed at a depth of several meters below the sea surface. The swept-frequency chirp source signal is from 500 to 4,500 hertz (Hz), and data are recorded by hydrophones located on the bottom of the fish. At boat speeds of 7.4 to 8.3 kilometers per hour (km/h; 4 to 4.5 nautical miles per hour, nmi/h), seismic traces are collected roughly every 1 to 2 m. The data consist of three channels: a raw channel, a 90° phase-shifted channel, and an “amplitude envelope” channel created and transformed internally from the other two channels. Data are recorded in standard SEG-Y 16-bit integer format using Triton subbottom logger (SBL) software that merged seismic-reflection data with differential global positioning system (GPS) navigation data. Chirp data were processed using Paradigm Echos seismic-processing software (available at https://www.pdgm.com/products/echos/) to produce seismic-reflection signals in units of two-way travel time (TWT) that were corrected for the vertical up-and-down movement of the fish. An example of these processed chirp data is available in Sliter and others (2017a).

Single-Channel Minisparker Data

Seismic-reflection data also were provided from a minisparker system. The system produces an acoustic signal by discharging a 500-joule (J), high-voltage electrical pulse that generates a frequency spectrum roughly from 200 to 1,600 Hz. At boat speeds of 7.4 to 8.3 km/h (4 to 4.5 nmi/h), seismic traces were collected roughly every 1 to 2 m. The data were recorded on a 15-m-long hydrophone streamer in standard SEG-Y 32-bit floating-point format using Triton SBL software that merged seismic-reflection data with differential GPS navigation data. The single-channel minisparker data were reprocessed to remove ocean-swell effects using Sioseis software (available at https://sioseis.ucsd.edu/procs.html). This reprocessing included user-defined point pairs to guide the automated water-bottom picker and a series of filters, including a general band pass filter, a swell filter, and a 120- to 800-Hz band-pass filter. The reprocessed data are shown in figure 5*B* along with an example of the raw minisparker data for southern California from Sliter and others (2010).

Geopulse Boomer Data

Seismic-reflection data were generated from a Geopulse boomer configured with a sound source consisting of two ORE Geopulse 5813A boomer plates mounted on an USGS-built catamaran sled that was towed at the water surface. The outgoing power level was 350 J, and the firing rate depended on water depth. Signals were received by a 5-m-long SIG streamer that had 8 hydrophones towed from a boom on the side of the vessel. Data were recorded by Triton-Elics International ‘Delph Seismic’ software, in SEG-Y format, using a sample frequency of 16 kilohertz (kHz) and a record length of 200 to 300 meters per second (m/s). Swell correction and deconvolution of the Geopulse seismic-reflection profiles were accomplished using the Paradigm Echos seismic processing software (available at http://www.pdgm.com/products/echos/). Processing included a minimum phase Butterworth filter that had a 200- to 1,000-Hz bandpass, the STATICT module to calculate a swell-correction static, algorithms for seafloor mute and spiking deconvolution, a water-depth static, and a bandpass filter. Gutmacher and others (2006) provided an example of the minisparker data for southern California.

Interpretation of Existing Geophysical Data

To map the thickness of the unconsolidated sediment on the continental shelf, digital seismic-reflection files were loaded into the interactive seismic-interpretation software package, Kingdom Suite by IHS Markit, using associated navigational data. The seafloor and subsurface horizons were then interpreted by USGS analysts, following the sequence-stratigraphy and seismic-reflection interpretation techniques of Johnson and others (2017), which are based on the principles of Mitchum and others (1977) and Catuneanu (2006). In general, unconsolidated sediment on the California continental shelf consists of uppermost Pleistocene and Holocene strata, deposited since the last maximum sea-level lowstand about 21,000 years ago; this sediment is distinguished from underlying units by a transgressive erosional surface.

Once the seismic-reflection profiles were interpreted, the TWT were determined for each horizon. The difference in TWT between seafloor surface and the base of the unconsolidated sediment horizon was calculated, and the thickness (in meters) was determined using a sediment velocity of 1,500 m/s. These mapped sediment-thickness values were then exported into an ArcGIS project and gridded using the methodology of Wong and others (2012), which includes minor editing of the preliminary sediment-thickness maps to incorporate the effects of faults and bedrock outcrops. The final map of the unconsolidated sediment is presented as an isopach map for each study site, and all calculations of sediment volumes and thicknesses were based on these maps.

Surficial Sediment Grain-Size Data

The use of sand as beach-nourishment sediment is fundamentally a function of the grain-size distribution. To evaluate the sediment grain-size distributions within and near the three study areas, historical sampling data were compiled and summarized. A primary dataset was usSEABED (Reid and others, 2006), a national inventory of coastal and marine sediment data developed through collaboration between the USGS and the Institute of Arctic and Alpine Research at the University of Colorado (Reid and others, 2006). More than 35 institutions, agencies, and universities have contributed to usSEABED. Additional sediment data were provided by the vibracore sampling in select inner shelf sites of southern

California by Sea Surveyor, Inc. (1999), and sampling by Warrick and others (2012).

There are several ways that sediment grain-size samples have been historically obtained, processed, and reported. We present a modified Wentworth size class (table 2) of each sample, based on median grain sizes reported in usSEABED in units of phi (a logarithm-based metric of grain size) so that the best available data can be easily compared. These size classes are included in table 2.

Table 2. Modified Wentworth sediment size classes used in the study of the San Francisco, Oceanside, and Silver Strand Littoral Cells.

[Modified from Wentworth (1922). Abbreviation: mm, millimeter]

Wentworth size class	Sediment diameter (mm)	phi
Clay	<0.004	>8
Silt	0.004 to 0.062	4 to 8
Very fine sand	0.062 to 0.125	3 to 4
Fine sand	0.125 to 0.25	2 to 3
Medium sand	0.25 to 0.5	1 to 2
Coarse sand	0.5 to 2	−1 to 1
Pebble	2 to 64	−6 to −1
Cobble	> 64	<−6

Results

San Francisco Littoral Cell

The San Francisco Littoral Cell has historical geophysical survey data extending throughout the study area and totaling more than 1,000 linear kilometers of data collection (fig. 6; tables 1, 2). Data from these surveys generally were of good quality, and the reprocessing to remove artifacts from ocean swell improved the identification of subsurface horizons. Data from much of the study area indicate that sediment thickness exceeds tens of meters offshore of the mouth of the San Francisco Bay (fig. 7). The thickness of these sediment deposits is controlled by the region's faults, such as those shown by profiles through the San Andreas Graben that lies between the San Andreas and Golden Gate Fault Zones (fig. 7).

The resulting isopach map, which provides an integrated thickness measurement of the unconsolidated sediment, reveals a massive deposit of sediment offshore of the mouth of the San Francisco Bay and well beyond the 5.6-km (3-nmi) limit of California State Waters (fig. 8). This sediment deposit averages about 30 m thick and is more than 50 m thick within the narrow constraints of the San Andreas Graben. It thins to the north, west, and south to less than 2 m thick, and rock outcrop is observed, especially on the north side of the study area (fig. 8; see also, Cochrane and others, 2015). In total, it

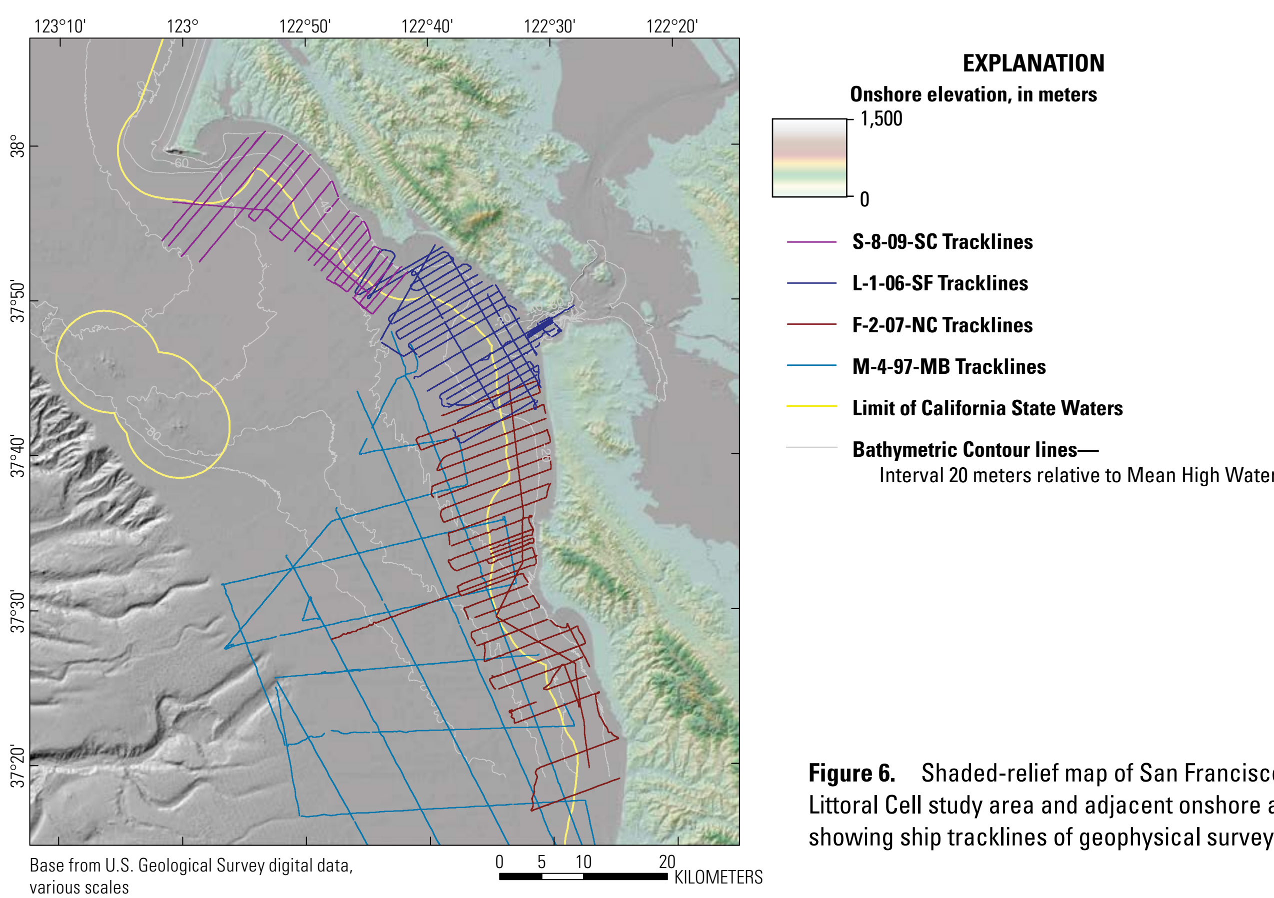


Figure 6. Shaded-relief map of San Francisco Littoral Cell study area and adjacent onshore area, showing ship tracklines of geophysical surveys.

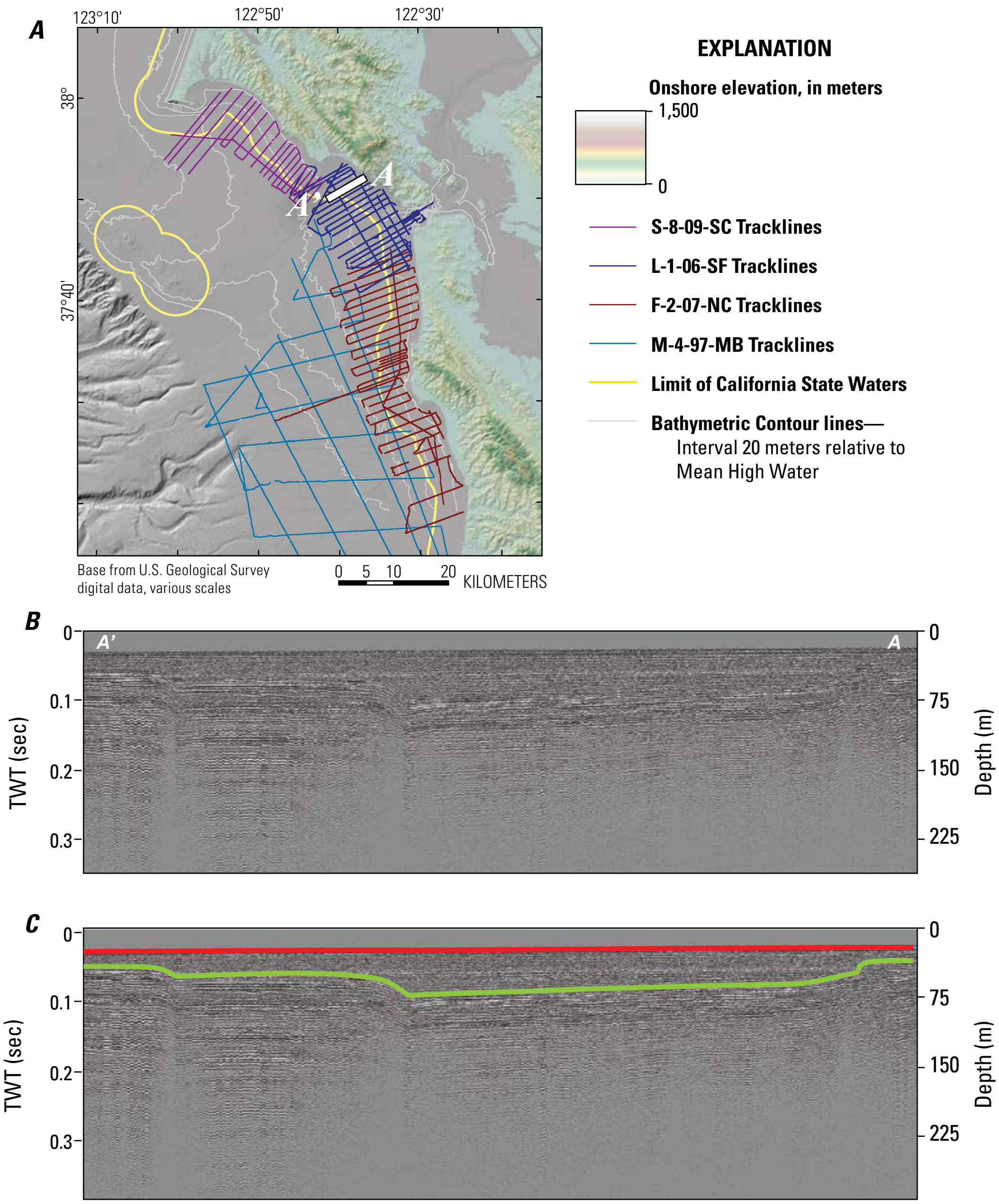


Figure 7. Seismic-reflection profiles from San Francisco Littoral Cell study area. *A*, Shaded-relief map showing location of seismic-reflection profile *A—A′* (white line) shown in *B*. *B*, Processed data of profile *A—A′*. *C*, Interpretated data of profile *A—A′* shown in *B*, showing seafloor (red line) and base of unconsolidated sediment (green line). Abbreviations: m, meter; sec, second; TWT, two-way travel time.

was estimated that greater than 10 billion cubic meters (m^3) of sediment exists in these deposits, about three-quarters of which lies outside of the 5.6-km (3-nmi) limit (table 3). Most of the sediment deposit is found in water depths of less than 20 m (fig. 8).

More than 500 sediment grain-size samples exist for the study area, which allowed for a thorough mapping of surficial grain size (fig. 9). Within the primary depocenter offshore of San Francisco Bay, sediment grain sizes are most commonly coarse and medium sand, which consist of grain sizes of 0.250 to 2.0 millimeters (mm) (fig. 9). These coarser sands were not unique to the “San Francisco Bar,” however, as such sands were observed throughout the study site. One exception is the finer grained sediments (very fine sand and silt) observed in areas south of the bar and offshore of Half Moon Bay (fig. 9); these areas are within a secondary sediment depocenter present in this southern region (fig. 8). In total, sediments were observed to have a broad range of grain sizes (very coarse sand to medium silt); the median grain size of the samples was very fine sand (table 3).

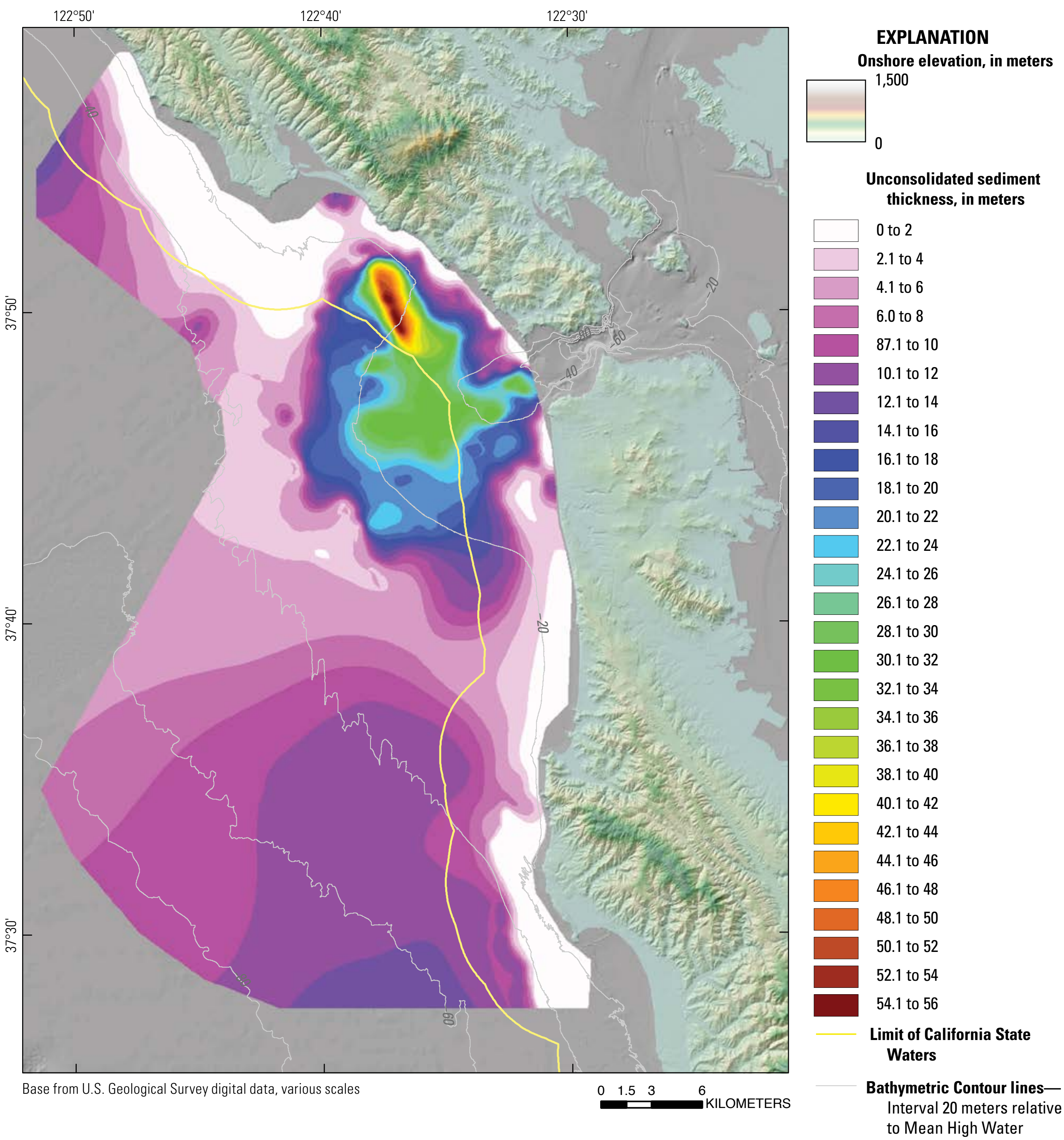


Figure 8. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing sediment thicknesses.

Table 3. Descriptions of the San Francisco, Oceanside, and Silver Strand Littoral Cell study areas.

[California State Waters extend from shoreline to 5.6-kilometer (km; 3-nautical-mile, nmi) limit. Federal Waters extend from California State Waters limit to 370 km (200 nmi) offshore. Other abbreviations: km, kilometer; km^2, square kilometer; m, meter; m^3, cubic meter; mm, millimeter; No., number]

Description parameters	Littoral cell study site		
	San Francisco	Oceanside	Silver Strand
Area of study site (km^2)	1,600	400	310
Area of study site in Federal Waters (km^2)	1,180	175	125
Depth range (m)	10–87	5–167	7–102
Total sediment volume (million m^3)	10,800	220	980
Total sediment volume in Federal Waters (million m^3)	7,740	40	600
Total length of seismic lines used (km)	1,089.5	104.4	120.2
No. sediment samples	510	24	33
Sediment grain size, median (phi) [size fraction]	3.3 [very fine sand]	4.8 [coarse silt]	4.2 [coarse silt]
Sediment grain size, range (phi) [size fraction]	0.1–5.6 [very coarse sand to medium silt]	3.4–5.6 [very fine sand to medium silt]	0.3–5.5 [very coarse sand to medium silt]

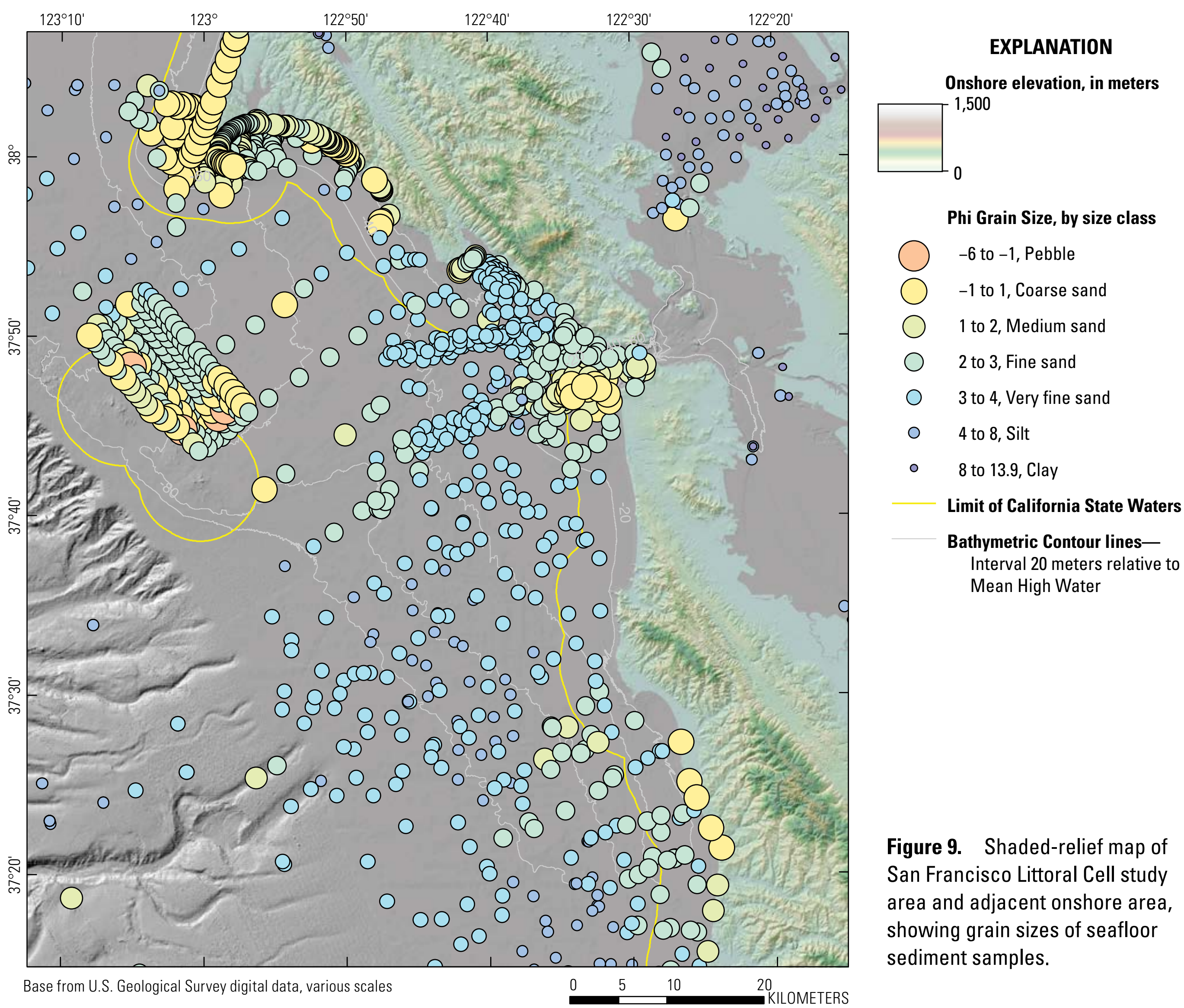


Figure 9. Shaded-relief map of San Francisco Littoral Cell study area and adjacent onshore area, showing grain sizes of seafloor sediment samples.

Oceanside Littoral Cell

The primary historical geophysical data for the Oceanside Littoral Cell were derived from USGS cruises in 1999 and 2000 (fig. 10; table 1). These data, which incorporated more than 100 km of survey lines, generally were adequate to identify subsurface horizons, including the surficial unconsolidated sediment once data artifacts from ocean swell were removed (table 2; fig. 11). The seismic profiles revealed that the unconsolidated sediment generally is thickest in the midshelf area and thins to negligible thicknesses at the shelf edge (fig. 11). The thickest deposits are more than 10 m thick. However, data quality in some profiles was not sufficient to determine whether subsurface horizons included sediment, such as those shown on the farthest offshore section of profile *B—B'* (fig. 11). In such cases, conservative estimates of the bounds of unconsolidated sediment were made using the shallowest observable horizons.

The thickness estimates of unconsolidated sediment were integrated into an isopach map of the study that shows an elongate deposit of sediment centered about on the 40-m bathymetric contour (fig. 12). This deposit extends beyond the 5.6-km (3-nmi) limit of California State Waters, in the central part of the study area where the shelf is widest (fig. 12). The sediment deposit, which is typically several meters to more than 10 m thick, is thickest in the northwest and thinnest in the southeast. Some evidence for rock outcrop is seen along the edge of the shelf, near the 80-m water depth. In total, about 220 million m^3 of sediment was mapped in the study area, of which 40 million m^3 are found beyond the 5.6-km (3-nmi) limit (table 3).

Only 24 sediment grain-size samples exist for the study area, which severely limited the mapping of surficial grain size (fig. 13; table 3). The sediment grain sizes are both silt and sand, although no consistent spatial or water-depth patterns appear in these results (fig. 13). The median grain size of the samples is coarse silt, although the samples vary from very fine sand to medium silt (table 3). The sandy sediments are most common on the inner shelf (shallower than 20 m), which is consistent with the vibracore results of Sea Surveyor, Inc. (1999) in this area, conducted at depths of 15 to 27 m, that commonly found silty sand on the seafloor. These inner shelf, finer grained surficial sediments range in thickness from 1 to 4 m and lie over more sandy sediments that were determined to be suitable for beach nourishment (Sea Surveyor, Inc., 1999). Thus, further investigation of the surface and subsurface grain-size distributions in this study area is a primary goal of field sampling in stage two of this project.

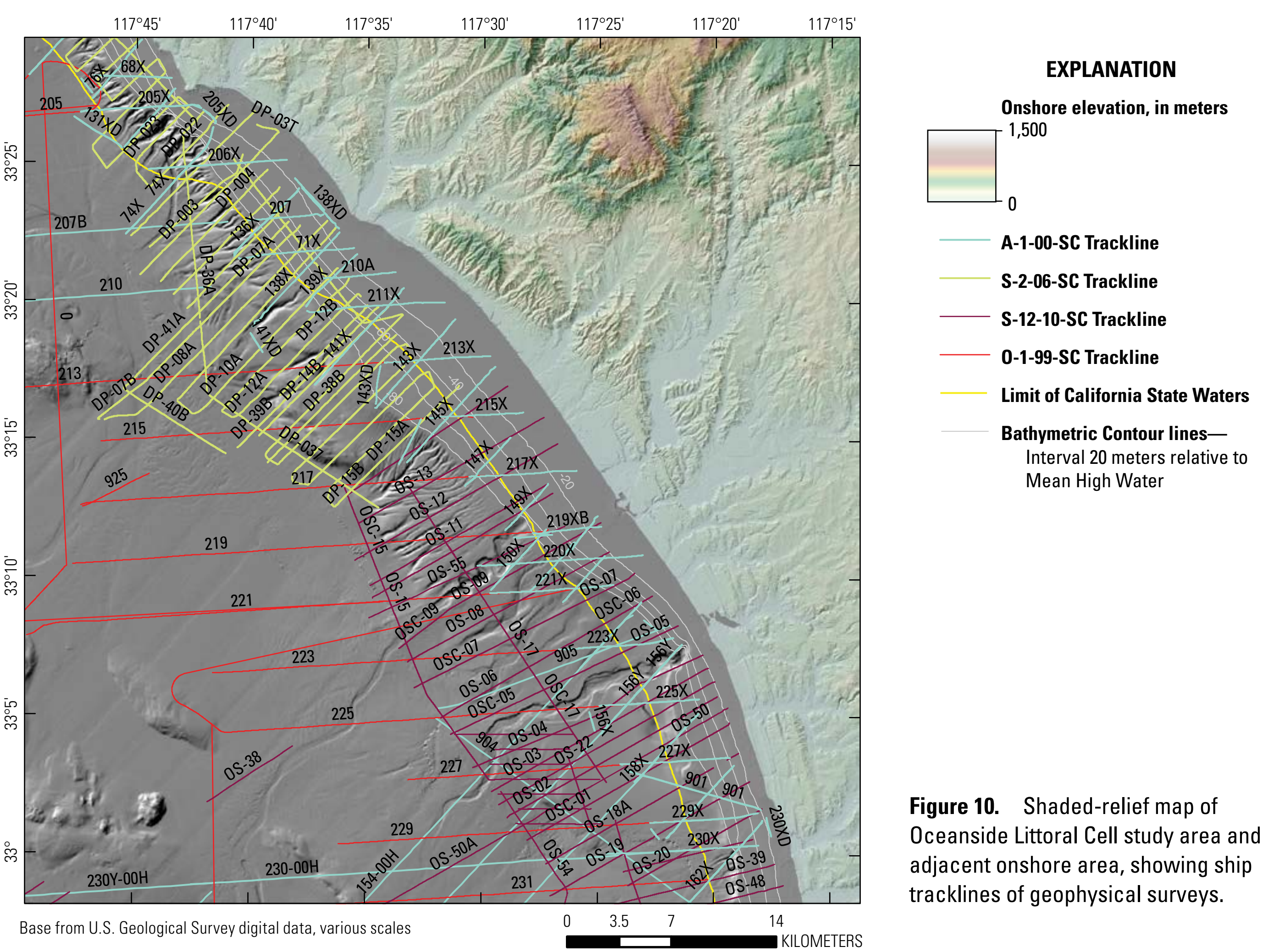


Figure 10. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing ship tracklines of geophysical surveys.

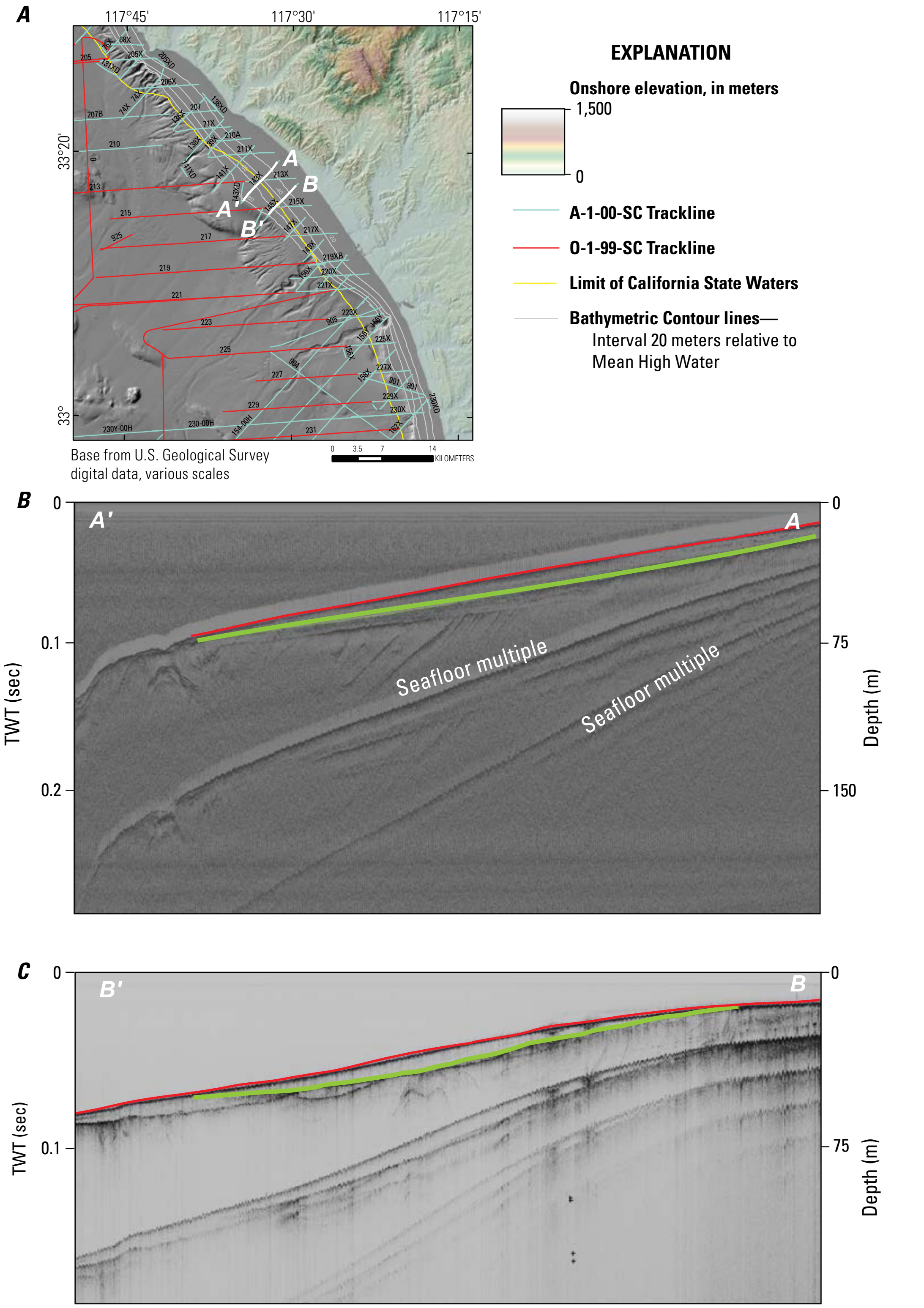


Figure 11. Seismic-reflection profiles of geophysical data from Oceanside Littoral Cell study area. *A*, Shaded-relief map showing location of seismic-reflection profiles *A—A′* and *B—B′* (white lines) shown in *B* and *C*, respectively. *B*, Interpreted data of profile *A—A′*, showing seafloor (red line) and base of unconsolidated sediment (green line). *C*, Interpreted data of profile *B—B′*. Abbreviations: m, meter; sec, second; TWT, two-way travel time.

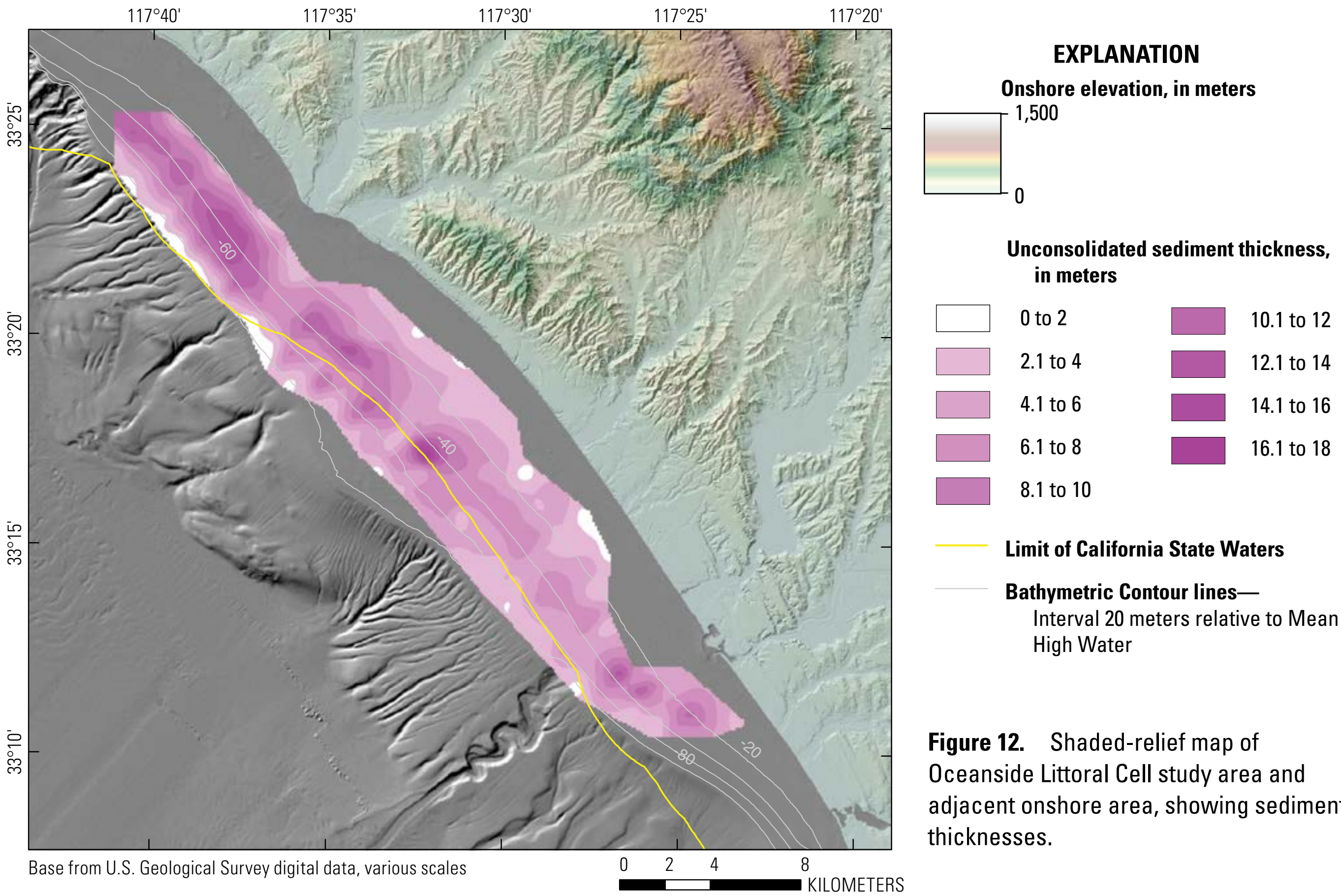


Figure 12. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing sediment thicknesses.

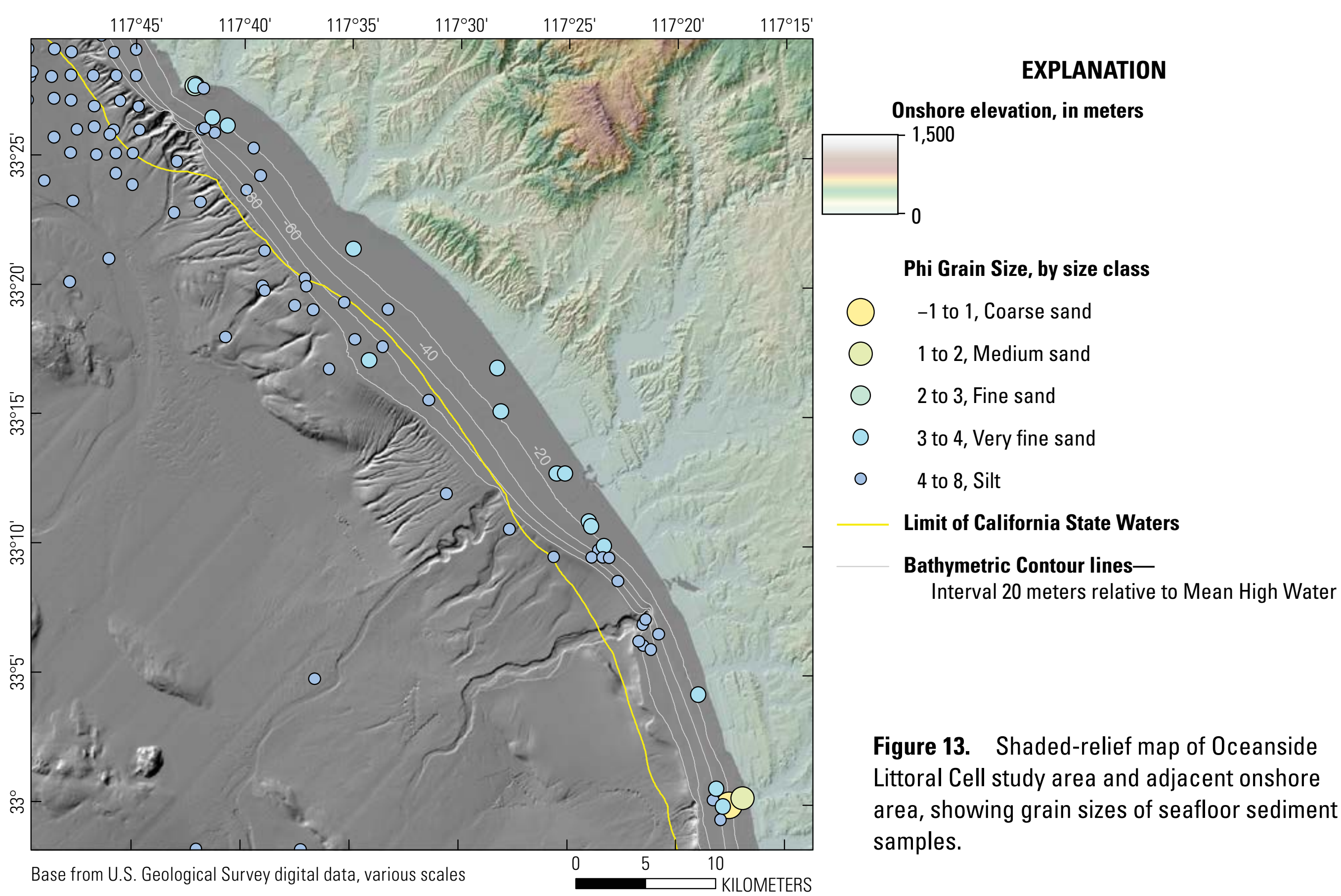


Figure 13. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing grain sizes of seafloor sediment samples.

Silver Strand Littoral Cell

Limited historical geophysical data exist for the Silver Strand Littoral Cell study area, most of which were derived from USGS cruises in 1999 and 2000 (fig. 14; table 1). In addition, limited high-resolution bathymetry data exist for part of the area outside the 5.6-km (3-nmi) limit of California State Waters (see fig. 4). Although the data are sparse (about 120 km of seismic survey lines; figure 14 and table 3), evidence exists that sediment deposits are not uniform throughout the area and that their location is determined by geologic control. For example, a seismic-reflection profile through the center of the area indicates that sediment deposits range in thickness from negligible in the western part to greater than 10 m in the central part of this profile (fig. 15).

Although few geophysical data exist for this area, thickness estimates of unconsolidated sediment were generated that reveal thinner deposits of sediment in the northern part and thicker deposits in the southern part of the study area (fig. 16). The sediment deposit thickness is typically negligible to greater than 14 m. Evidence for rock outcrop is observed throughout the study area, and a more detailed geophysical survey would assist with mapping these rocky features. From the sparse geophysical data, an estimated 980 million m^3 of sediment were mapped in the study area, of which 600 million m^3 exist beyond the 5.6-km (3-nmi) limit of California State Waters (table 3). These estimates need to be refined with more thorough geophysical mapping of the study area.

The number of historical sediment grain-size samples in the Silver Strand Littoral Cell study area were limited, especially in the central area (fig. 17; table 3). The median sediment grain size of all samples was coarse silt, and a wide range of sizes, from very coarse sand to medium silt

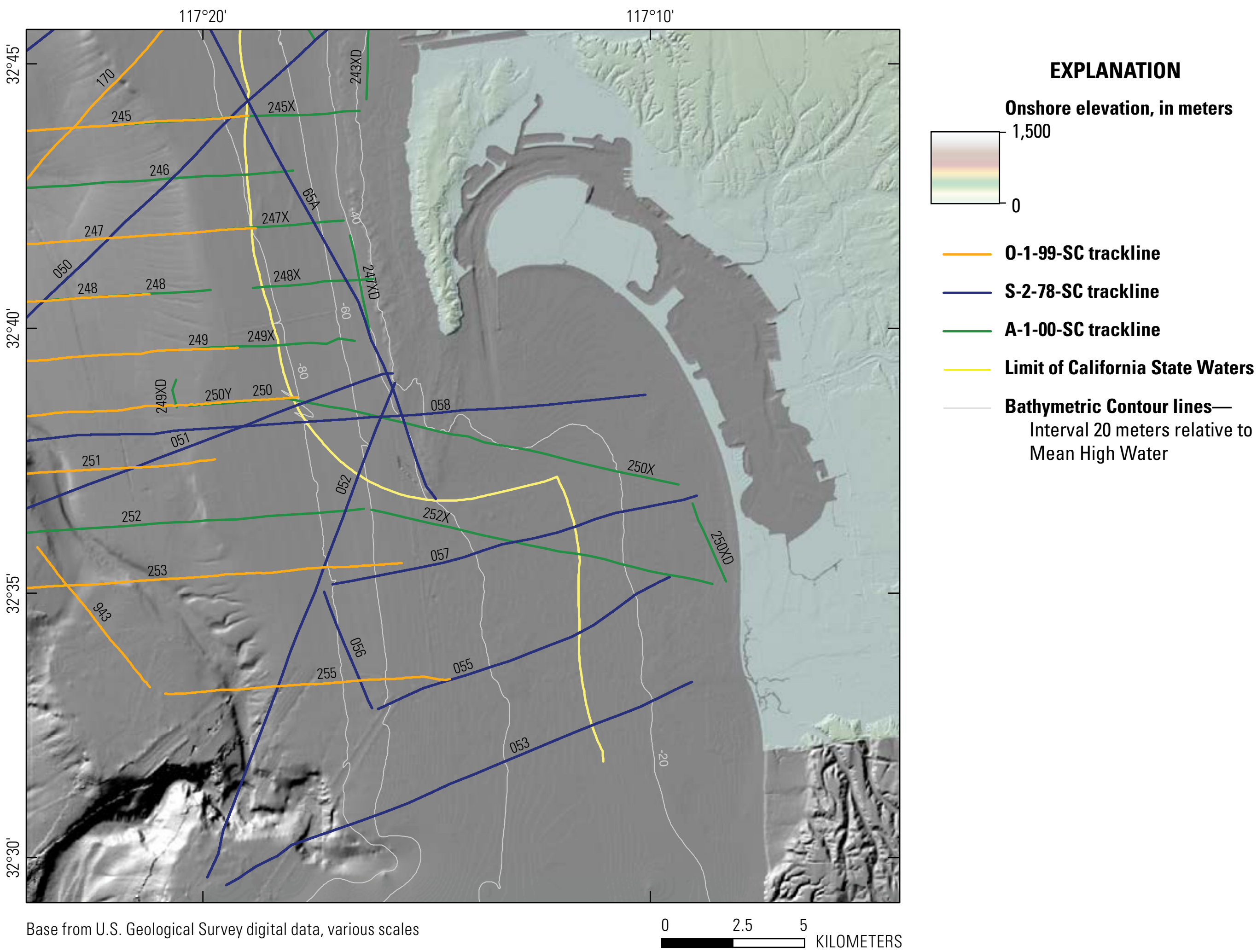


Figure 14. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing ship tracklines of geophysical surveys.

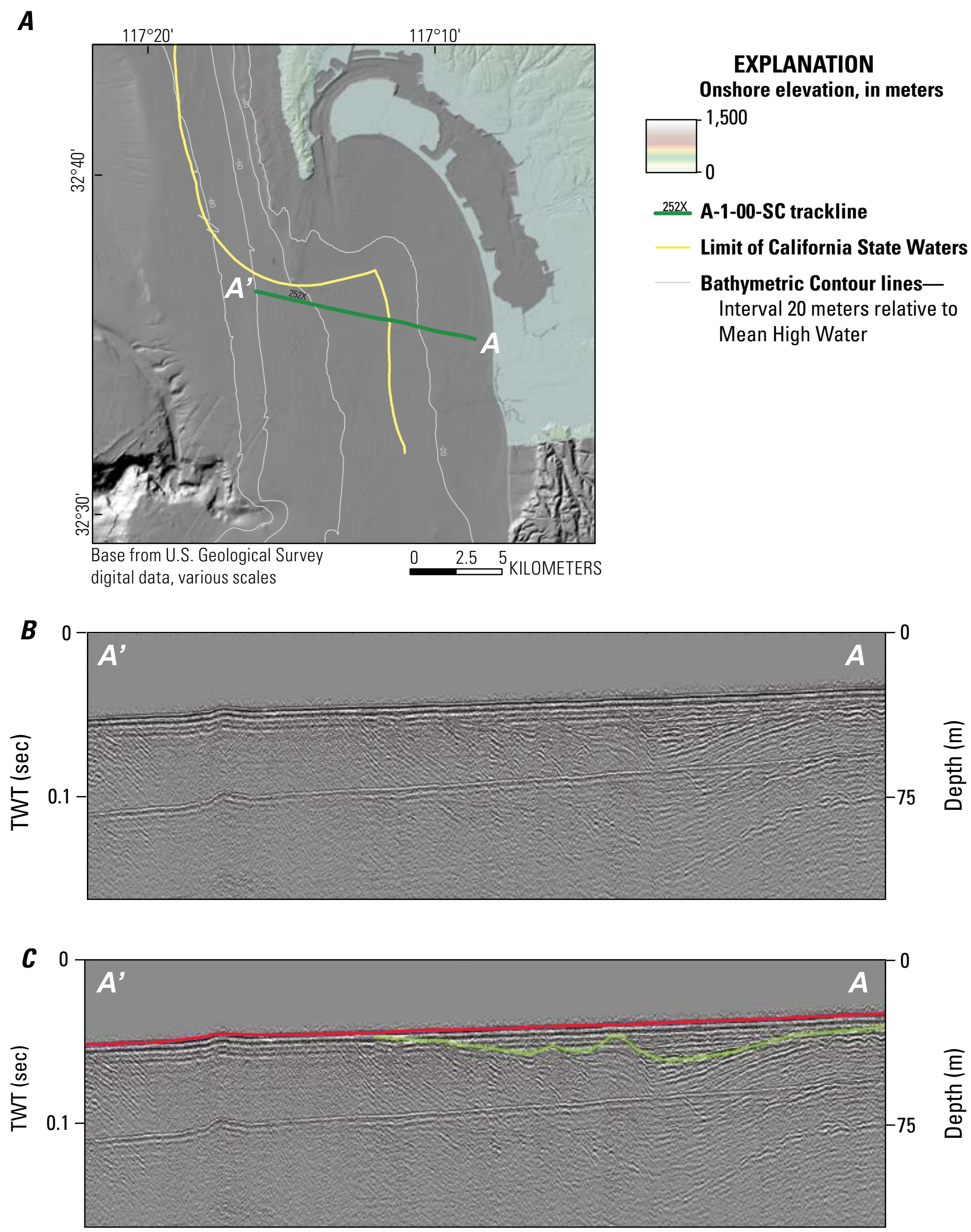


Figure 15. Seismic-reflection profiles of geophysical data from Silver Strand Littoral Cell study area. *A*, Shaded-relief map showing location of seismic-reflection profile *A—A′* (green line). *B*, Processed data of profile *A—A′*. *C*, Interpreted data of profile *A—A′*, showing seafloor (red line) and base of unconsolidated sediment (green line). Abbreviations: m, meter; sec, second; TWT, two-way travel time.

(table 3) was observed. However, sediment grain sizes in the southernmost part of the area were sandy, consistently medium to coarse sand (fig. 17). The five sediment samples beyond the 5.6-km (3-nmi) limit in this region were consistently coarser than the samples within the 5.6-km (3-nmi) limit, which include the silty sediments in the northernmost part (fig. 17). The silty texture of much of the study area is consistent with inner shelf sampling by Warrick and others (2012) and the vibracore results of Sea Surveyor, Inc. (1999), which found that limited suitable beach-nourishment sand is exposed on the seafloor and that “most of the suitable beach replenishment sand within the site is buried under a 2 to 6 foot (0.6–2 m) layer of silty sand that is not suitable for beach replenishment” (Sea Surveyor, Inc., 1999, their p. 52–57).

Combined, the data summarized for this study area provide evidence that sand-rich sediment deposits may exist on the midshelf to outer shelf areas, and that these deposits may be suitable for future beach-nourishment projects. Further field studies of this area are warranted given these findings.

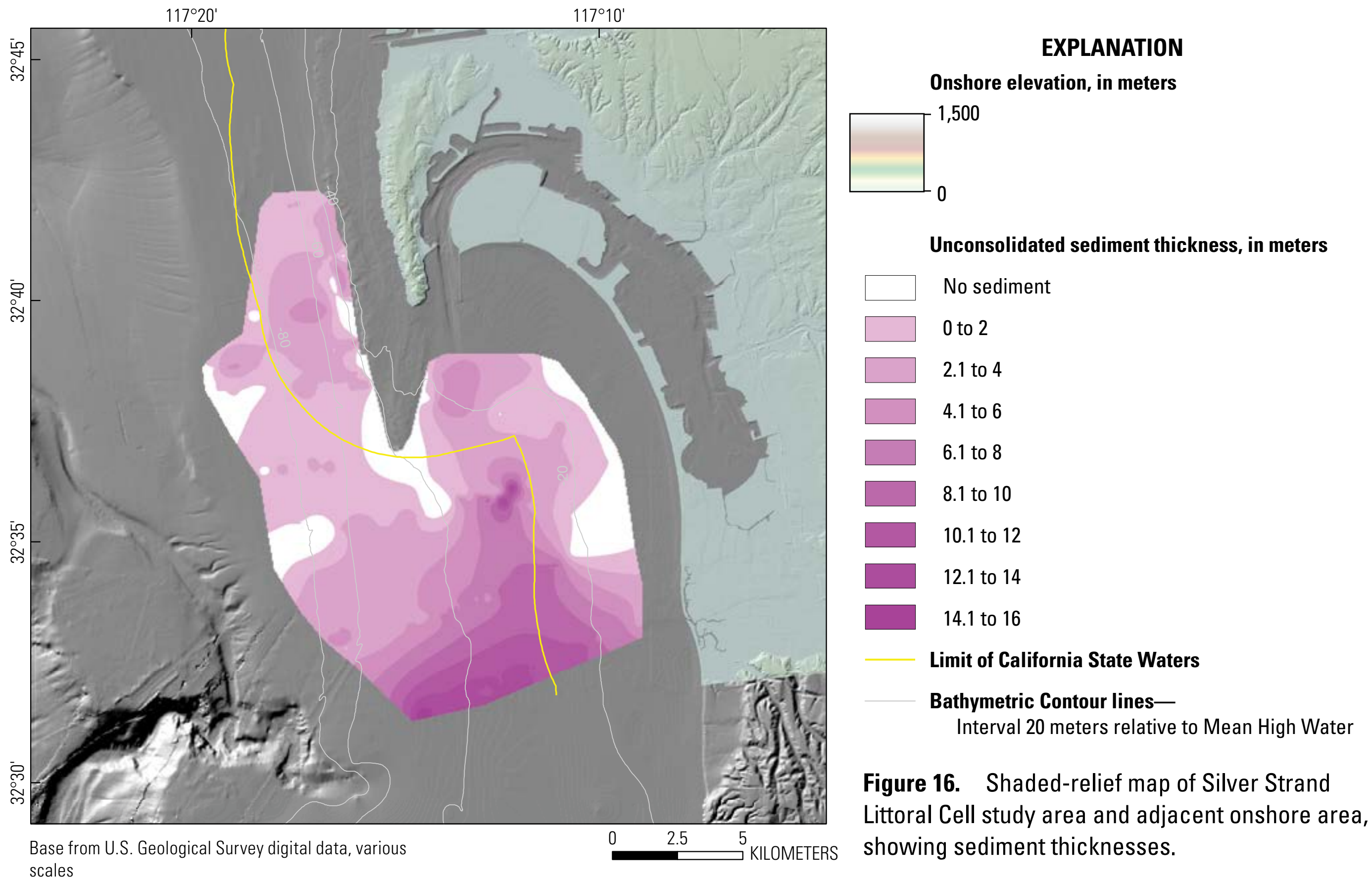


Figure 16. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing sediment thicknesses.

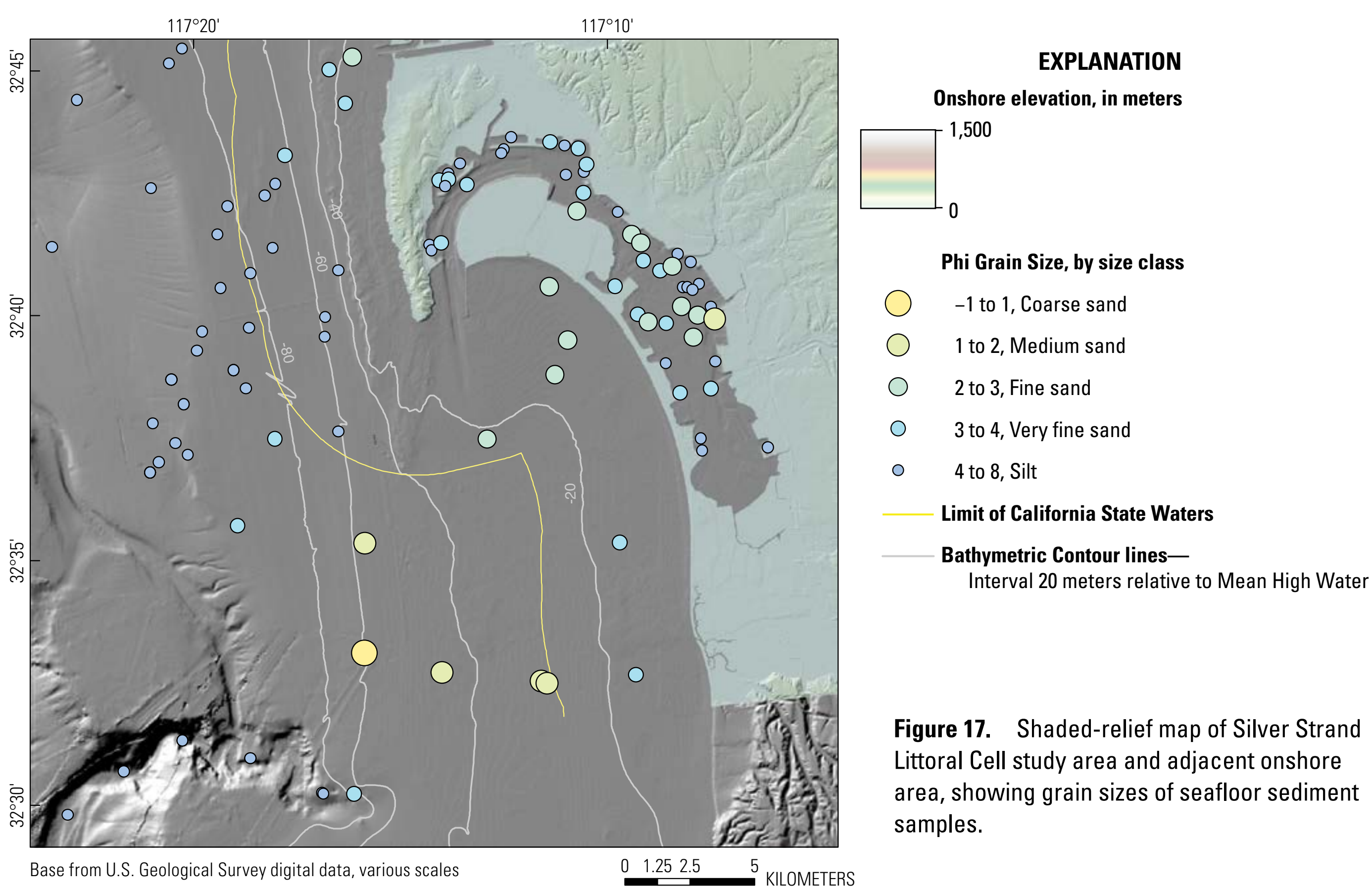


Figure 17. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing grain sizes of seafloor sediment samples.

Conclusions

During the first year of the Sand Resources Project, a reprocessing and synthesis of existing geophysical data, along with a compilation of grain-size data, was conducted to better describe the potential of finding beach-nourishment-quality sand within combined Federal and California State Waters. Three study areas were examined, and this resulted in different findings:

San Francisco Littoral Cell.—This area has an extensive deposit of sediment offshore of the mouth of San Francisco Bay, represented by medium and coarse sands over most of the seafloor. The sediment deposit generally is greater than 20 meters (m) thick (locally, more than 50 m thick), and it lies in water depths largely shallower than 20 m and outside of the 5.6 kilometer (km; 3-nautical-mile, nmi) limit of California State Waters. A secondary sediment deposit appears to be located south of the mouth of San Francisco Bay, immediately northwest of Half Moon Bay. This secondary deposit, although greater than 10 m thick in places, is represented by fine sediments (silt and very fine sand) on the seafloor. Although coarser sediment may be present underneath this surficial layer of fine sediments that may be used for beach nourishment, the most prospective location for nourishment sediment appears to be on and (or) near the “San Francisco Bar.”

Oceanside Littoral Cell.—This area has a thin (2–16 m) and spatially variable deposit of sediment that trends northwest-to-southeast along the continental shelf. The limited historical sediment sampling within this study area shows that silt and sand are within the area of interest. These grain-size results are consistent with the spatially variable grain-size distributions of the inner shelf within the area that generally consists of a silty surface layer over a sandy subsurface layer.

Silver Strand Littoral Cell.—Sediment thicknesses and grain-size characteristics of the Silver Strand Littoral Cell are influenced by the underlying geologic structure that has created basement-rock highs and lows. The thickest and most sand-rich deposits are found in the southernmost part of the area, outside of the 5.6-km (3-nmi) limit of California State Waters, although historical sampling has been limited. Review of a limited number of grain-size samples from this area indicates that a deposit of medium and coarse sand may be present. In contrast, sediment deposits from the inner shelf are reported to have a silty surface layer and a sandy subsurface layer. Thus, this study area may have sand-rich deposits in the midshelf to outer shelf area that are suitable for future beach-nourishment projects, although further high-resolution bathymetric surveys, geophysical surveys, and field sampling will be necessary to fully evaluate this potential.

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