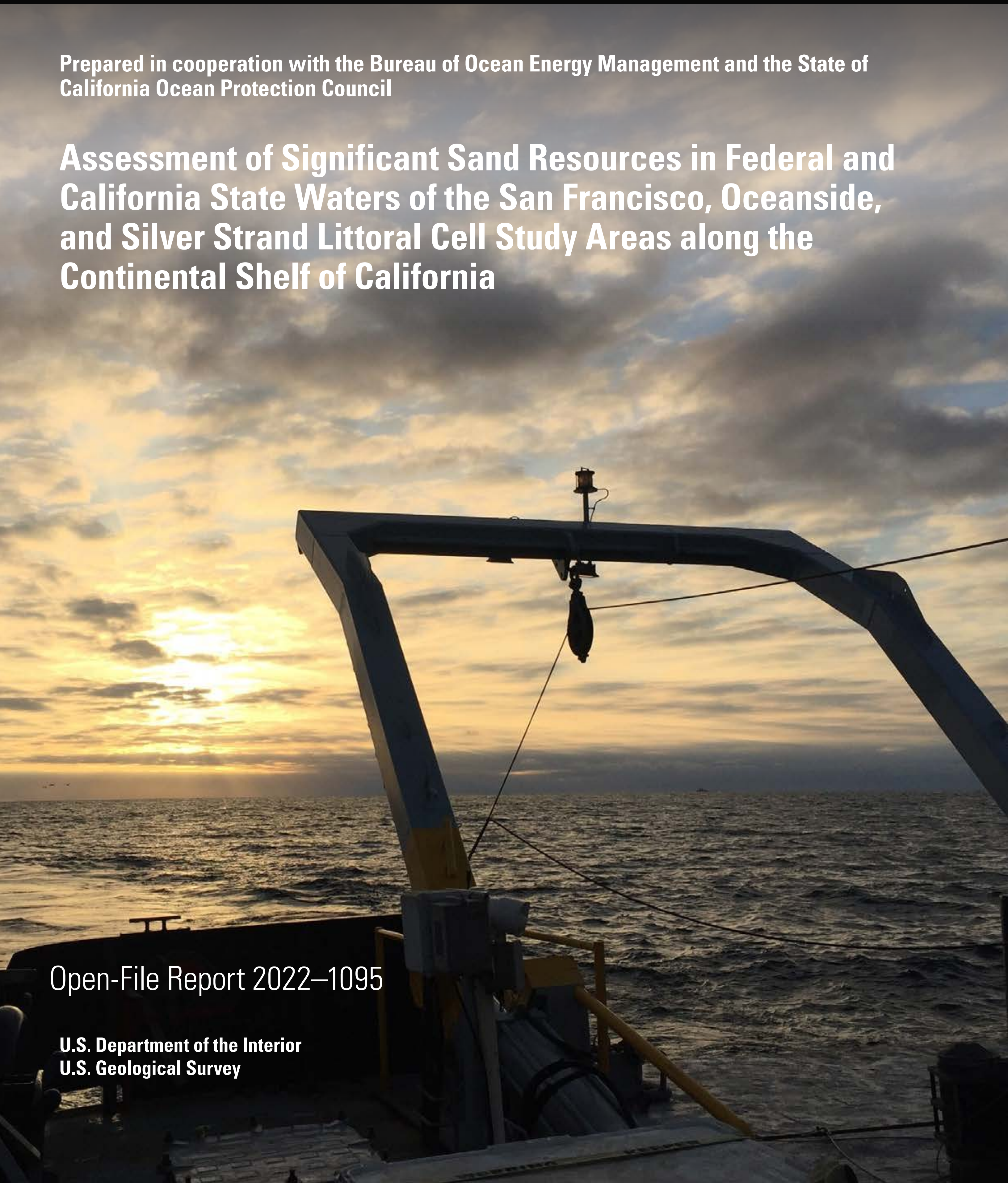
Prepared in cooperation with the Bureau of Ocean Energy Management and the State of California Ocean Protection Council

Assessment of Significant Sand Resources in Federal and California State Waters of the San Francisco, Oceanside, and Silver Strand Littoral Cell Study Areas along the Continental Shelf of California



Open-File Report 2022–1095

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

Cover: Photograph of open ocean off the coast of California by James Conrad, U.S. Geological Survey.

Assessment of Significant Sand Resources in Federal and California State Waters of the San Francisco, Oceanside, and Silver Strand Littoral Cell Study Areas along the Continental Shelf of California

By Jonathan A. Warrick, James E. Conrad, Antoinette Papesh, Tom Lorenson, and Ray Sliter

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
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)
	Volume	
liter (L)	0.2642	gallon (gal)
	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
IGRF	International Geomagnetic Reference Field
INSTAAR	Institute of Arctic and Alpine Research
MSCL	Multi-Sensor Core Logger
M/V	motor vessel
OCS	outer continental shelf
OPC	California Ocean Protection Council
R/V	research vessel
TOC	total organic content
TWT	two-way travel time
USGS	U.S. Geological Survey

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By Jonathan A. Warrick, James E. Conrad, Antoinette Papesh, Tom Lorenson, and Ray Sliter

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. The initial stage was 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 synthesis was published in a separate USGS open-file report (Warrick and others, 2022). The findings from this assessment were used to refine study area boundaries and develop sampling plans for stage two of the project.

Stage two of the project is the collection, processing, and synthesis of new data, including high-resolution geophysical surveys and sediment cores—this report addresses the second stage. The work focuses on two of the study areas—the San Francisco and the Oceanside Littoral Cells, where several research cruises have been conducted. A more limited, exploratory approach was used for the Silver Strand Littoral Cell, owing to the lack of existing high-resolution bathymetric data for this study area. The data collected provide new information about the three study areas, including sediment thickness, grain-size distributions, and total organic carbon.

Sediment in all three study areas of the Sand Resources Study was suitable for beach nourishment, as reflected by their grain-size distributions and sediment thicknesses. For example, sandy sediment in the San Francisco Littoral Cell study area was on and immediately outside of the ebb-tidal bar of the San Francisco Bay, a landform that has a strong influence on grain-size patterns of the region. The presence of thick sediment deposits in this area was interpreted to be a function of tectonics, which has caused physical features that include a graben north of the Golden Gate whose deposits were thicker and siltier than the remaining area. Sandy sediment on the inner and outer parts of the continental shelf in the Oceanside Littoral Cell may be useful for nourishment, whereas the midshelf between these areas was dominated by silty sediment. Sediment in the Silver Strand Littoral Cell, which was only sampled selectively, had the greatest potential for beach nourishment because of the greater prevalence of beach-comparable grain sizes, especially in the more distal and deeper areas where medium sands were found.

The Sand Resources Project did identify several sandy regions of the continental shelf that are deeper than dredging technologies currently (2022) available in the United States, which are generally limited to 30 meters (m) water depth or less. Although sandy sediment exists in all three study areas at water depths of 30 m or less, additional sediment supplies—most of which are in Federal Waters—are present in deeper settings, especially for the Oceanside and Silver Strand Littoral Cell study areas. Although the Silver Strand Littoral Cell study area was found to be considerably replete in sand resources, these conclusions are based on a limited sampling exercise across that study area. Thus, it may be beneficial to complete a more thorough characterization of the sediment resources in the Silver Strand Littoral Cell study area if it is determined that a need for sandy coastal sediment exists in this region.

As a result of the Sand Resources Project, several areas of sand resources in Federal and California State Waters were found where they were previously unknown. As such, this project may provide important data for future coastal-management decisions in California, and it should provide a model for future investigations of sediment resources in other regions of the State.

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, which focused on the collection and evaluation of new data, was conducted under inter-agency agreements between the USGS, BOEM, and OPC.

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 that 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 is, 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):

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

Two of the three study areas, 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.

Because of the availability of existing data (Warrick and others, 2022), the Sand Resources Project focused on new data collection in only two of the three study areas (San Francisco and Oceanside Littoral Cells) where systematic geophysical and sediment-coring surveys were conducted. Although the project partners determined that the Silver Strand Littoral Cell study area would not receive additional new data, the USGS supported a single day of exploratory geophysical-data collection and sediment-coring in this study area at the end of the Oceanside cruise. This limited effort for the Silver Strand Littoral Cell should allow BOEM, OPC, and other partner agencies to assess whether further data collection—including bathymetric surveys, geophysical surveys, and sediment sampling and coring—may be helpful in locating sand resources in the southernmost part of this study area, possibly including areas in adjacent California State Waters.

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.

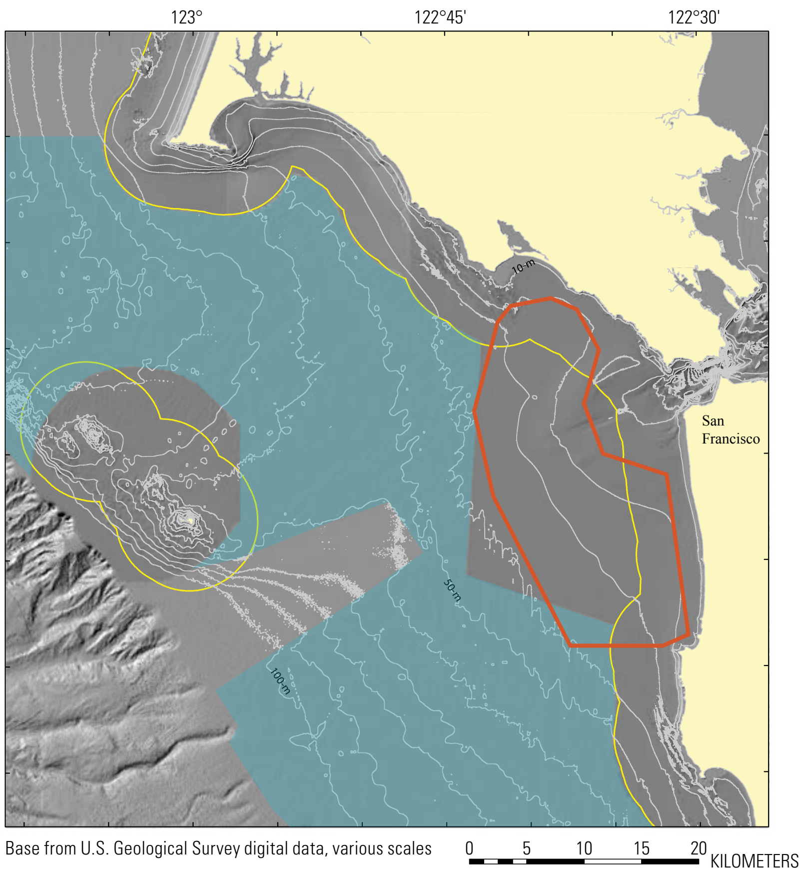


Figure 2. Shaded-relief bathymetry map of San Francisco Littoral Cell study area.

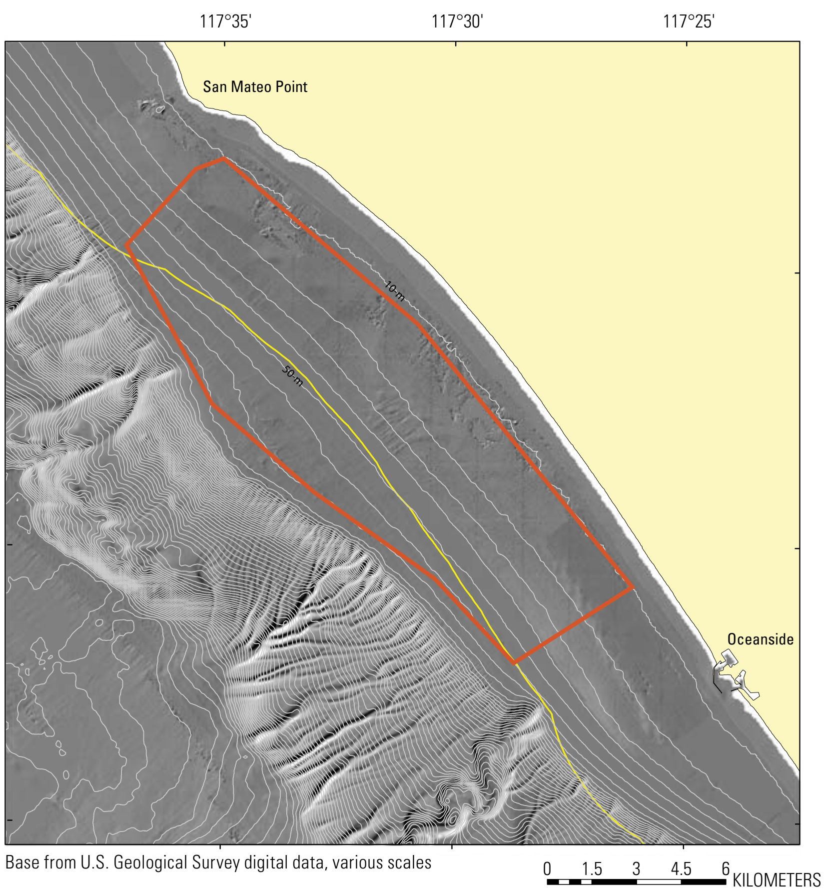


Figure 3. Shaded-relief bathymetry map of Oceanside Littoral Cell study area.

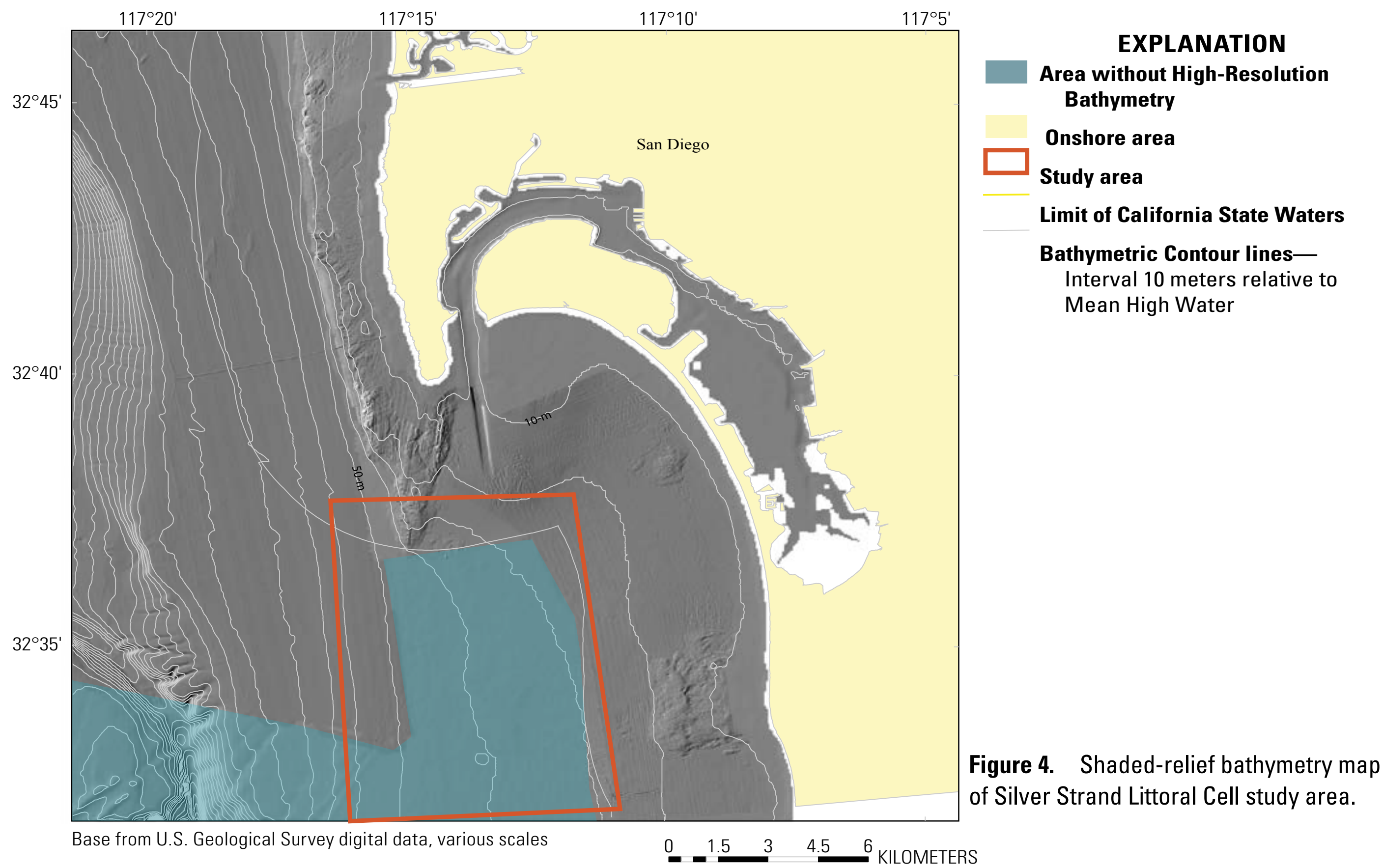


Figure 4. Shaded-relief bathymetry map of Silver Strand Littoral Cell study area.

Objectives

The primary objective of the Sand Resources Project is to produce maps for the study areas that contain the locations, thicknesses, and sediment grain-size information of sand and gravel deposits. To reach this goal, an early project task was to examine existing data to (1) assess the applicability of existing data to meet the project objectives and (2) provide information to the project partners about where new data collection may be the most useful. The synthesis task included examination, analysis, and summary of data, including high-resolution bathymetric maps, seafloor characteristics derived from multibeam acoustic-backscatter and interferometric-backscatter data, subbottom geophysical surveys, seafloor sediment-grab samples, and sediment cores. The results of this synthesis were included in a separate USGS open-file report (Warrick and others, 2022).

Following the synthesis of existing data, the project partners met to prioritize new data-collection activities. The goal of the prioritization was to identify survey areas that have the highest potential to result in significant resources of sand. On the basis of consensus among project partners, the USGS conducted new seismic-reflection surveys and coring in 2018 and 2019 to fill gaps in existing data across the study areas. These measurements included new high-resolution geophysical measurements, seabed-sediment samples, and sediment cores. As noted in the "Study Areas" section above, new measurements were focused on the San Francisco and Oceanside Littoral Cells, where thorough geophysical surveying and sediment coring was conducted. For the Silver Strand Littoral Cell, a more limited exploratory approach was taken with the geophysical surveying and coring.

Report Organization

This report is organized into introduction, methods, results, and discussion and conclusion sections. As noted above, the Sand Resources Project followed a two-stage work plan that included (1) the synthesis of existing data and (2) the collection and summary of new data. Because the data synthesis was conducted to inform and direct new data-collection activities, and because the new data collection consistently improved the maps of the study areas, the presentation of data synthesis methods and results was provided in a separate report (Warrick and others, 2022). Readers are directed to that report for further details on the first stage of this project.

This organization is intended to limit any potential confusion between the sediment-thickness maps and other results derived from existing data (presented in Warrick and others, 2022) and those derived from new data, which are presented herein. The new sediment-thickness maps provided in the "Results" section below are greatly improved from those derived from the existing data.

Methods

Three cruises were conducted to collect new geophysical data, sediment samples, and sediment cores in the study areas (fig. 5). In general, geophysical surveys were conducted first to identify regions of the seafloor draped with sediment, and then coring was conducted following these surveys. For the Oceanside Littoral Cell, this plan resulted in two separate cruises—an October 2017 geophysical and surface-sediment sampling cruise and a May 2018 coring cruise (table 1). The second cruise included a day of surveying and coring for the Silver Strand Littoral Cell (table 1). For the San Francisco Littoral Cell, it was determined that a combined geophysics and sediment-coring cruise using 24-hour operations would be more efficient and cost effective (table 1). The complete details of the new data collection, including survey tracklines,

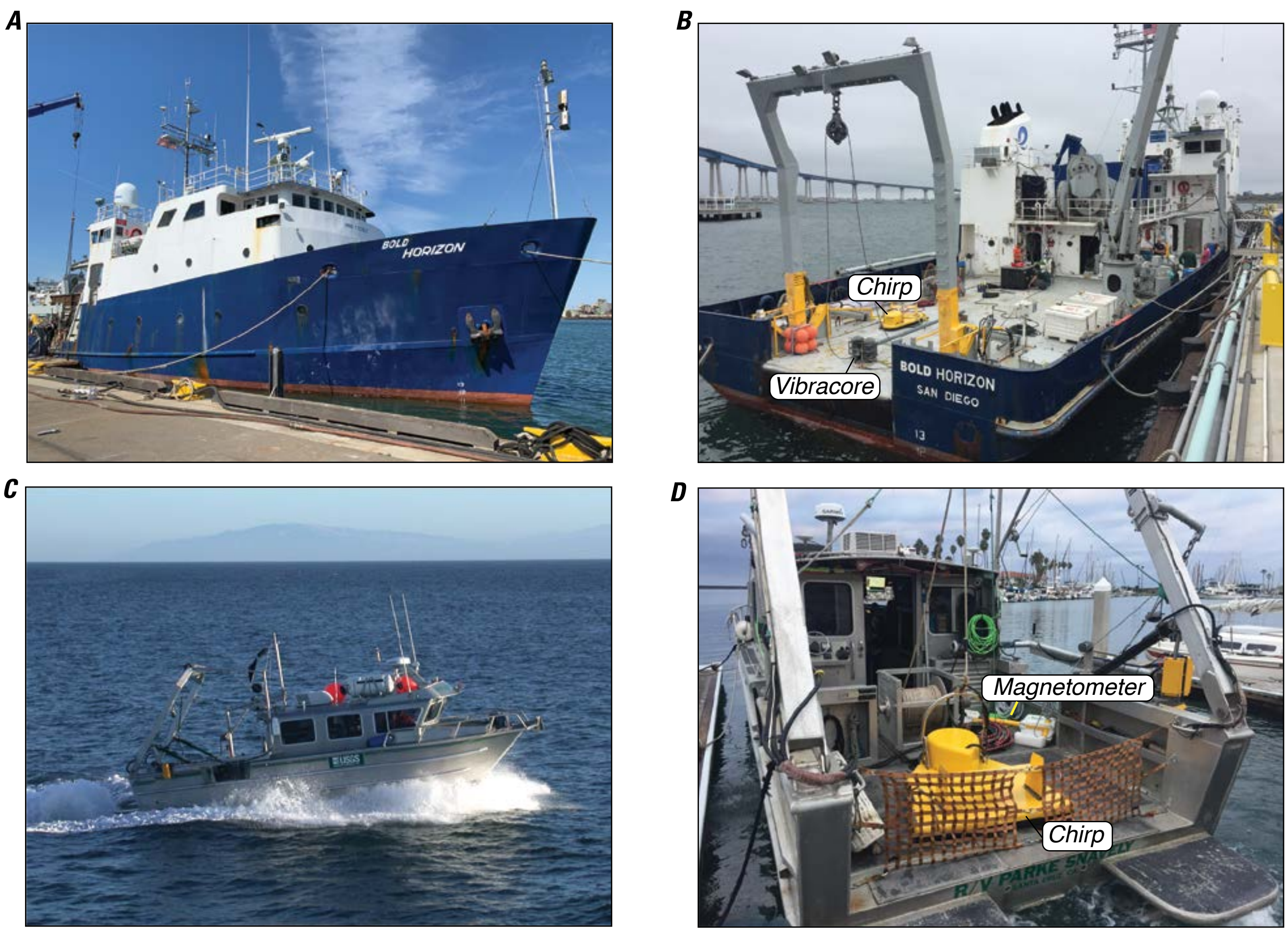


Figure 5. Photographs of research vessels used in Sand Resources Project. *A, B,* M/V *Bold Horizon*, 170-foot (ft) (51.8-meter [m])-long oceanographic vessel leased from Endurance Exploration Group. In *B*, U.S. Geological Survey (USGS) vibracore and chirp systems are shown loaded on fantail. *C, D*, USGS R/V *Parke Snavely*, 34-ft (10.4-m)-long aluminum-hulled catamaran. In *D*, USGS chirp and magnetometer systems are loaded on fantail. Photographs by: James Conrad, USGS, 2022.

Table 1. Summary of data-collection efforts for the Sand Resources Project in the San Francisco, Oceanside, and Silver Strand Littoral Cells.

[km, kilometer; M/V, motor vessel; no., number; R/V, research vessel; USGS, U.S. Geological Survey]

	San Francisco Littoral Cell	Oceanside Littoral Cell	Silver Strand Littoral Cell
	Geophysical cruises		
Date(s)	**Oct. 11–18, 2019**	**Oct. 23–31, 2017**	**May 26, 2018**
Vessel	M/V Bold Horizon	R/V Parke Snavely	M/V Bold Horizon
USGS field activity no.	2019-649-FA	2017-686-FA	2018-638-FA
Target line spacing	1 km along-shore, 1 km cross-shore	0.5 km along-shore, 1 km cross-shore	1 km along-shore, 3 km cross-shore
Total survey length	783 km	369 km	125 km
Data collected	Chirp seismic reflection, marine magnetic anomalies	Chirp seismic reflection, marine magnetic anomalies, and 23 sediment samples	Chirp seismic reflection, marine magnetic anomalies
	Coring cruises		
Date(s)	**Oct. 11–18, 2019**	**May 20–26, 2018**	**May 26, 2018**
Vessel	M/V Bold Horizon	M/V Bold Horizon	M/V Bold Horizon
USGS field activity no.	2019-649-FA	2018-638-FA	2018-638-FA
No. of cores in Federal Waters	19	24	6
No. of cores in State Waters	15	10	0
Total no. of cores	34	34	6

sampling and coring locations, and raw data from these activities, are available in USGS data reports for each field activity (Sliter and others, 2021a, b, c).

Geophysical-Data Collection

During the geophysical cruises, the USGS collected a combination of high-resolution seismic-reflection data using a towed chirp system and seafloor magnetic properties using a magnetometer. Geophysical data for the San Francisco Littoral Cell study area were collected from the motor vessel (M/V) *Bold Horizon* during an eight-day cruise (table 1; figs. 5, 6). These operations were carried out primarily during daylight hours, whereas sediment coring generally was conducted during the night. As a result of input from project partners, the San Francisco geophysical survey was carried out over a broad area north and south of the “San Francisco Bar,” which resulted in a nominal along-shore and cross-shore line spacing of 1,000 m (fig. 6). In total, 783 line-kilometers (423 nmi) of processed, high-resolution chirp seismic-reflection profiles were collected (fig. 6).

For the Oceanside Littoral Cell study area, geophysical data were collected from the USGS research vessel (R/V) *Parke Snavely* on survey lines extending in the along-shore and cross-shore directions (figs. 5, 7). Nominal line spacing was 500 m for the along-shore lines and 1,000 m for the cross-shore lines, which resulted in 369 line-kilometers (199 nmi) of processed, high-resolution chirp seismic-reflection profiles and magnetic data (table 1; fig. 7).

Lastly, geophysical-data collection was conducted on a limited number of transects in the Silver Strand Littoral Cell study area using the M/V *Bold Horizon* (fig. 8; table 1). This chirp survey totaled about 125 line-kilometers (67.5 nmi) of data collection, and survey lines were oriented perpendicular to the Silver Strand shoreline using nominal line spacing of about 1,000 m (fig. 8). Additionally, three shore-parallel lines were collected using an average spacing of about 3 km.

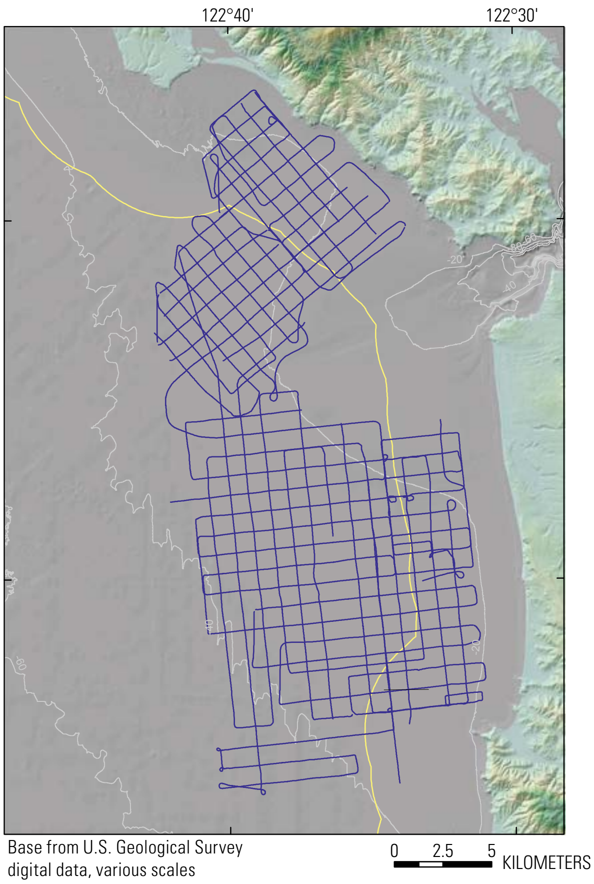


Figure 6. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing ship tracklines of geophysical surveys that included chirp and magnetometer measurements. See table 1 for details of cruises.

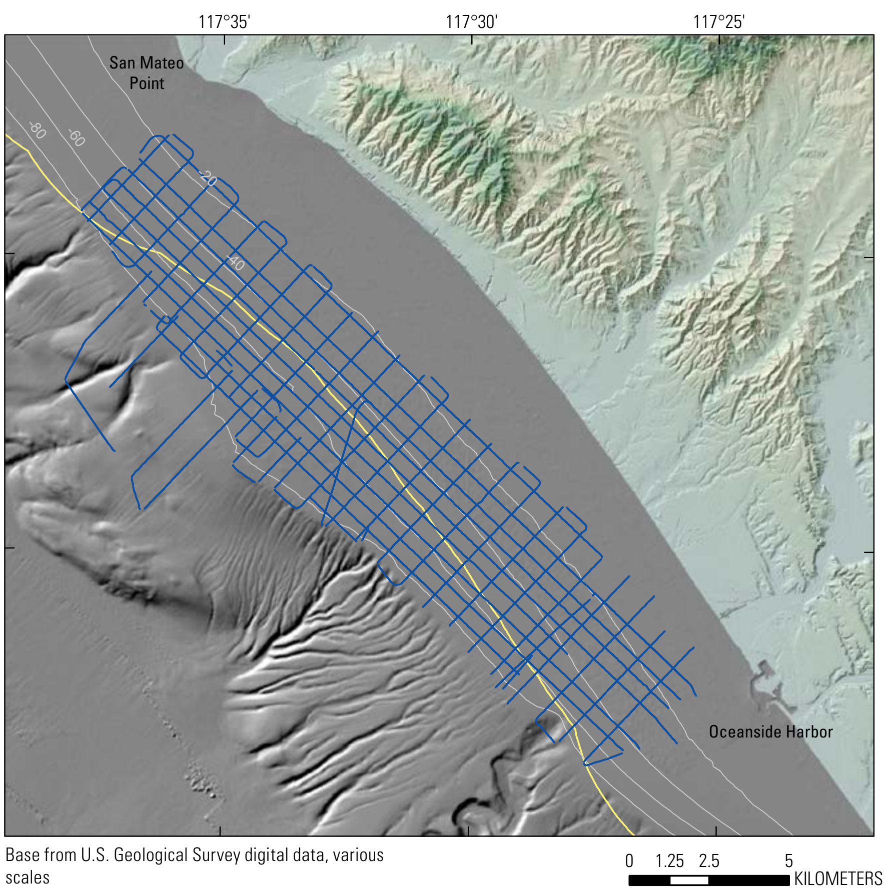


Figure 7. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing ship tracklines of geophysical surveys that included chirp and magnetometer measurements. See table 1 for details of cruises.

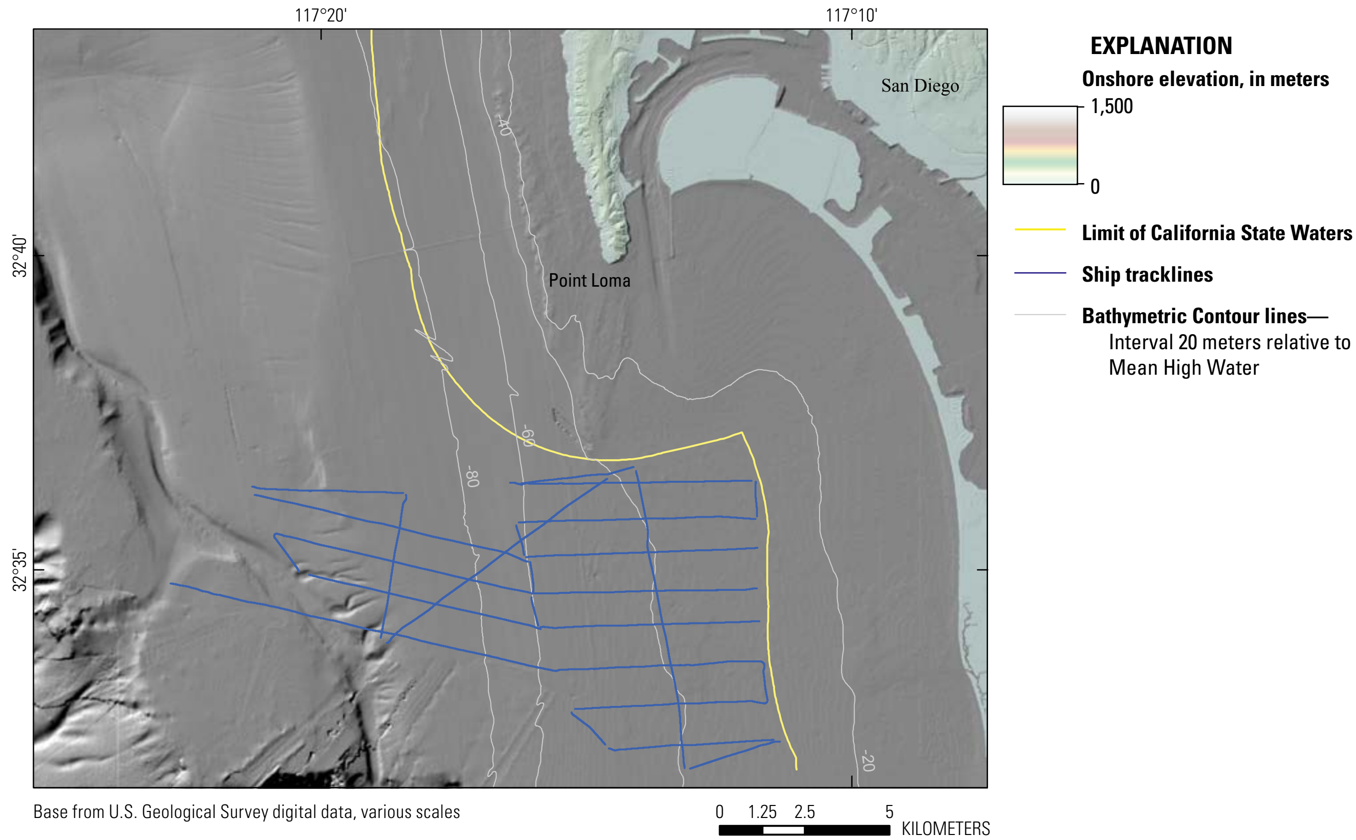


Figure 8. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing ship tracklines of geophysical surveys that included chirp and magnetometer measurements. See table 1 for details of cruises.

Chirp Seismic-Reflection Data

For all study areas, seismic-reflection profiles were collected using an Edgetech 512i chirp (Oceanside and Silver Strand Littoral Cells) or Edgetech 516 Chirp (San Francisco Littoral Cell) subbottom profiling system (fig. 5). These systems consist 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 was from 500 to 6,000 hertz (Hz), and data were recorded by hydrophones located on the bottom of the towed 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 were collected roughly every 1 to 2 m. The data consisted 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 were recorded in standard SEG-Y 16-bit integer format with 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 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 chirp fish.

Magnetometer

Seafloor magnetic properties were collected using a Geometrics G882 cesium-vapor marine magnetometer that was sampled once per second along the chirp survey tracks for the San Francisco and Oceanside Littoral Cells study areas (figs. 5, 6, 7). The magnetometer was operated simultaneously with the chirp subbottom profiling system for the efficiency of data collection. Raw measured magnetic values were converted into magnetic anomalies (in nanoteslas [nT]) by comparing with back-calculated total magnetic field values at a base station and the International Geomagnetic Reference Field (IGRF) values for each G882 measurement (Sliter and others, 2021a, c). Areas of lower and higher anomalies may be associated with either natural (geologic) or artificial characteristics of the seafloor, the latter of which may include wastewater outfalls, shipwrecks, or other metal objects, as noted in the “Results” section below. However, as noted in Sliter and others (2021c), the computations of the IGRF were compromised on two days of the San Francisco Littoral Cell survey, and approximations had to be made for the geomagnetic reference field during these survey times. These approximations introduce subtle mismatching in output values between survey days, although the overall patterns of higher and lower magnetic anomalies were preserved across the entire survey.

Processing and Interpretation of the Geophysics Data

Sediment-Thickness Maps

To map the thickness of the unconsolidated sediment on the continental shelf, seismic-reflection data were interpreted and integrated across each study area (fig. 9). Initial processing of the data was conducted to remove wave and swell artifacts in the data and to correct for chirp fish depth. The result of this preprocessing step was seafloor data that more closely followed the true bathymetry of the study area (fig. 9*B*). The digital seismic-reflection profiles were then loaded into an interactive seismic-interpretation software package, Kingdom Suite by IHS Markit, using the associated navigation data. The primary goal of the interpretations was to map subsurface horizons, which are geologic bedding surfaces that are defined by seismic reflectors and generally represent a change in sediment or rock properties across the boundary. Additionally, interpretations included locations of the seafloor and faults. These interpretations were conducted 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 is of the uppermost Pleistocene and Holocene, deposited since the last maximum sea-level lowstand about 21,000 years ago, and it is distinguished from underlying stratigraphic units by a transgressive erosional surface, below which is bedrock (fig. 9*C*). The unconsolidated sediment was defined by the horizons between the seafloor and the transgressive erosional surface.

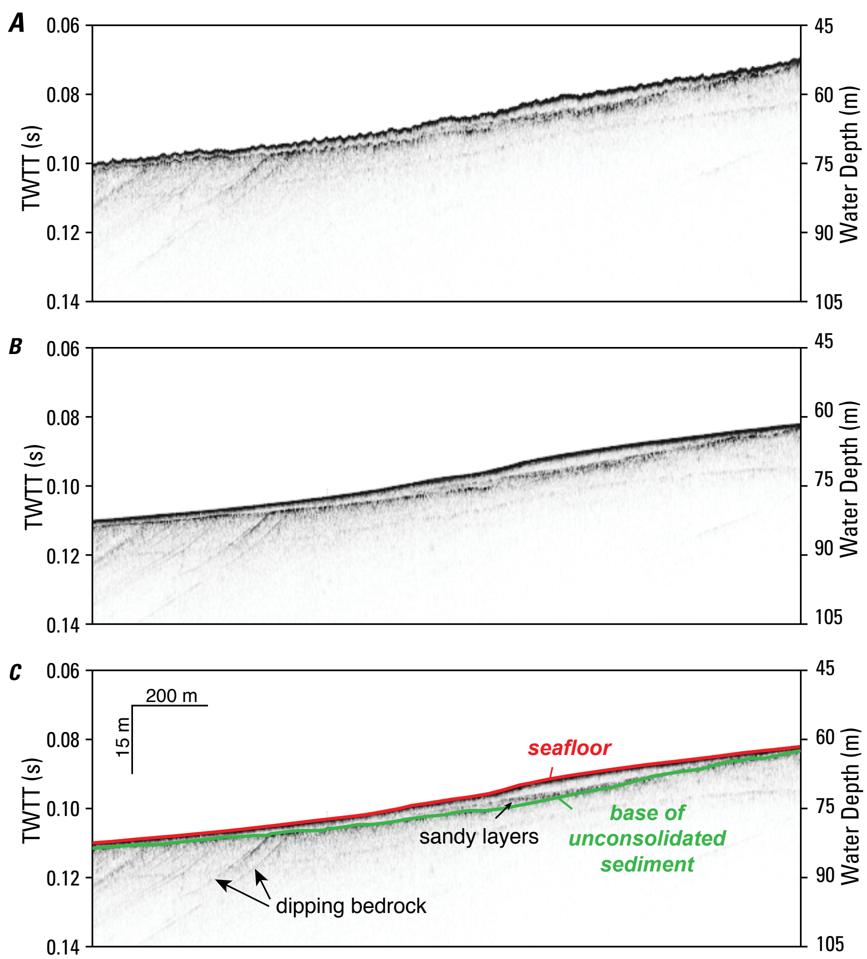


Figure 9. Seismic-reflection profiles showing examples of raw, processed, and interpretated chirp seismic-reflection data. Abbreviations: m, meter; s, second; TWT, two-way travel time. Note vertical exaggeration of profiles. *A*. Raw data. *B*. Processed data, after removal of wave artifacts and correcting for sensor depth. *C*. Interpreted data, showing measurement of sediment thickness from interpretated seafloor (red line) and base of unconsolidated sediment (green line).

Once the seismic-reflection profiles were interpreted, the TWT values were determined for each horizon. The differences in TWT between the upper and lower horizons of the unconsolidated sediment were calculated and converted to thicknesses (in meters) using a sediment acoustic velocity of 1,600 meters per second (m/s). These mapped sediment-thickness values were then exported with geographic coordinates 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. Maps of the unconsolidated sediment thickness, or isopach maps, were generated for all three study areas. The more widely spaced geophysical data collected for the Silver Strand Littoral Cell study area resulted in a less detailed map of unconsolidated sediments but was adequate to describe general sedimentary patterns in the area.

Seafloor Sampling

During the first cruise for the Oceanside Littoral Cell, sediment samples of shelf seafloor were collected at 23 locations using a Van Veen sediment sampler (fig. 10). The goal of this sampling was to provide general grain-size patterns of the seafloor surface in the study area because the existing sediment grain-size data were sparse (see Warrick and others, 2022, for a presentation of these data). Samples were collected along four shore-perpendicular transects spaced 5 to 9 km apart along previously collected seismic profile lines at depths ranging from about 20 to 80 m. An additional sample (BSS-06) on the outer shelf was collected to evaluate an area where sand occurrence was suspected on the basis of evaluation of the existing data (Warrick and others, 2022). Two duplicate samples (BSS-08) were collected at one location to evaluate local sample reproducibility.

Sediment grain-size analyses were conducted at the USGS Sediment Laboratory in Santa Cruz, Calif., by digesting organics with hydrogen peroxide, computing total organic carbon, removing soluble components with deionized water, and wet sieving through 2-millimeter (mm) and 63-micrometer (µm) sieves to isolate the gravel (>2 mm), sand (63 µm to 2 mm), and mud (<63 µm) sediment fractions. The dry sediment fractions were then weighed, and particle-size distributions were measured using a Beckman Coulter LS230 laser diffraction particle-size analyzer that produces quarter-phi increment results (figs. 11*C*, *D*). Results of these analyses for the surface samples of the Oceanside Littoral Cell were provided in Sliter and others (2021a).

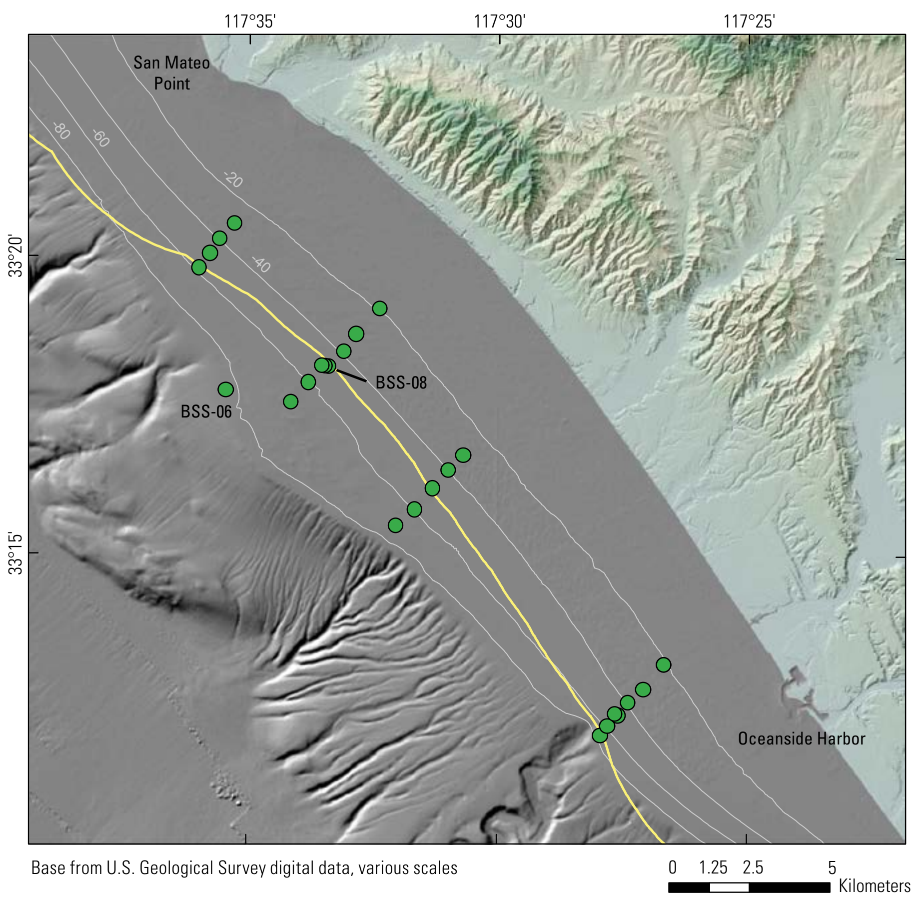


Figure 10. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing locations of surface sediment-grab samples. Sample collection was undertaken during geophysical cruise, owing to limited amount of existing data in region (see Warrick and others, 2022).

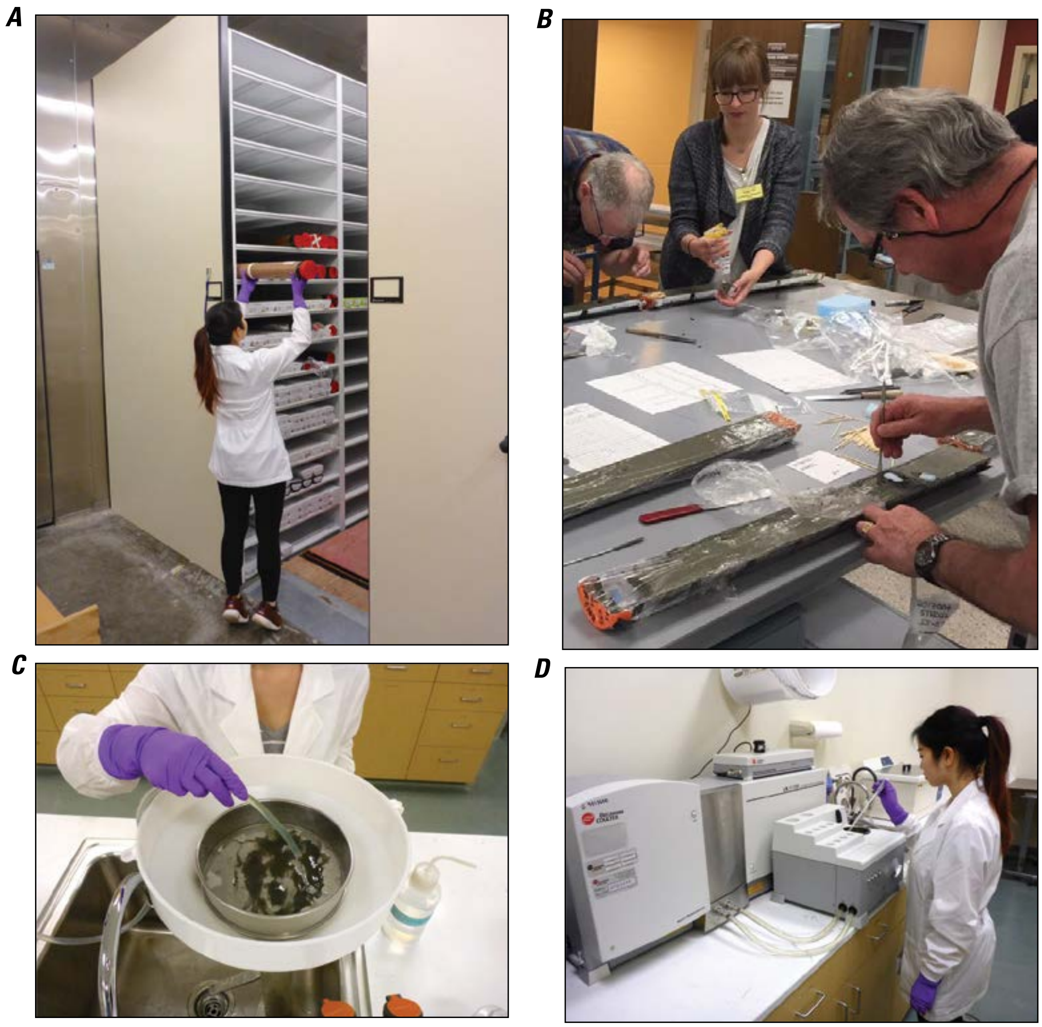


Figure 11. Photographs of core-sampling and sediment-analysis activities at U.S. Geological Surveys laboratories in Santa Cruz, Calif. *A*, Cold storage of sediment cores. *B*, Describing split cores and sampling for sediment properties. *C*, Wet sieving to isolate sand grains from fine-grained sediment. *D*, Performing grain-size analyses using Beckman Coulter LS230 laser-diffraction particle-size analyzer. Photographs by, Rex Sanders USGS, 2022.

Sediment Coring

Shallow coring was conducted at each study area using a 5-m vibracore system to evaluate sediment properties with depth in each study area (figs. 12 to 15). The Rossfelder P-5 vibracorer system included an electric percussive system and a 7.6-centimeter (cm)-diameter steel core barrel equipped with a plastic core liner and core catcher. During coring operations, the ships were stationed to maintain position as a hydraulic crane deployed and recovered the coring rig. Following recovery, the core liner was removed from the core barrel; the bottom of the core liner was capped with a plastic cap; water was drained from the top of the core liner above the sediment-water interface; and lastly, the core liner pipe was cut at this interface and capped. Each core was stored upright in the ship's walk-in refrigerator.

Coring for the three study areas was conducted during two cruises. For the San Francisco Littoral Cell, coring was conducted using the M/V *Bold Horizon* from October 11 to 18, 2019 (table 1). A total of 34 cores were obtained north and south of the "San Francisco Bar" (fig. 13). The cores obtained north of the bar were focused near the thick sediment accumulations in the San Andreas graben. The remaining cores were obtained in gridlike patterns that were coincident

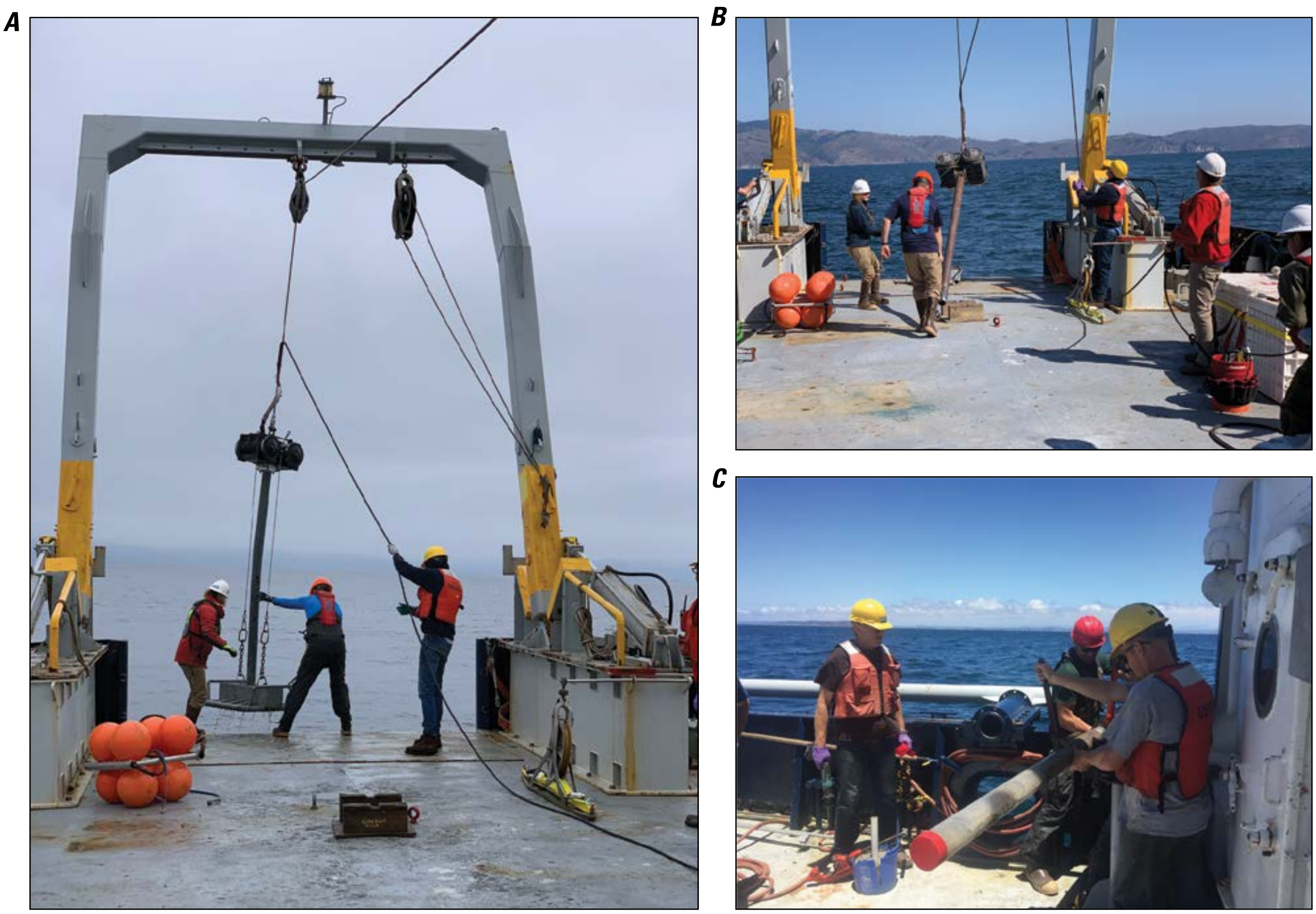


Figure 12. Photographs of vibracoring operations by U.S. Geological Survey from M/V *Bold Horizon*, showing assembly of vibracore system (*A*), deploying vibracore system (*B*), and cutting core liner from vibracore to preserve sample (*C*). Photographs by James Conrad, USGS, 2022.

with the geophysical survey lines and had along-shore and cross-shore spacings of 3 and 4 km, respectively (fig. 13). Most cores from the San Francisco Littoral Cell study area were obtained in water depths of 20 to 40 m; 19 cores were collected in Federal Waters, and the remaining 15 cores were collected in California State Waters (table 1; fig 13).

From May 20 to 26, 2018, the M/V *Bold Horizon* was used to collect sediment vibracore samples in the Oceanside Littoral Cell study area (table 1). A total of 34 cores from 32 sites were collected from the Oceanside Littoral Cell study area (fig. 14). Of these cores, 10 were collected in California State Waters, and 24 were collected in Federal Waters. Of the 24 cores on the Outer Continental Shelf, 17 were collected from depths less than about 60 m. Consistent with the surface-sediment samples collected in October 2017, most sampling sites were selected along seismic-reflection lines oriented perpendicular to the coast, typically with two or three cores per transect that had a general spacing of 2 km between sampled transects (fig. 14). In several places, several closely spaced vibracore samples were collected in areas of unusual or interesting sedimentary features identified on the seismic-reflection profiles. Average core collection length was about 135 cm, with a maximum collection length of 225 cm.

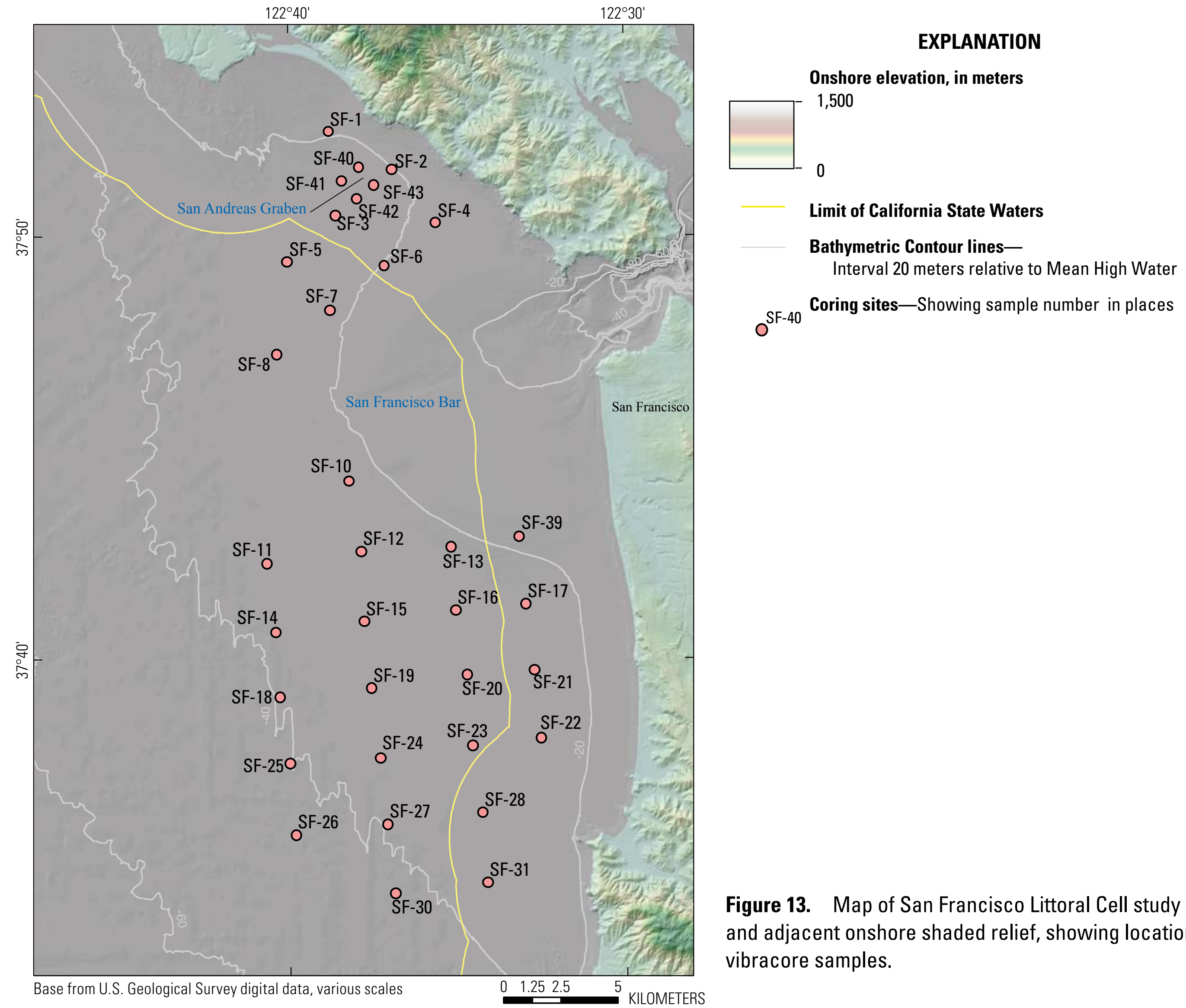


Figure 13. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing locations of vibracore samples.

Six vibracores also were collected in the Silver Strand Littoral Cell study area (fig. 15). All were sited along newly collected chirp profiles. Four coring sites were located along the east edge of the area surveyed, just outside of California State Waters, at a depth of about 25 m. Two core sites were located farther offshore in sediments identified by the chirp surveys in water depths of about 55 m. Average core length collection was about 125 cm.

Sediment Core and Sample Analyses

Vibracores were processed in the USGS Core Laboratory in Santa Cruz, Calif., where they were logged for physical properties, split in half lengthwise, photographed, described, and subsampled for sediment grain-size analyses (fig. 11). Physical properties of the cores were logged with a Geotek Multi-Sensor Core Logger (MSCL), which measured P-wave velocity, gamma-ray sediment density, and (or) magnetic susceptibility, depending on the functionality of the equipment, at intervals of 1 cm. All cores were photographed using a Geotek GeoScan V line-scan imaging system at resolutions of 10-µm pixel widths. Polarizing filters on the camera lens and the LED lamp lights were used to reduce glare effects from the wet split cores. The photographs included a composite ruler, and the camera was calibrated for color balance before each use.

Following data collection with the MSCL and imaging systems, all cores were visually described and manually sampled for sediment-laboratory measurements. Visual descriptions included Munsell color, the location and type

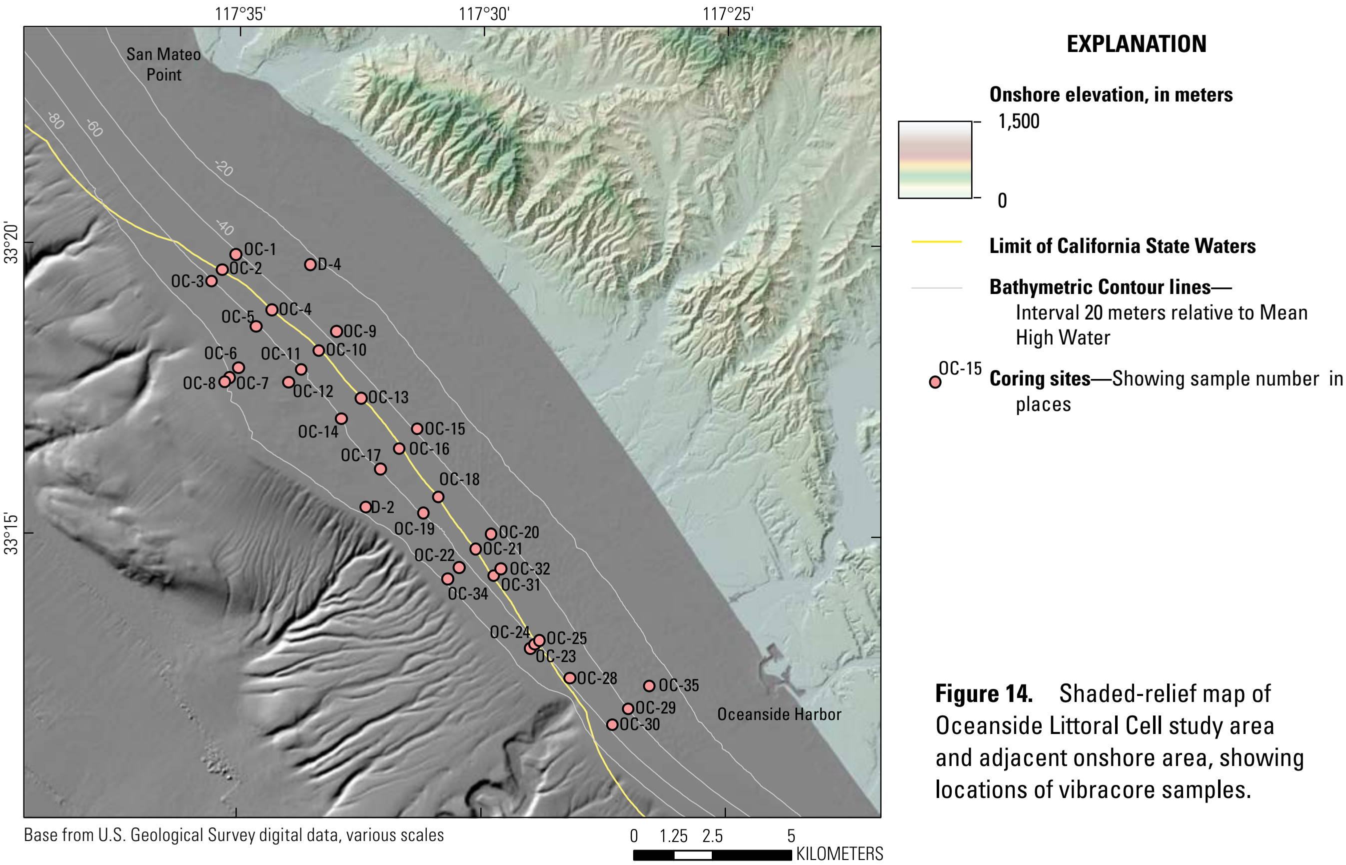


Figure 14. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing locations of vibracore samples.

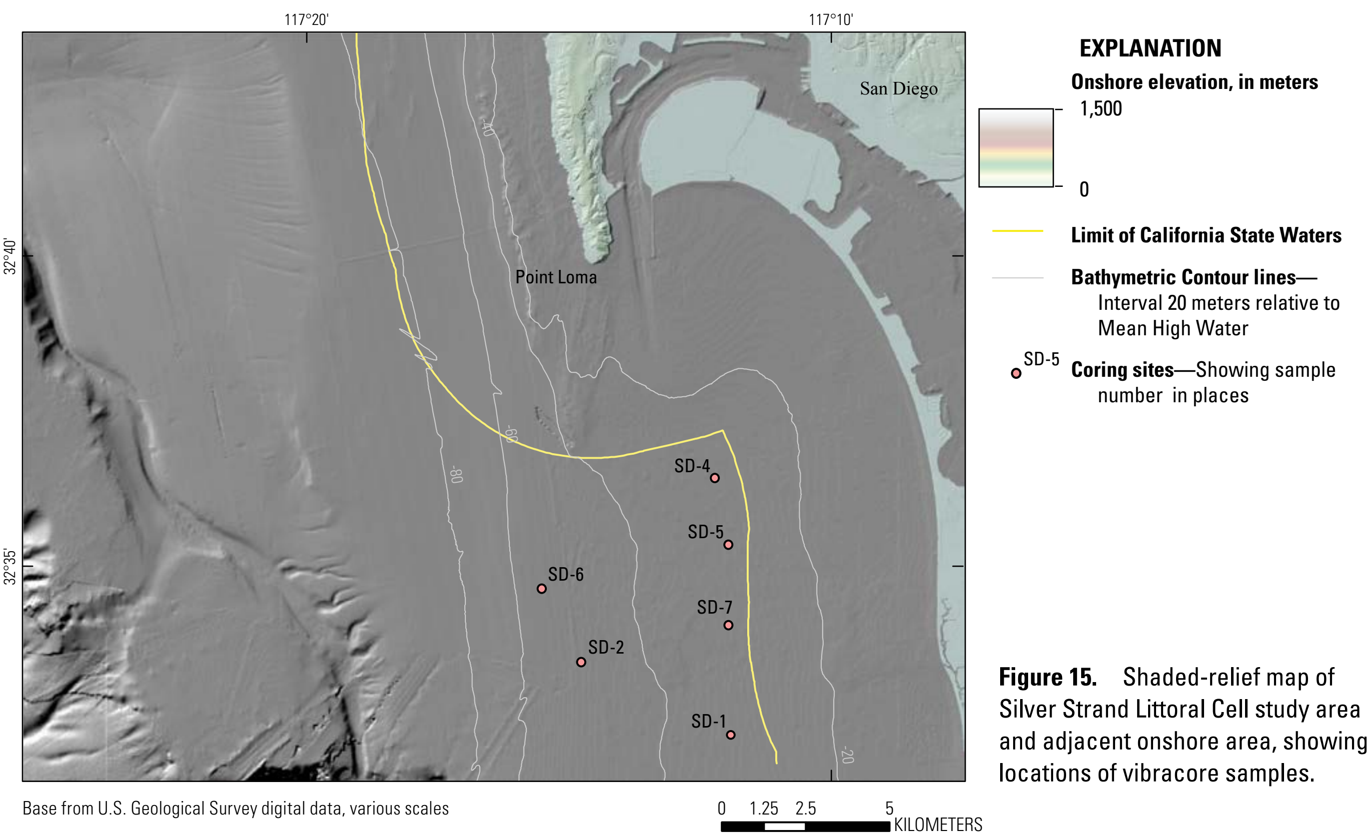


Figure 15. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing locations of vibracore samples.

of structural features (including animal burrows, bedding, erosional contacts, mottling, organic materials, and shell fragments), and an approximate sediment grain-size class that was based on manual manipulation of the sediment. Sediment samples were then obtained within each core at several locations, including near the sediment-water interface and at depth to characterize the overall grain-size patterns in the core.

The sediment samples from the vibracores were analyzed at the USGS Sediment Laboratory in Santa Cruz, Calif., using the same techniques described above for surface-sediment samples. In addition, some sediment samples were photographed using a microscope camera to reveal grain-size and -shape patterns at granular scales. Results of the grain-size analyses are presented for individual samples within the core and also as core-averaged results. Lastly, the remaining core materials from these activities were preserved and cold-temperature archived at the USGS Pacific Coastal and Marine Science Center, Santa Cruz, Calif., where they can be examined and sampled for additional analyses, if necessary.

Results

San Francisco Littoral Cell

Historical data collection in the San Francisco Littoral Cell, which included several geophysical surveys, provided evidence that sediment thicknesses exceed tens of meters just offshore of the mouth of San Francisco Bay, but then thin with distance from the bay mouth (Warrick and other, 2022). Much of the “San Francisco Bar” and the sediment within the Golden Gate was determined to be sandy, and the coarsest sands were found generally between the Golden Gate and the crest of the bar (Warrick and others, 2022; see also, Barnard and others, 2013a). However, owing to the important role that the bar plays in wave attenuation and the overall coastal sediment budget of the region, the Sand Resources Project’s expert panel[1] concluded that new data collected during this second phase of the project should focus on sediment north and south of the bar rather than in the well-studied and highly managed area immediately around the bar. Thus, the new high-resolution data collected during the second phase provide new insights about the distribution and patterns of sediment north and south of the “San Francisco Bar” (figs. 6, 13).

The chirp geophysical data indicate a substantial variability in sediment thickness throughout the San Francisco study area, owing to the strong influences of the region’s faults and its overall tectonic setting. Two examples of chirp profiles highlight some of the general patterns observed north and south of the “San Francisco Bar” (fig. 16). In the northern profile (sample no. SF-59A; fig. 16*B*), sediment is thickest inshore of the San Andreas Fault. The San Andreas Fault provides a distinct boundary between an area that has sediment thicknesses ranging from 3 to 5 m (the deposit thickens rapidly to the southeast) and an offshore area that has a negligible amount (less than 1 m) of sediment (fig. 16*B*). In contrast, the southern chirp profile (sample no. SF-20; fig. 16*C*) reveals that sediment thicknesses are negligible in the inshore area until a break in the seafloor slope. Offshore of this slope break, the sediment ranges in thickness from a few meters to approximately 10 m, and a distinct change in thickness is seen at the San Gregorio Fault where about 2 to 4 m of offset is observed at the base of the unconsolidated sediment.

The resulting San Francisco Littoral Cell isopach map, derived from integration of the complete set of chirp measurements, indicates that the sediment thicknesses vary greatly from negligible (<1 m) to more than 60 m (fig. 17). The thickest areas of sediment generally follow a north-south-trending axis that is defined by the region’s major faults, the San Gregorio, San Andreas, and Golden Gate Faults (fig. 17). The abundant sedimentation between these faults is consistent with the tectonic history of the region in which subsiding grabens are present in the blocks between these faults (Ryan and others, 2008).

Offshore of the graben-focused sedimentation and the “San Francisco Bar,” sediment thicknesses decrease markedly. For example, offshore of the 20-m bathymetric contour, the sediment generally thins from 5 to 10 m to only a few meters (fig. 17). Exceptions to this pattern lie only within the fault-bounded areas immediately north and south of the bar. Sediment is especially thin in the southern part of the study area in California State Waters where thicknesses approach 0 to 2 m in some inshore areas (fig. 17), which is consistent with the seismic profile shown in figure 16*C*. Much of the area of thinner sediment outside of the graben and the “San Francisco Bar” ranges in thickness from several meters to 10 m (fig. 17).

Magnetic anomalies in the San Francisco Littoral Cell generally are moderate throughout the study area, and the highest values were measured in the southern and inshore parts of the study area (fig. 18). One of these high anomalies lies southeast of San Francisco’s Oceanside Water Pollution Control Plant near the 7.2-km-long outfall pipeline (fig. 18). High magnetic anomalies in this area may be associated with the outfall infrastructure, magnetic properties of constituents in the wastewater plume or sediment deposit, or other materials on or under the seafloor at this area. A southern area of high magnetic anomalies is about 3 km long and trends in the northwest-southeast direction, offshore of the City of Pacifica (fig. 18). Examination of the existing high-resolution bathymetry and associated mapping products by the USGS, however, shows no evidence of artificial structures, shipwrecks, or other materials exists in this location (Edwards and others, 2014). Rather, the southern area of anomalously high magnetic anomalies may be associated with underlying mafic rocks that are observed onshore and similarly lie in a northwest-southeast-trending orientation (Edwards and others, 2014).

Sediment coring for the San Francisco Littoral Cell study area focused on areas north and south of the “San Francisco Bar” (fig. 13), owing to the existing understanding of the bar and the unique role the bar plays in the oceanography and

[1] A list of members of the expert panel is provided in the “Acknowledgments” section.

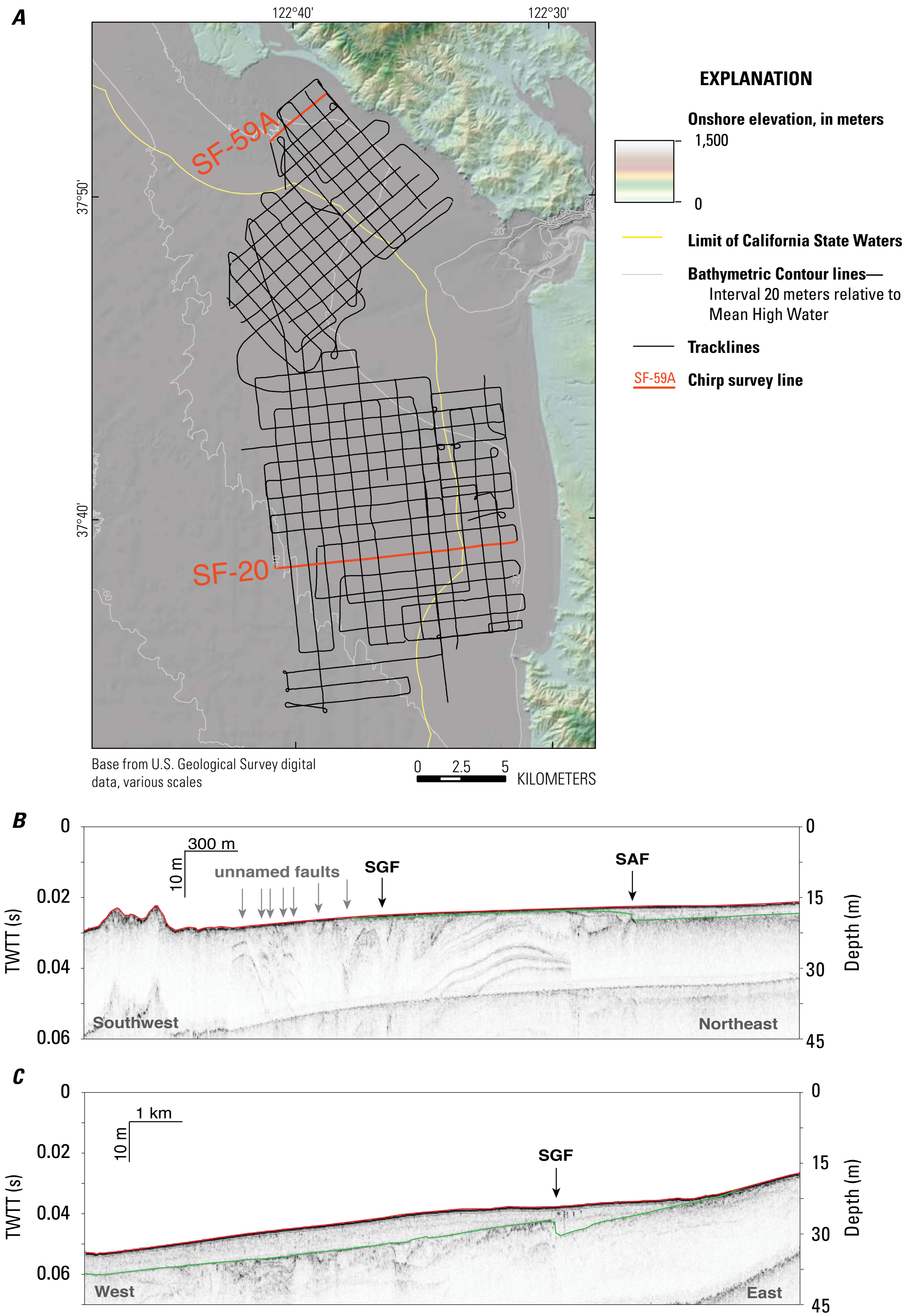


Figure 16. *A*, Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing tracklines of chirp seismic-reflection profile surveys. Tracklines of seismic-reflection profiles SF-59A and SF-20 highlighted in red. *B*, Seismic-reflection profile SF-59A. *C*, Seismic-reflection profile SF-20. Faults: SAF, San Andreas Fault; SGF, San Gregorio Fault. Other abbreviations: km, kilometer; m, meter; s, second; TWT, two-way travel time. In profiles, red lines highlight seafloor. Note vertical exaggeration of profiles.

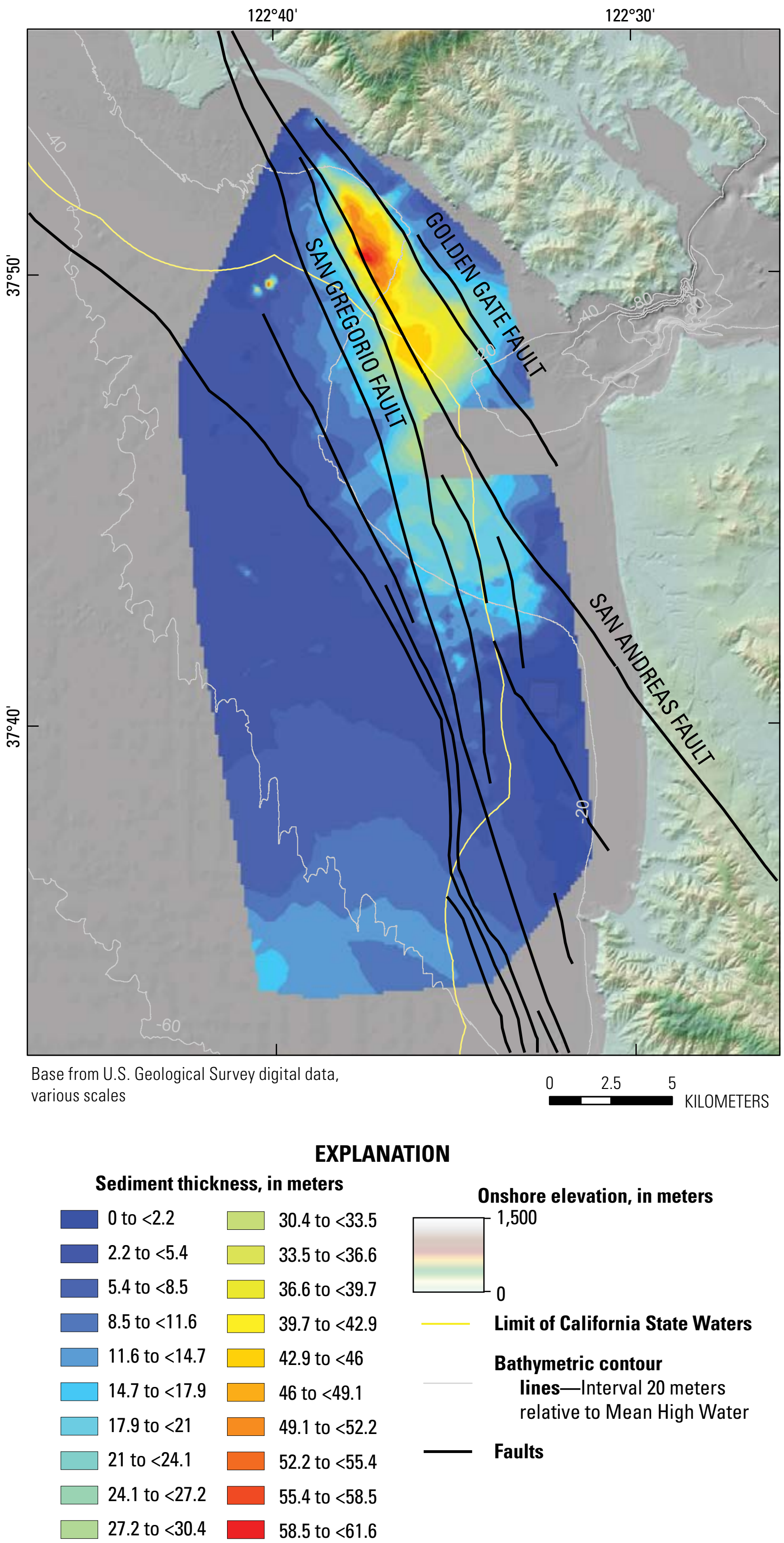


Figure 17. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing sediment thickness from geophysical data acquired during Sand Resources Project. Regional faults (Golden Gate Fault, San Andreas Fault, and San Gregorio Fault) shown to highlight tectonic control on sedimentation.

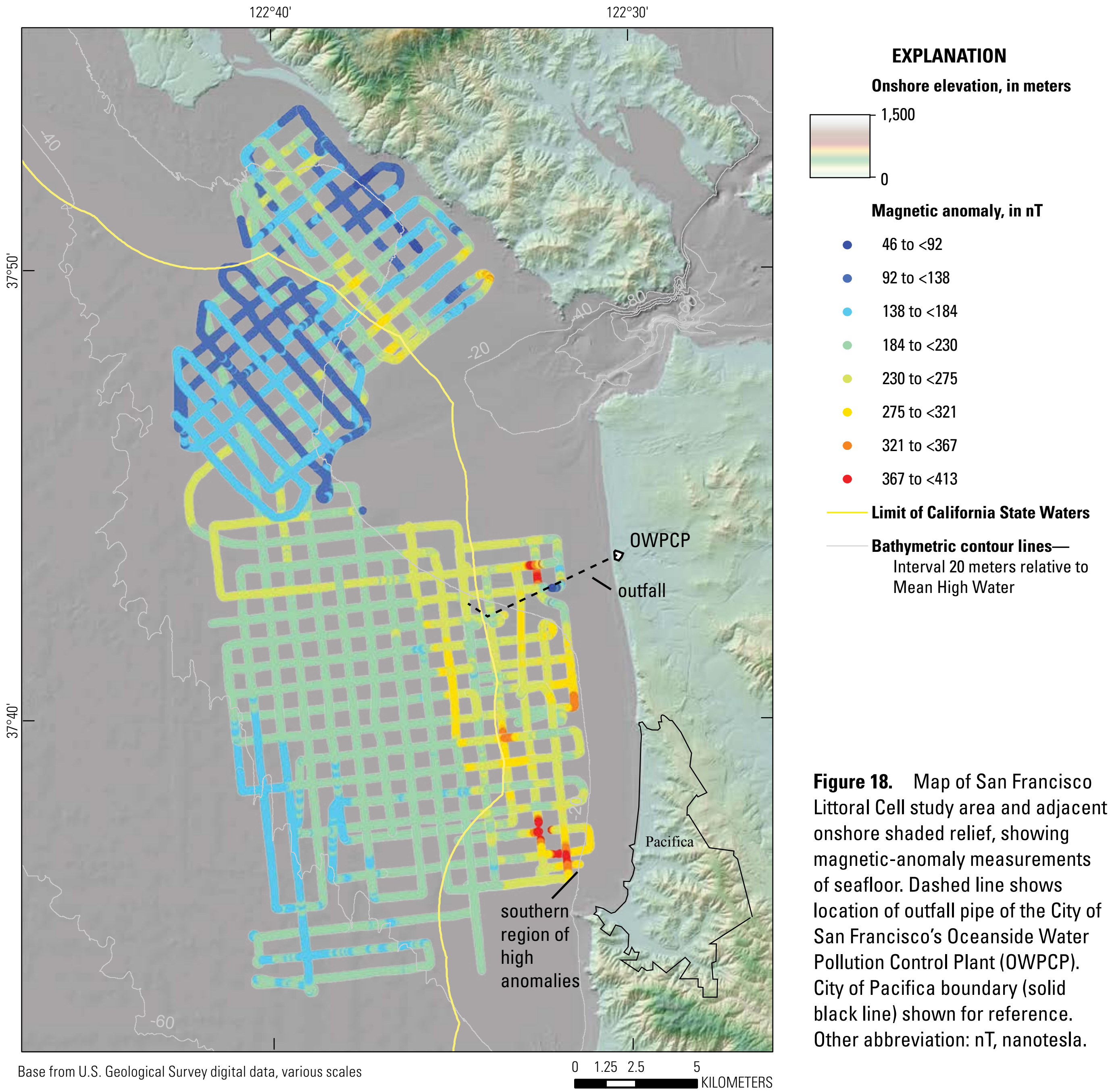


Figure 18. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing magnetic-anomaly measurements of seafloor. Dashed line shows location of outfall pipe of the City of San Francisco's Oceanside Water Pollution Control Plant (OWPCP). City of Pacifica boundary (solid black line) shown for reference. Other abbreviation: nT, nanotesla.

seafloor morphology of the area. The integrated mean grain size of the sediment is largely an inverse function of distance from the bar, with the coarsest sediment lying near the bar and the finest sediment away from the bar (fig. 19). This is consistent with the general grain-size patterns provided in the historical surface samples (Warrick and others, 2022) and other sediment-sampling work that has focused on the bar (Barnard and others, 2012, 2013a).

Most mean grain sizes of the vibracore samples are classified as very fine sand (63 to 125 micrometers [µm]; fig. 19), which generally is finer than the littoral cut-off diameter of about 125 µm for the Ocean Beach, San Francisco, area as reported by Limber and others (2008). This does not mean that no beach-comparable sediments are present at these areas. On the contrary, between 25 and 50 percent of the sediment mass of most of these very fine sand samples

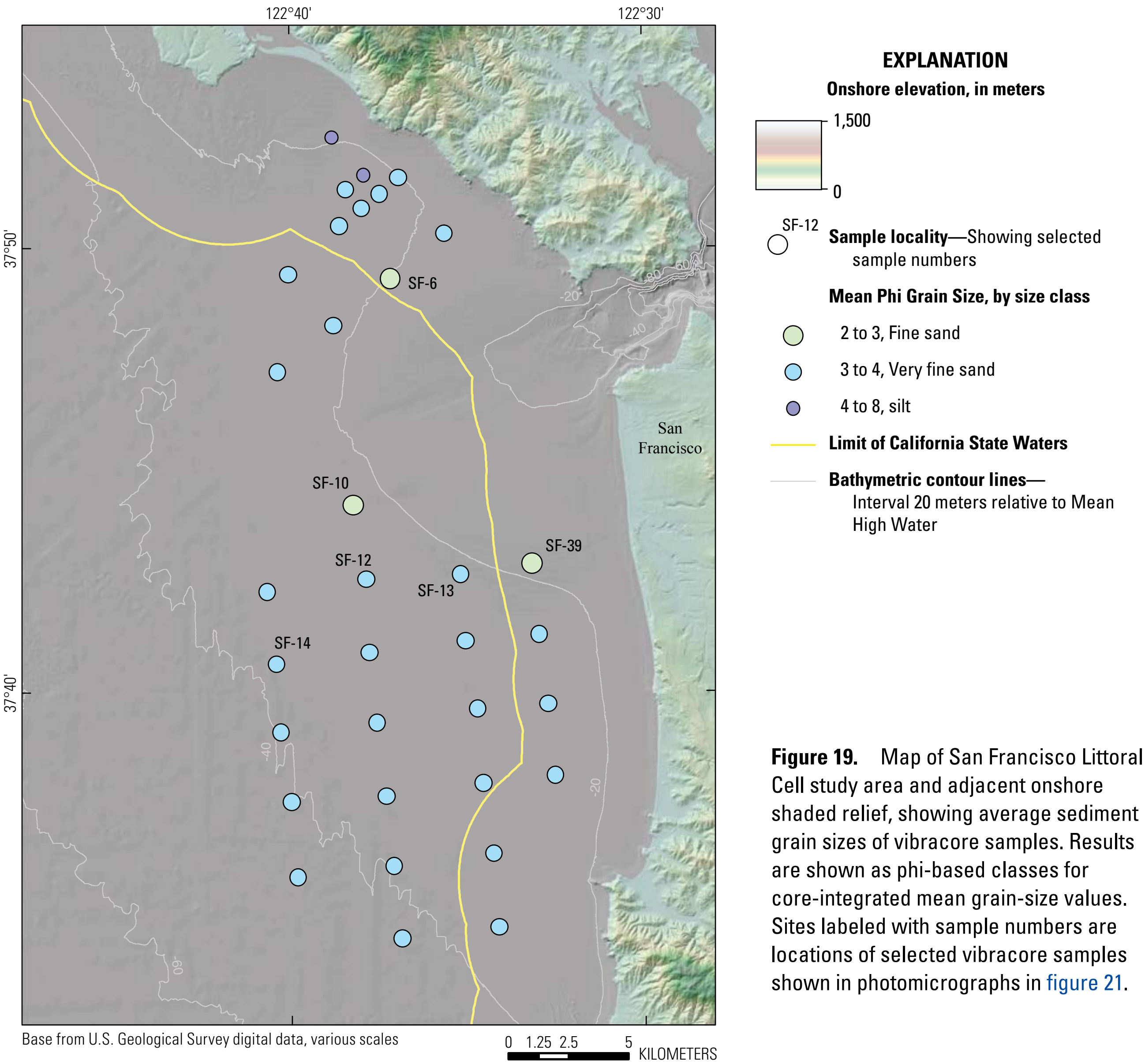


Figure 19. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing average sediment grain sizes of vibracore samples. Results are shown as phi-based classes for core-integrated mean grain-size values. Sites labeled with sample numbers are locations of selected vibracore samples shown in photomicrographs in figure 21.

is greater than the 125-µm (or 3-phi) size threshold (Sliter and others, 2021c). However, the sediments from these areas also are generally 5 to 20 percent fine sediment (silt and clay; < 63 µm) by mass, which is a function of their moderate sorting. Three sites (sample nos. SF-6, SF-10, and SF-39) had mean grain sizes classified as fine sand (125–250 µm), and these sites are consistently located on the outer part of the bar in water depths of about 20 m (fig. 19). Sediments from these three sites are similarly moderately sorted; they have between 50 and 75 percent of their sediment mass greater than 125 µm and 5 to 10 percent fine sediment (silt and clay; <63 µm) by mass (Sliter and others, 2021c).

The total organic content (TOC) of these vibracore samples generally was a function of distance from the “San Francisco Bar,” and the highest integrated values (0.25–0.75 percent) are in samples farthest from the mouth of bar (fig. 20). The site that has the highest mean value (SF-1, the northernmost site) also has consistently high values down core, where three samples were obtained between 0.511 and 0.767 percent TOC; the second value is the highest measured

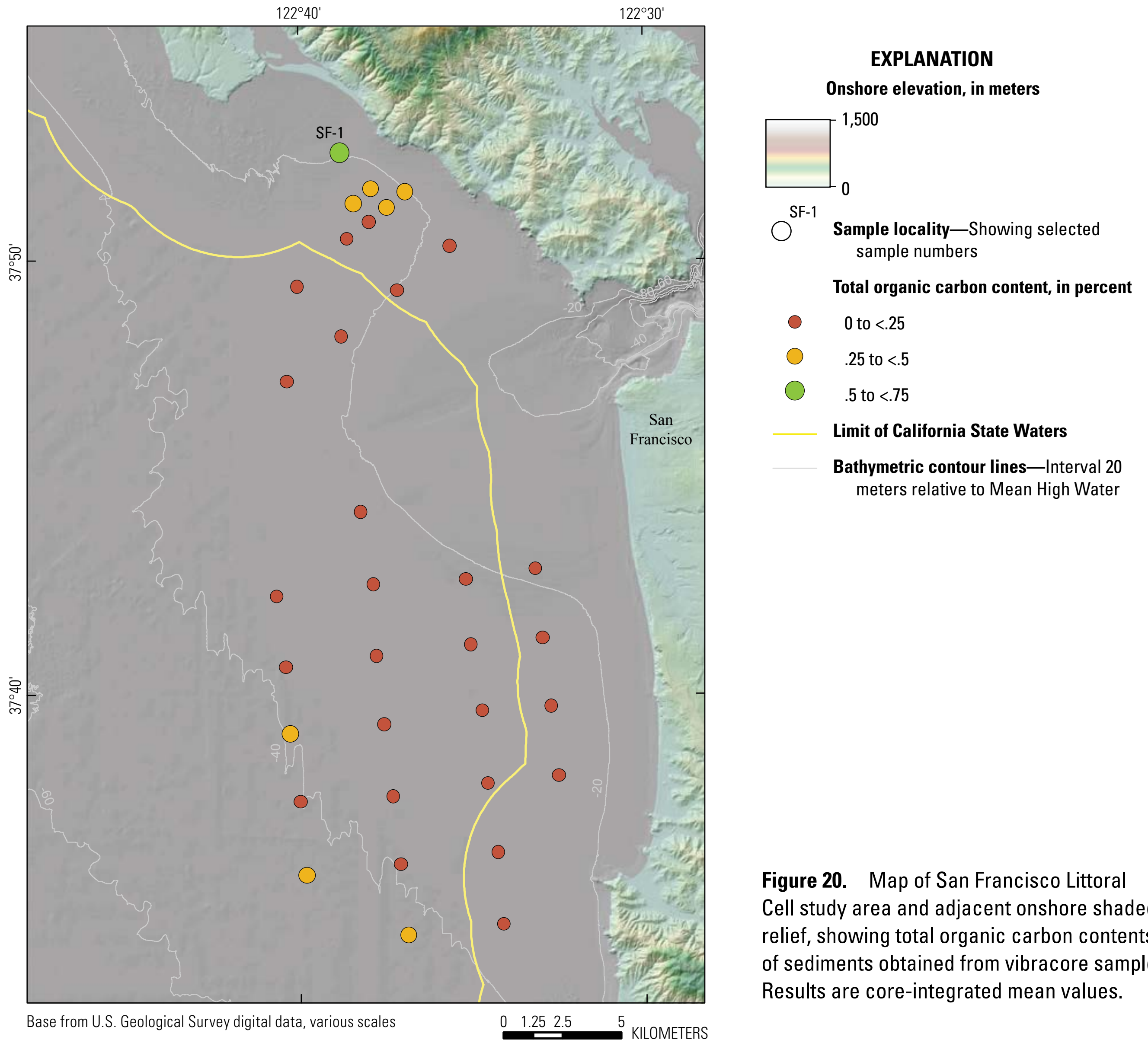


Figure 20. Map of San Francisco Littoral Cell study area and adjacent onshore shaded relief, showing total organic carbon contents of sediments obtained from vibracore samples. Results are core-integrated mean values.

value from the San Francisco Littoral Cell study area. As noted in the "Discussion and Conclusions" section below these TOC values are inversely related to sediment grain size.

Photomicrographs of the San Francisco Littoral Cell vibracore samples provide additional information about the grain colors, shapes, and mineralogy of these sediments (fig. 21). Three photomicrographs show that the samples are composed of light- to medium-gray, subrounded to subangular, very fine sand (fig. 21): the samples consist of clear quartz grains, minor amounts of biotite, and minor amounts of colorful lithic fragments (sample no. SF-12); feldspars and colorful fragments of red chert and green grains that resemble jadeite (characteristic of blocks in mélange of the Franciscan Complex) (sample no. SF-13); and feldspars and other lighter colored phyllosilicate minerals and other colorful lithic fragments (sample no. SF-14).

Further details about the San Francisco Littoral Cell sediments are provided in core logs and associated core data (appendix 1). In general, data from these cores suggest that the sediment properties are relatively uniform with depth in

***A.* Vibracore SF12 at 139-141cm**

Mean = 103 *µm* (very fine sand)
Sorting = 0.745 *phi* (moderately sorted)

***B.* Vibracore SF13 at 50-52cm**

Mean = 96 *µm* (very fine sand)
Sorting = 0.897 *phi* (moderately sorted)

***C.* Vibracore SF14 at 50-52cm**

Mean = 76 *µm* (very fine sand)
Sorting = 0.810 *phi* (moderately sorted)

Figure 21. Photomicrographs of example sediments from selected vibracore samples in San Francisco Littoral Cell (see fig. 19 for locations), showing vibracore sample number and distance along core, as well as sample mean grain size, sorting, and associated grain-size class of sediments. *A*, Sample SF-12, at 139–141 centimeters (cm). *B*, Sample SF-13, at 50–52 cm. *C*, Sample SF-14, at 50–52 cm. Abbreviations: cm, centimeter; mm, millimeter; µm, micrometer.

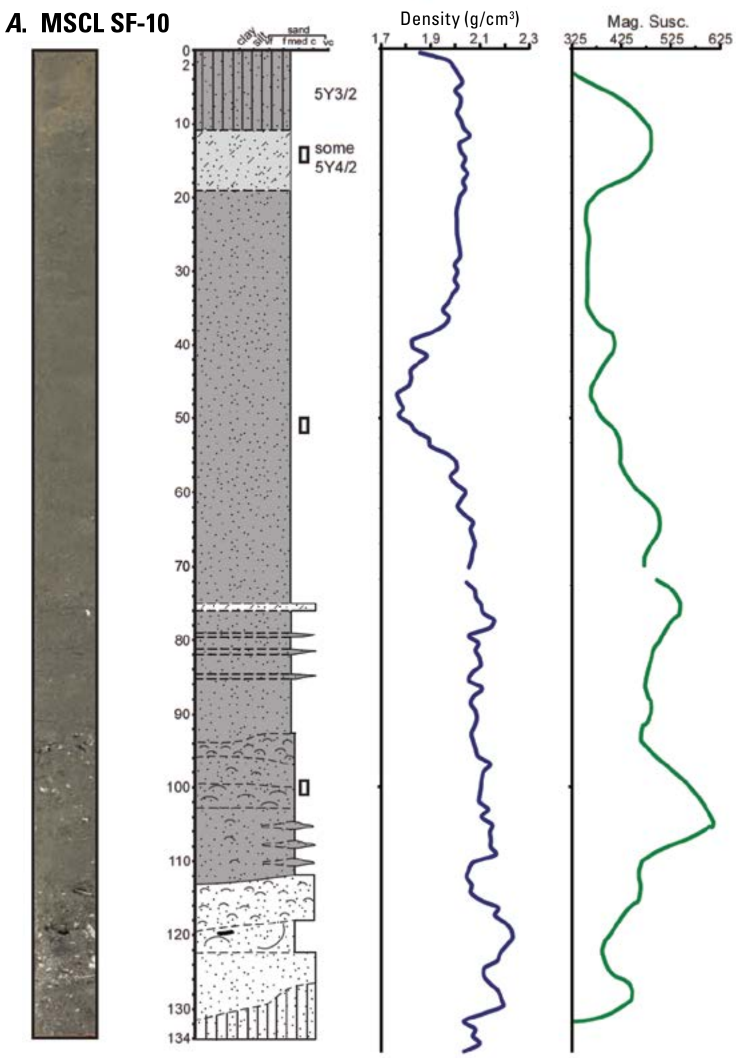
structure and texture. One of the cores that has the fine sand grain sizes (sample no. SF-10) is shown in figure 22*A*. This core is shown to have relatively uniform, silty sand sediment that transitions into sand at a depth of about 100 cm. These lower layers include shell fragments and represent a transition from mean grain sizes between 105 and 130 µm (very fine to fine sand) in the upper layers, to 178 µm (fine sand) at 100 cm, and to 344 µm (medium sand) in the core catcher, which represents depths of between 134 and 159 cm (Sliter and others, 2021c). Although several other cores have similar increases in grain size with depth (for example, sample nos. SF-19 and SF-22; appendix 1), several cores also indicate decreases in grain size with depth (for example, sample nos. SF-01, SF-02, SF-08, and SF-13; appendix 1). However, these grain-size changes generally represent transitions between only one phi-based size class (for example, fine sand to very fine sand), and no sand-deficient layers were found in any of the cores.

A unique core (sample no. SF-39) includes some of the coarser grain sizes sampled in the San Francisco Littoral Cell study area. The dark-gray-to-black sediment colors (5Y 2.5/2 and 5Y 2.5/1 for the Munsell system; fig. 22*B*) in this core show abundant mottling and provide evidence of oxygen-reducing conditions. This core also had foul organic odors in the surface layers. Combined with the location of this core near the outfall of the City of San Francisco's Oceanside Water Pollution Control Plant, strong evidence exists that this site has been influenced by sedimentation related to the wastewater outfall.

Oceanside Littoral Cell

The geophysical data of the Oceanside Littoral Cell study area indicate that sediment generally is present in lobes that range in thickness from 10 to 20 m, centered in the midshelf area. One cross-shore chirp profile reveals that these sediment deposits are thickest in the midshelf area and then thin in the onshore and offshore directions (fig. 23). A flat platform is present on the outer shelf near the shelf break that generally is constrained by two faults (fig. 23). This platform is observed to be bare of sediment, as is shown in the geophysical profile in figure 23*B*, which is a common observation for most of this flat platform. However, toward the northwest end of the platform, sediment thicknesses exceed several meters (fig. 24).

The isopach map derived from the integration of the chirp data measurements indicates that the Oceanside Littoral Cell study area has several lobes of sediment deposition in the midshelf area that are centered at water depths of about 40 m and extend from depths of less than 20 m to about 70 to 80 m (fig. 24). The thickest area of midshelf sediment is in the southernmost part of the study area, which is offshore of the mouth of the Santa Margarita River (fig. 24). This deposit reaches thicknesses of about 30 m and thins to less than 10 m toward the northwest, although it was not fully constrained on the southeast side. A second lobe of midshelf sediment that extends across an area of about 5 km in the along-shore



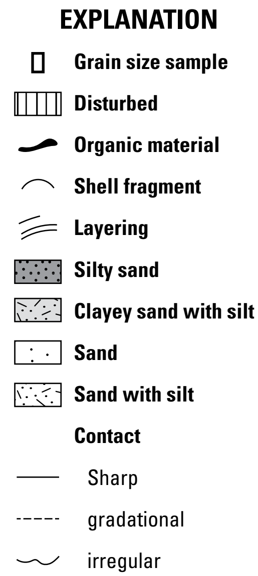
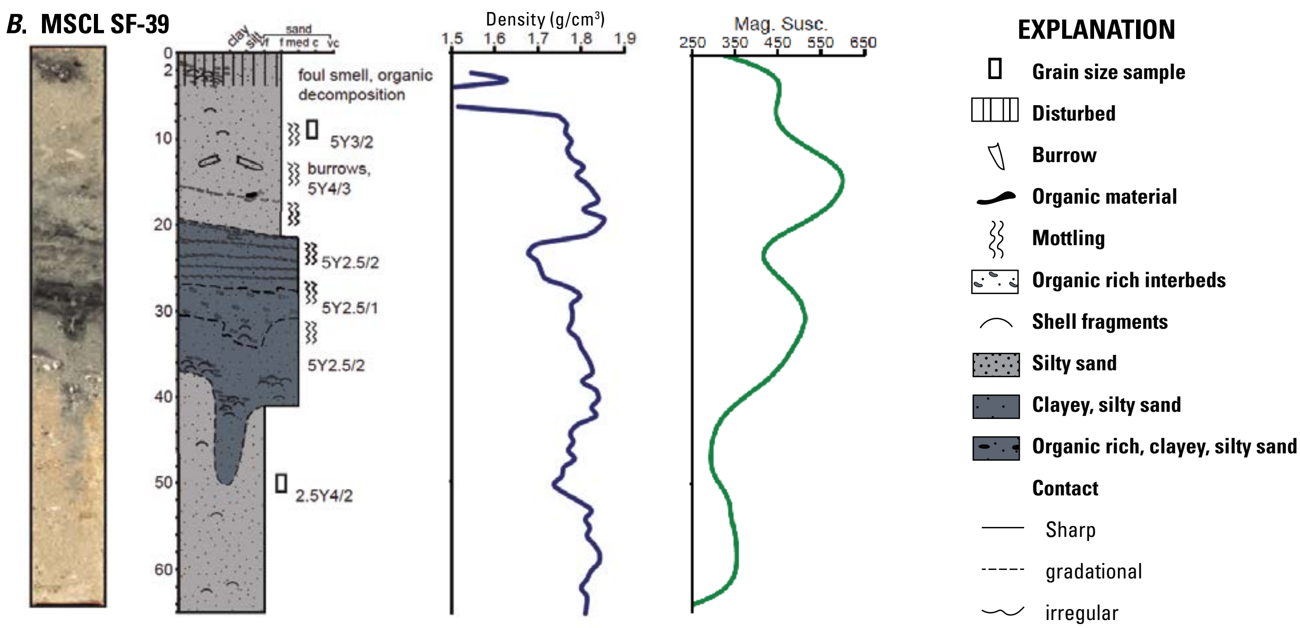


Figure 22. Core logs of selected vibracore samples (*A*, Sample MSCL SF-10; *B*, Sample MSCL SF-39) from San Francisco Littoral Cell study area. Logs consist of (from left to right) photograph of split core; core description, showing distance along core (on left, in centimeters [cm]), grain-size classes (along top: c, coarse sand; f, fine sand; med, medium sand; vc, very coarse sand; vf, very fine sand), and core descriptions and colors (on right; see explanation for lithology symbols); density, in grams per cubic centimeter (g/cm³); and magnetic susceptibility (Mag. Susc., dimensionless). Density and magnetic susceptibility values from multisensor logger. Complete set of core logs is provided in appendix 1.



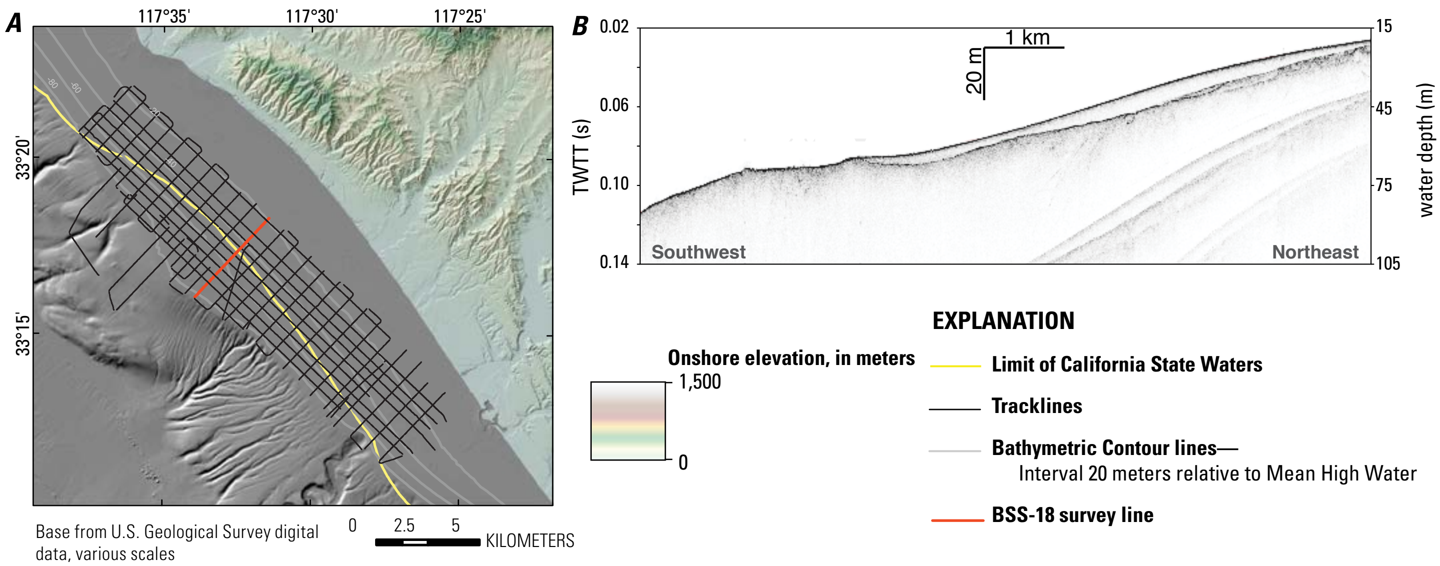


Figure 23. *A*, Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing tracklines of chirp seismic-reflection profile surveys. Trackline of seismic-reflection profile BSS-18 highlighted in red. *B*, Seismic-reflection profile BSS-18 (note vertical exaggeration of profile). Abbreviations: km, kilometer; m, meter; s, second; TWT, two-way travel time.

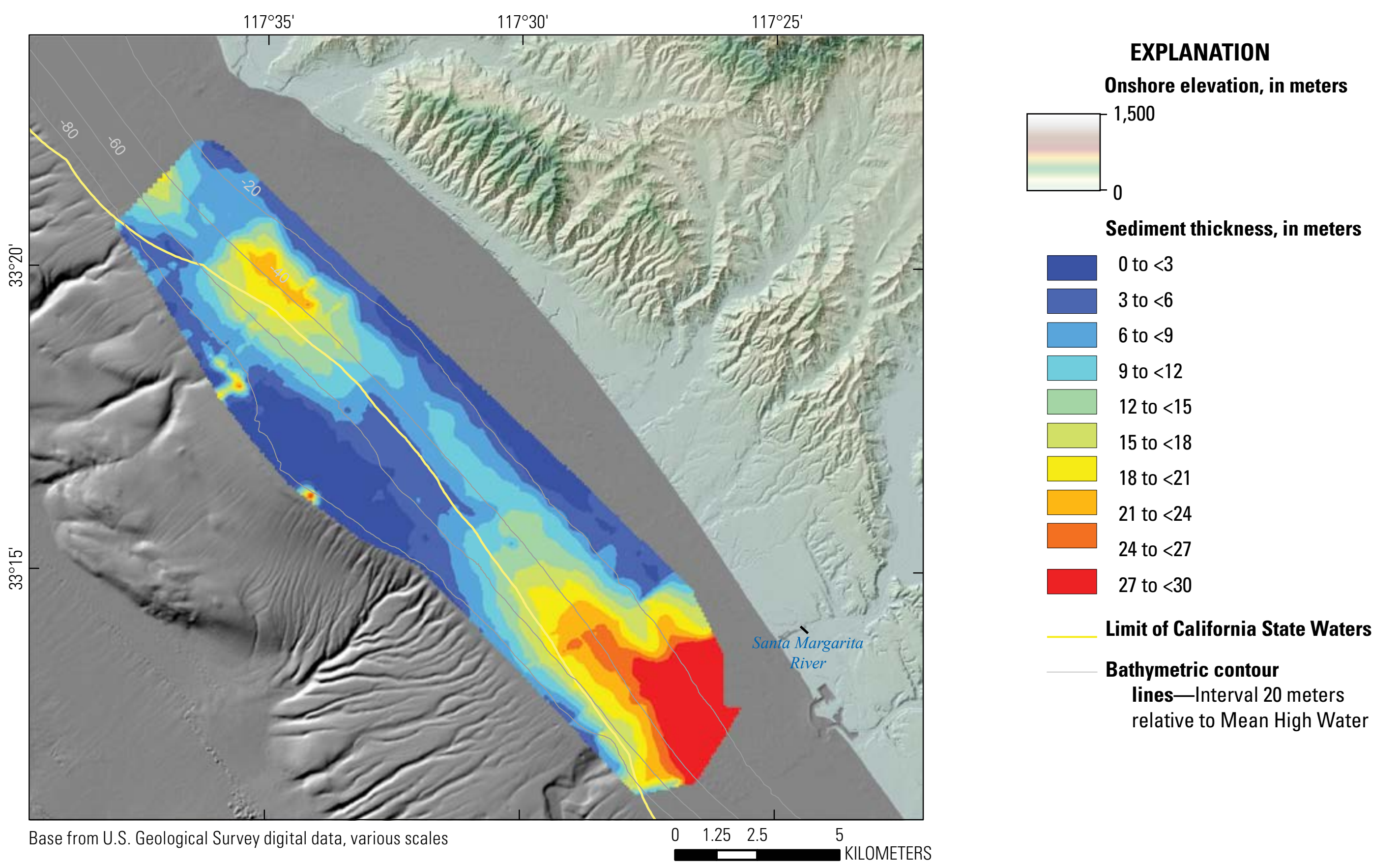


Figure 24. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing sediment thicknesses interpreted from geophysical data acquired during Sand Resources Project.

direction and 3 km in the cross-shore direction reaches thicknesses of greater than 20 m (fig. 24). On the northwest end of the Oceanside Littoral Cell study area, the isopach map shows part of a third midshelf sediment deposit that likely extends toward the northwest (fig. 24).

Areas of relatively thin to negligible sediment deposits (<3 m) are found in the shallowest areas (water depths of <20 m) and on the broad, flat outer shelf platform (fig. 24). These areas of thin sediment generally are observed in the middle part of the study area, and measurable sediment deposits are found in the shallow (water depths of <20 m) and along the outer shelf (water depths of >60 m) at the southeast and northwest ends of the study area. The outer shelf sediment at the northwestern end of the study area is especially interesting because the historical data suggest that this area may be sandy (Warrick and others, 2022).

Magnetic anomalies generally were moderate throughout the Oceanside Littoral Cell study area; the total range in values is less than 100 nT (fig. 25), which is significantly less than the range of about 400 nT for the San Francisco Littoral Cell study area (fig. 18). The magnetic anomalies generally follow an inverse relationship with sediment thickness, whereas the anomalies are highest in the central area of the thinnest sediment (fig. 25). Magnetic anomalies are highest in a broad, continuous area on the south end of the Oceanside Littoral Cell study area. The area of these high values extends more than 1 km, which suggests that they are likely caused by broad-scale geologic properties of the midshelf sediments or underlying bedrock minerals.

Sediment coring for the Oceanside Littoral Cell study area is distributed across the entire study area, and cores were collocated along the geophysical survey lines. The integrated mean grain size of sediment from these cores are largely the coarsest in the shallowest and deepest areas, whereas the cores throughout the central part of the study area had grain sizes classified as silt (fig. 26). Most of these finer samples only had 5 to 10 percent of the total sediment mass greater than the area's littoral cutoff diameter of 90 µm (Limber and others, 2008; Sliter and others, 2021b). The coarser samples from the inner and outer parts of the shelf were generally from

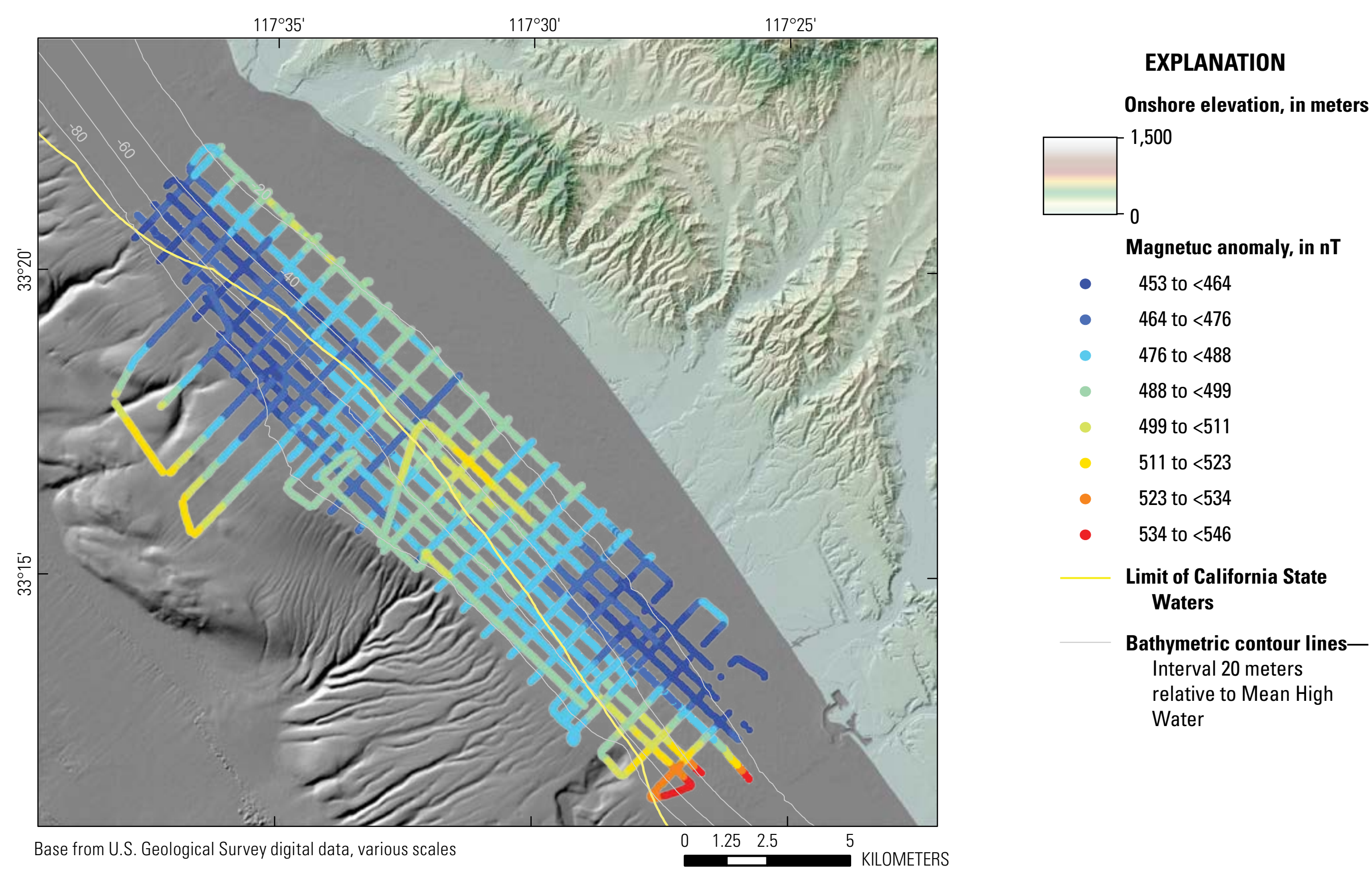


Figure 25. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing magnetic-anomaly measurements of seafloor. Abbreviation: nT, nanotesla.

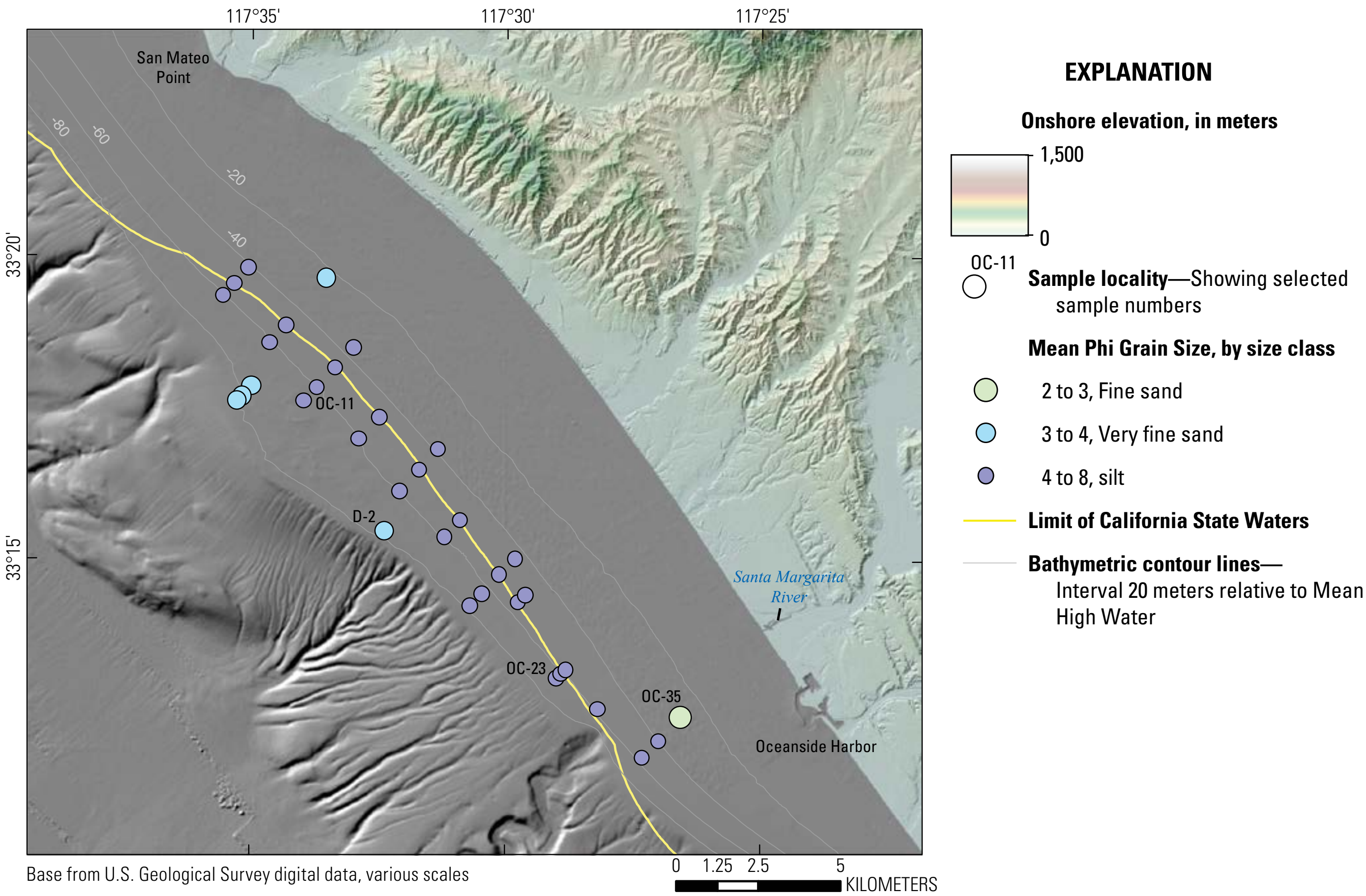


Figure 26. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing average sediment grain sizes of vibracore samples. Results are shown as phi-based classes for core-integrated mean grain-size values. Sites labeled with sample numbers are locations of selected vibracore samples shown in photomicrographs in figure 28.

50 to more than 75 percent of the sediment mass greater than this littoral cutoff diameter of 90 µm. Most of the Oceanside Littoral Cell study area sediment samples were poorly sorted (Folk and Ward sorting parameters from 1 to 2 phi), so these sediments generally include significant distributions of silt-through sand-size particles.

The TOC values of the Oceanside Littoral Cell study area vibracore samples generally are an inverse function of the sediment grain size because TOC is lowest (<0.25 percent) in the sand samples, whereas TOC-integrated values were from 0.25 to more than 1.0 percent in the silt samples (fig. 27). The TOC was higher in the southeastern part of the study area than in the northwestern part, which may be a function of organic supplies from terrestrial sources such as the Santa Margarita River or a function of sedimentation from ocean biological productivity.

Photomicrographs of the Oceanside Littoral Cell vibracore samples provide additional information about the grain colors, shapes, and mineralogy of these sediments (fig. 28). Three photomicrographs show some of the similarities and differences between the sediments of the study area. Two samples (nos. OC-11, OC-23) are similar, having light-brown to gray colors and containing poorly sorted coarse silt, composed primarily of subrounded to subangular quartz grains and lesser amounts of

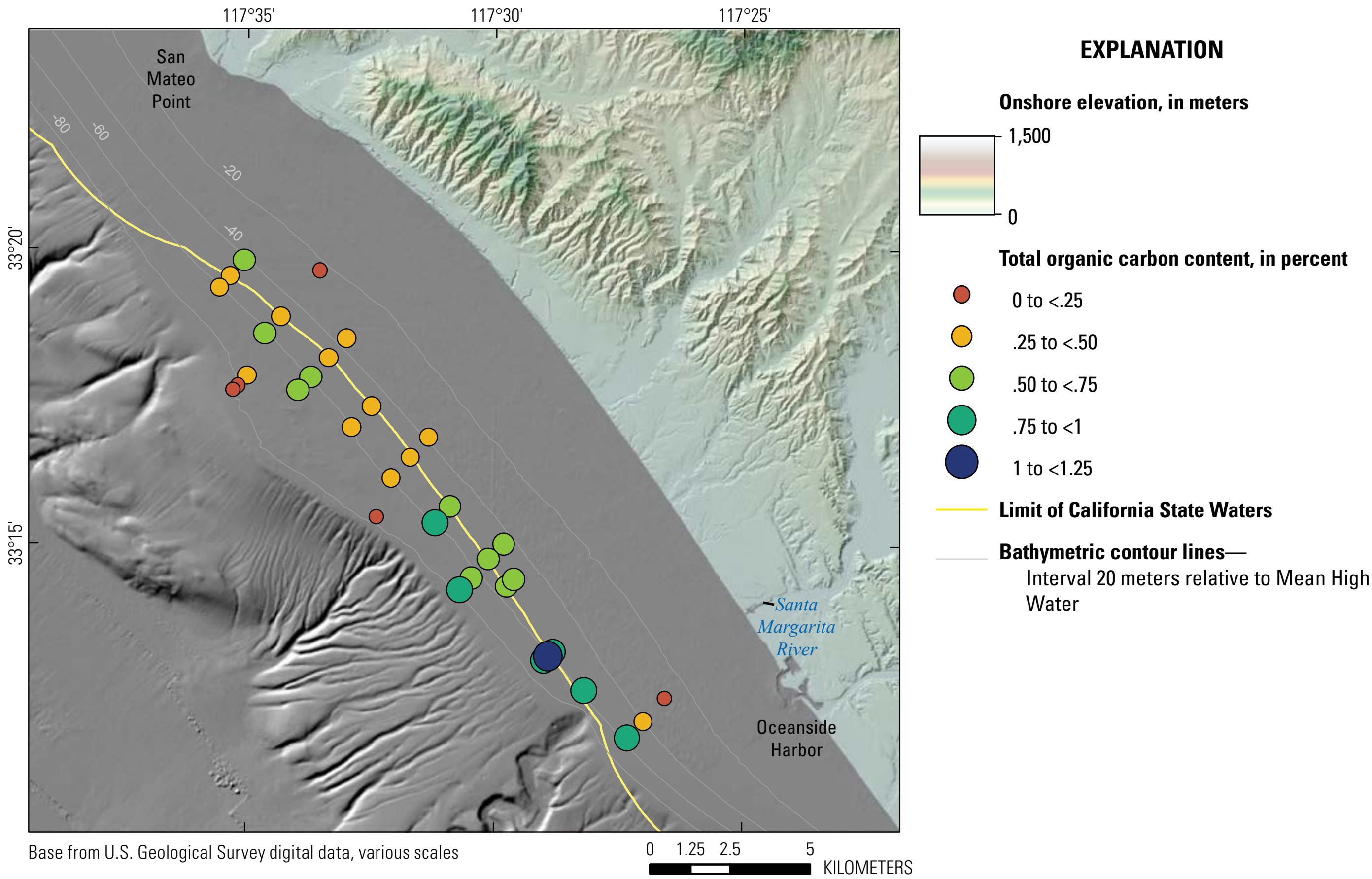


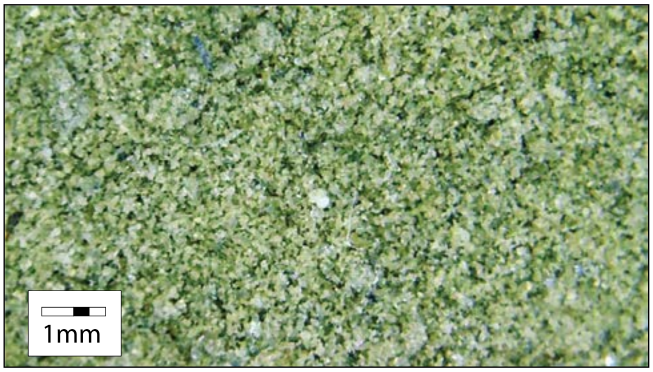
Figure 27. Shaded-relief map of Oceanside Littoral Cell study area and adjacent onshore area, showing total organic carbon contents of sediments obtained from vibracore samples. Results are core-integrated mean values.

phyllosilicates (biotite and phlogopite), lithic fragments, and feldspar grains (figs. 28*A*, *C*). The primary difference between these two samples of coarse silt is the size of the grains, which are approximately 20 percent larger in sample no. OC-23.

In contrast, the sample from vibracore D-2 shows a light-gray, moderately sorted, very fine sand that is composed of subrounded to subangular, white, translucent quartz grains and only minor quantities of phyllosilicates and subrounded lithic fragments of the same size (fig. 28*B*). This sand, which is found in the deeper parts of the study area on the outer shelf, differs significantly from sediments in the midshelf area because it has a more uniform grain size and is more abundant in quartz, properties that lead lends to an interpretation that it likely represents a Pleistocene or early Holocene stranded beach deposit.

Further details about the Oceanside Littoral Cell sediments are provided in the core logs and associated core data (appendix 1). Similar to the San Francisco Littoral Cell, the Oceanside Littoral Cell study area cores suggest that the sediment properties are relatively uniform with depth with respect to structure and texture. A core from the center of Oceanside Littoral Cell study area (sample no. OC-13) (fig. 29*A*) is dominated by a poorly sorted coarse silt that is mottled near the seafloor. Centered at about 80 cm below the surface, a coarser layer of sediment is present that includes

A. **Vibracore OC11 100cm**



Mean = 33 *µm* (coarse silt)
Sorting = 1.622 *phi* (poorly sorted)

B. **Vibracore D2 85cm**

Mean = 90 *µm* (very fine sand)
Sorting = 0.811 *phi* (moderately sorted)

C. **Vibracore OC23 50cm**

Mean = 40 *µm* (coarse silt)
Sorting = 1.765 *phi* (poorly sorted)

Figure 28. Photomicrographs of example sediments from selected vibracore samples in Oceanside Littoral Cell (see fig. 26 for locations), showing vibracore sample number and distance along core, as well as sample mean grain size, sorting, and associated grain-size class of sediments. *A*, Sample OC-11, at 100 centimeters (cm). *B*, Sample D-2, at 85 cm. *C*, Sample OC-23, at 50 cm. Abbreviations: cm, centimeter; mm, millimeter; µm, micrometer.

shell fragments and shows a change in color (fig. 29*A*). This coarse layer has a mean grain size of 63 µm (on the boundary between coarse silt and very fine sand), which contrasts with the finer sediment above and below this layer, which range from 32 to 37 µm. Layers of coarser subsurface sediment are found in several cores of the Oceanside Littoral Cell study area, including sample nos. OC-3, OC-6, OC-7, OC-15, OC-16, OC-19, OC-20, OC-24, OC-25, and OC-32 (appendix 1).

The coarsest sediments in the Oceanside Littoral Cell study area are found at an inner shelf site near the Santa Margarita River mouth (sample no. OC-35; fig. 26). The log from this core shows that this fine sand is fairly continuous with depth but includes layers that contain shell hash (fig. 29*B*). A sediment sample within the shell hash interval at 50 cm depth contained 4.8 percent gravel-sized (>2 mm) material by weight and 0.80 percent $CaCO_3$ by weight, likely owing to the presence of shell material. Overall, however, mean sediment grain size is fairly continuous in this core, ranging from 96 to 138 µm, and the percentage of sediment larger than the littoral cutoff diameter of 90 µm (Limber and others, 2008) ranges from 75 to 90 percent.

Silver Strand Littoral Cell

A limited amount of new geophysical-data collection and coring was conducted at the Silver Strand Littoral Cell study area. The chirp data indicate that distinct areas of sediment deposits are separated by rocky outcrops. For example, a cross-shore geophysical profile collected from the boundary between Federal and California State Waters toward the shelf break reveals two distinct areas of sediment deposition separated by more than 1 km of rocky outcrop (fig. 30). On either side of this outcrop, sediment ranges in thickness from less than 1 m to more than 5 m (fig. 30).

Because the geophysical-data collection is an exploratory operation conducted with broad line spacing, the isopach map for the Silver Strand Littoral Cell study area is considered to be less accurate and less detailed than that of the other study areas. Nonetheless, the area appears to consist of a central, rocky, north-south-trending high that has little or no sedimentary cover, flanked by sandy deposits on its east and west sides (fig. 31). The subbottom profiles do suggest a

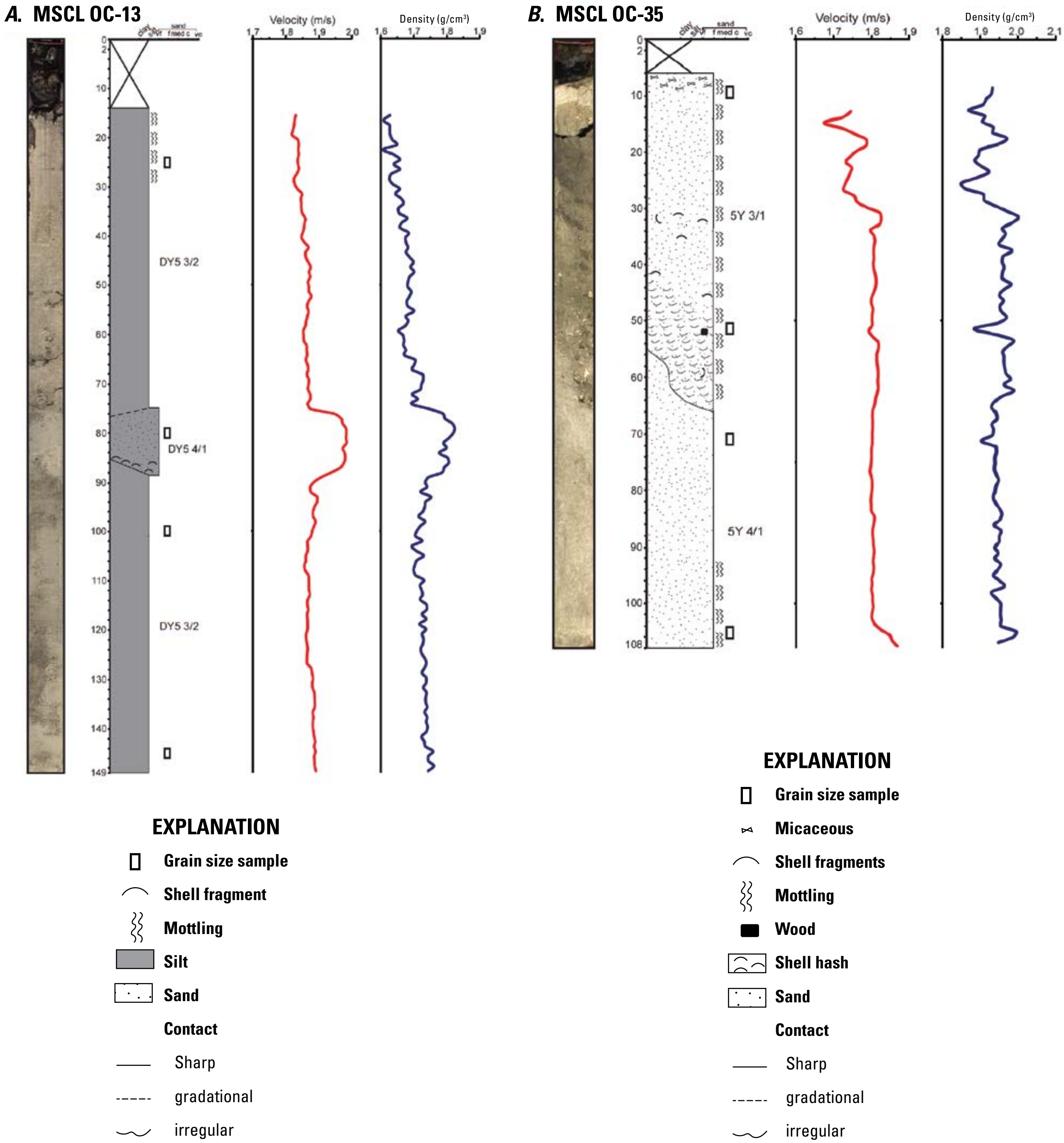


Figure 29. *A*, Core logs of selected vibracore samples from Oceanside Littoral Cell study area. Logs consist of (from left to right) photograph of split core; core description, showing distance along core (on left, in centimeters [cm]), grain-size classes (along top: c, coarse sand; f, fine sand; med, medium sand; vc, very coarse sand; vf, very fine sand), and core descriptions and colors (on right; see explanation for lithology symbols) (large X indicates missing core material); velocity, in meters per second (m/s); and density, in grams per cubic centimeter (g/cm³). Density values from multisensor logger. Complete set of logs is provided in appendix 1. *A*, Sample MSCL OC-13, silty site in midshelf area. *B*, Sample MSCL OC-35, sandy site on inner shelf.

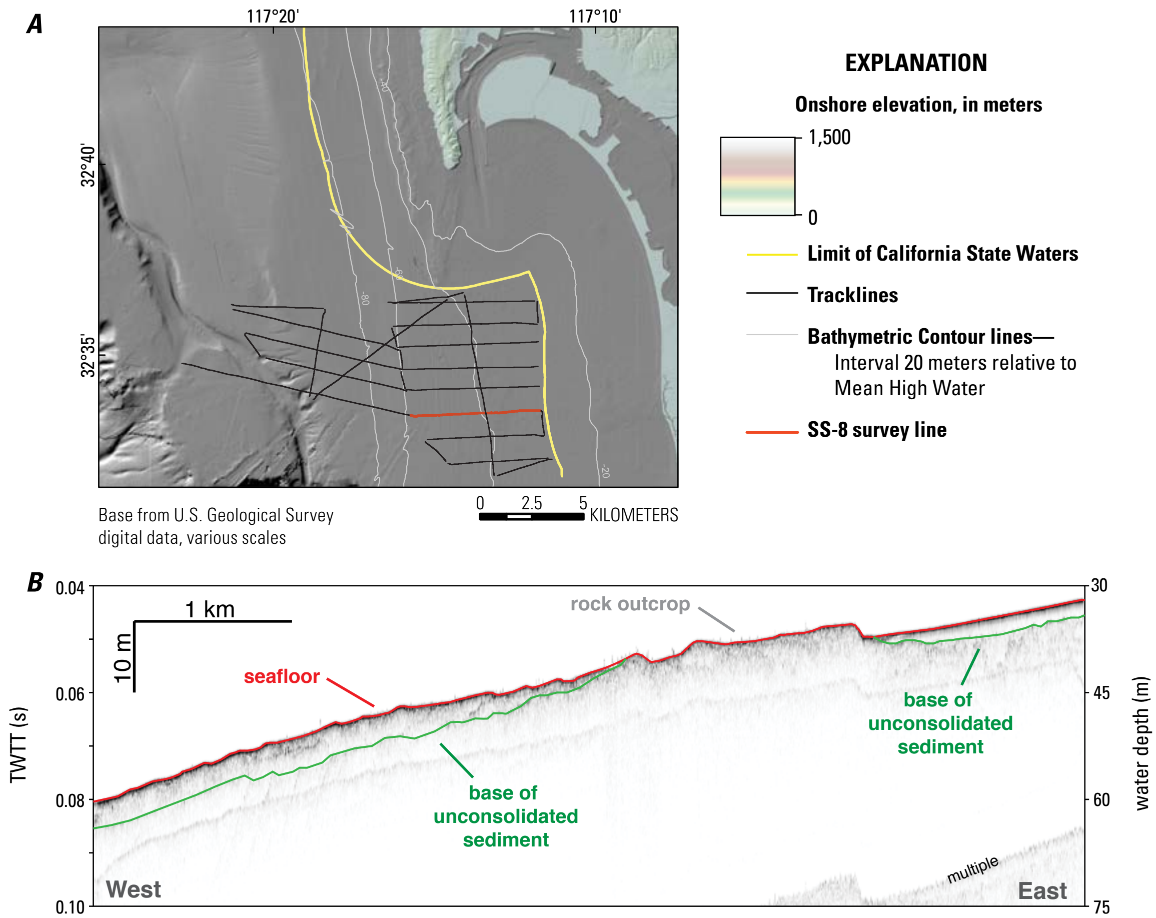


Figure 30. *A*, Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing tracklines of chirp seismic-reflection profile surveys. Trackline of seismic-reflection profile SS-8 highlighted in red. *B*, Interpreted seismic-reflection profile SS-8, showing measurement of sediment thickness from interpretation of seafloor (red line) and base of unconsolidated sediment (green line). In lower right part of profile, "multiple" label highlights faint trace of seafloor multiple (echo of seafloor reflector). Note vertical exaggeration of profile. Abbreviations: km, kilometer; m, meter; s, second; TWT, two-way travel time.

relatively complex distribution of irregular ridges and small basins, both on the seafloor and on the basement-rock surface, so additional surveys using narrower line spacing will be required to more accurately define the extent of rocky outcrops and the thickness of the sediment deposits. Additionally, the single-day operation by the USGS at this site did not include magnetometer measurements.

Six vibracore samples were obtained for the Silver Strand Littoral Cell study area; the integrated mean grain size of sediment from these cores ranges from very fine sand to medium sand (fig. 32). The coarsest samples were in the deepest and farthest offshore sites (sample nos. SD-2, SD-6), which were obtained in water depths of 49 and 58 m, respectively. These samples have very little silt or clay (typically only about 2 percent) and similarly have very little TOC (<0.25 percent; fig. 33). The finest grain sizes measured at the Silver Strand Littoral Cell study area are the inshore cores obtained at water depths of 29 to 31 m, which have an average grain size of very fine sand (fig. 32).

Photomicrographs of the Silver Strand Littoral Cell samples (fig. 34) show these sediments to be markedly coarser than the samples for either the San Francisco or Oceanside

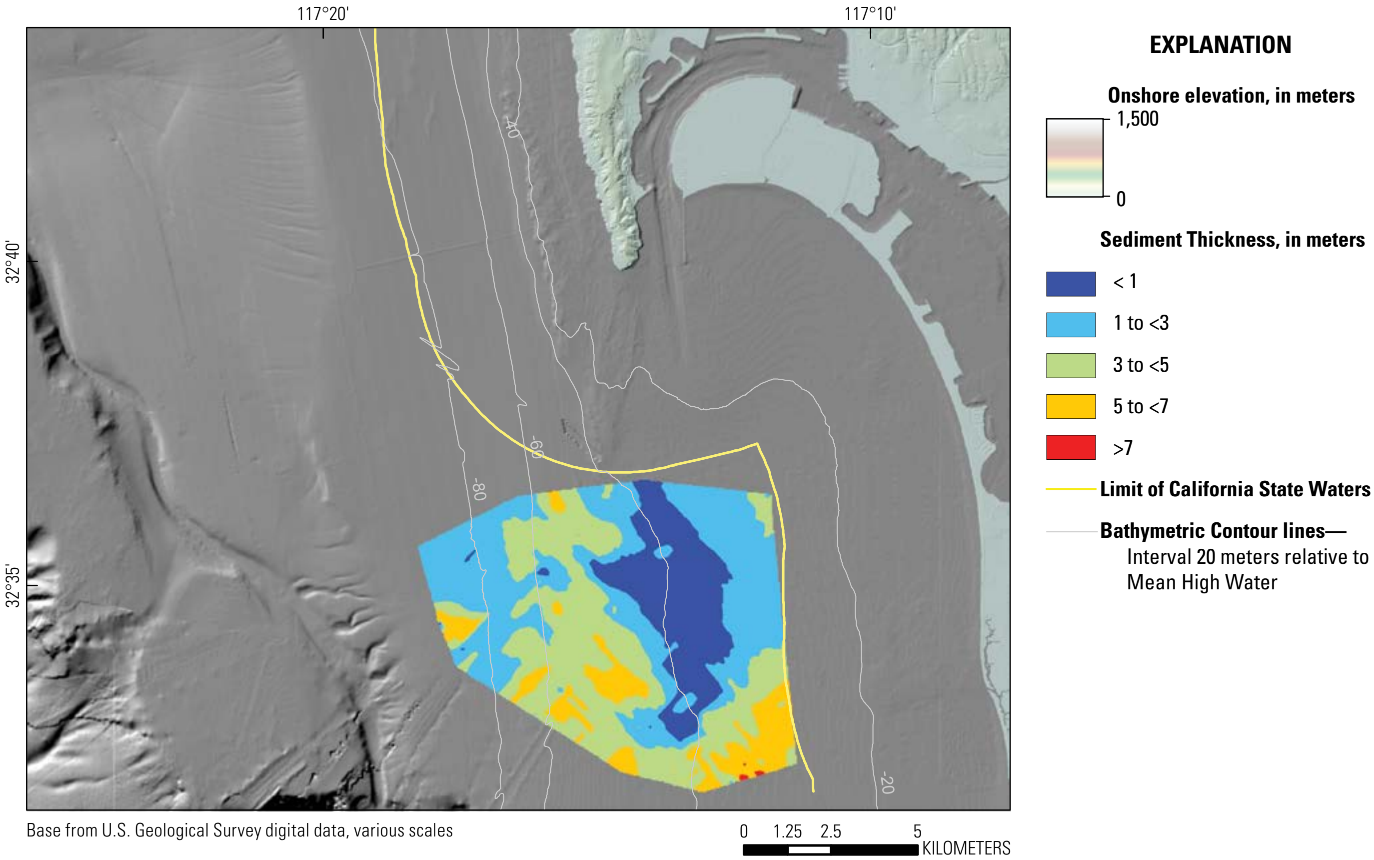


Figure 31. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing sediment thicknesses interpreted from chirp geophysical data acquired during Sand Resources Project.

Littoral Cell study areas (figs. 21, 28, respectively). Although these samples were all sandy, they also were somewhat diverse. The sample from the southernmost core (sample no. SD-1) was from a light-gray, poorly sorted, fine sand that was primarily subrounded to subangular quartz with minor amounts of biotite, smaller subrounded black fragments, and subrounded feldspar grains (fig. 34*A*). The medium sand from the offshore core (sample no. SD-2) was a buff-colored, poorly sorted, medium sand composed of subrounded to subangular, highly variably sized quartz grains, some of which are rose colored or have a rust-colored patina, and minor components of biotite, lithic fragments, and subrounded feldspar (fig. 34*B*). Lastly, the finer grained inshore core (sample no. SD-5) contained a light-gray, moderately sorted, fine sand composed mainly of subrounded to subangular quartz grains, some subrounded lithic fragments of much smaller size, and local biotite grains (fig. 34*C*).

Core logs of the Silver Strand Littoral Cell for all six vibracore samples (appendix 1) provide evidence that most of these sites have downcore variations in sediment grain size and structures. For example, the core from the medium sand at sample no. SD-2 provides evidence of several erosional contacts and sections with and without shell fragments.

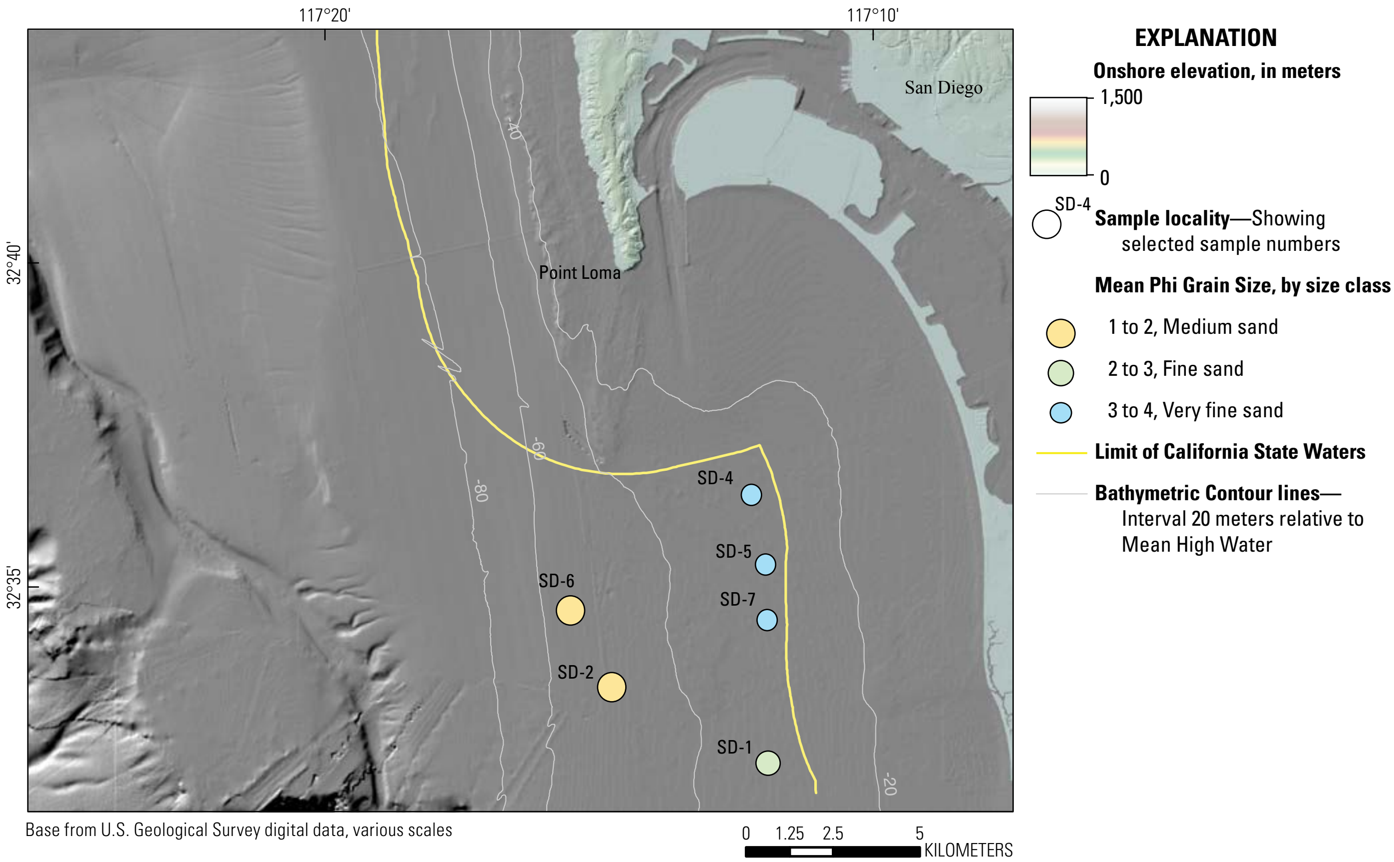


Figure 32. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing average sediment grain sizes of vibracore samples. Results are shown as phi-based classes for core-integrated mean grain-size values. Sites labeled with sample numbers are locations of selected vibracore samples shown in photomicrographs in figure 34.

Sampled grain sizes within this core ranged from 267 to 450 µm (fig. 35*A*). The core from the inshore, finer grained sample no. SD-5 had a distinct increase in sediment grain size from a very fine sand near the surface (mean value, 74–78 µm) to fine sand (mean value, 146–181 µm), which represents a doubling of grain size with depth (fig. 35*B*). This latter observation is consistent with inner shelf sampling by Warrick and others (2012) and the vibracore results of Sea Surveyor, Inc. (1999), within the study area, which together suggest that limited suitable beach-nourishment sand exists on the seafloor surface and that “most of the suitable beach replenishment sand within the site is buried under a 2 to 6 ft (0.6–2 m) layer of silty sand that is not suitable for beach replenishment” (Sea Surveyor, Inc., 1999, their p. 52–57).

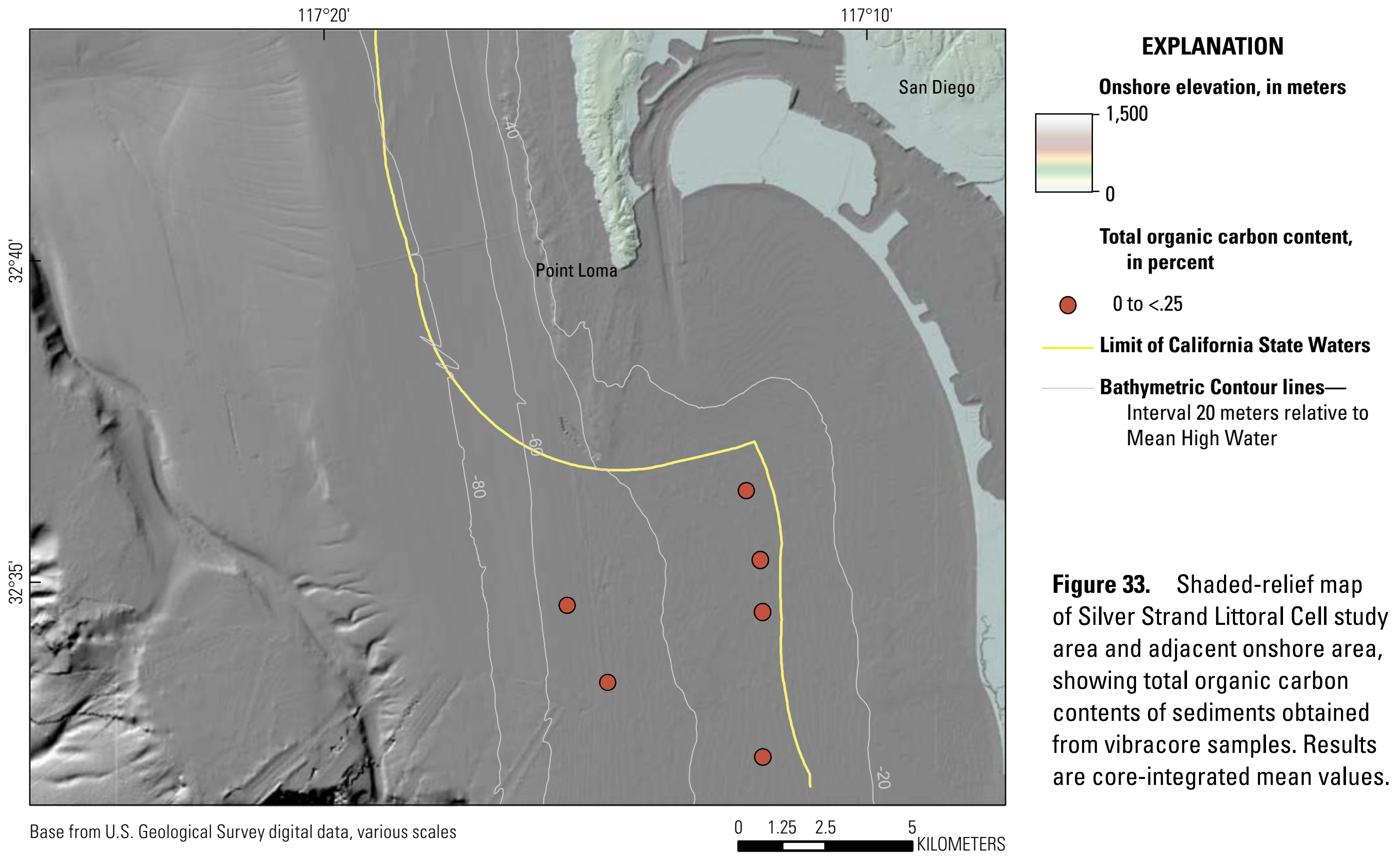
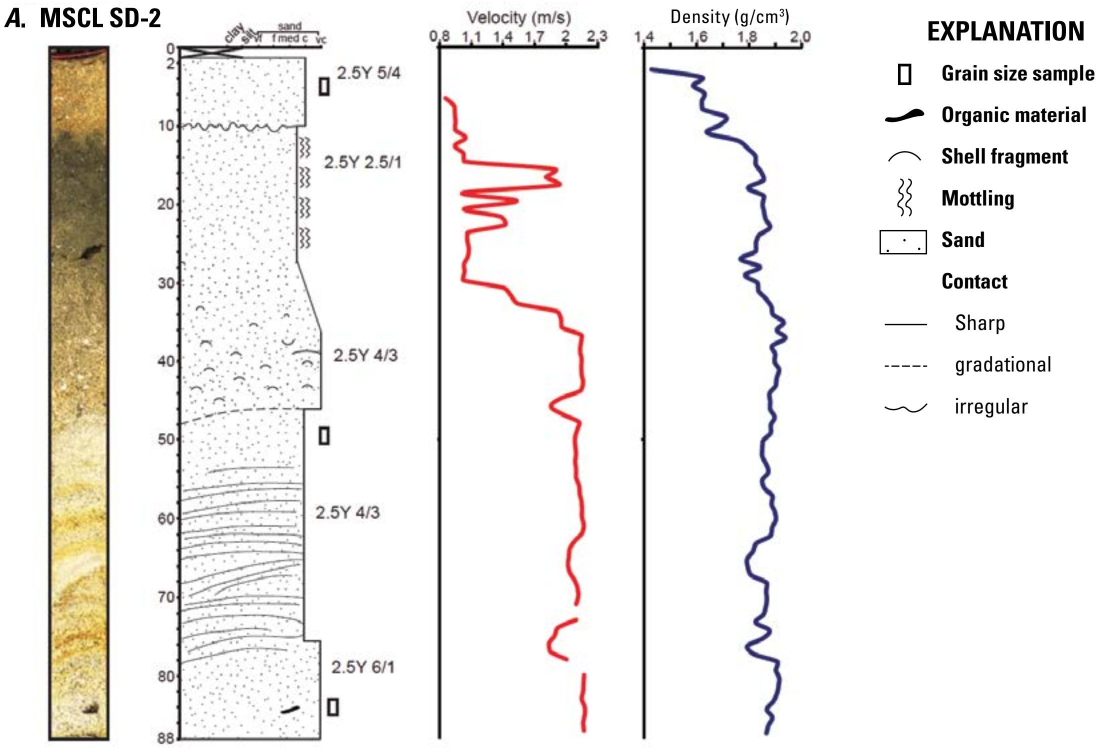
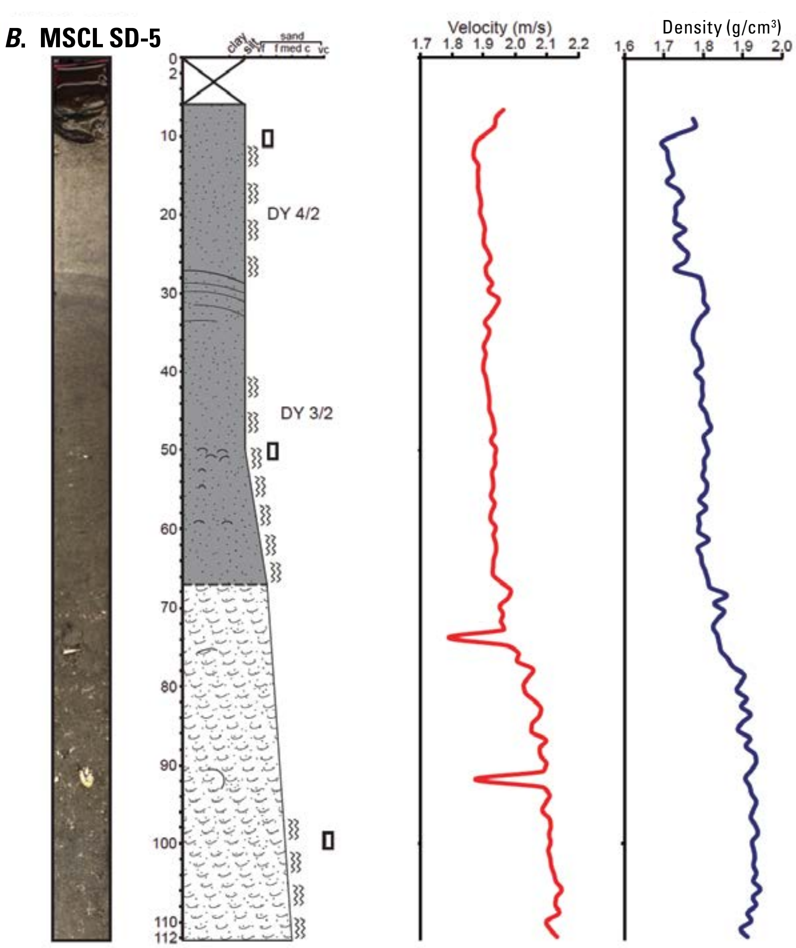


Figure 33. Shaded-relief map of Silver Strand Littoral Cell study area and adjacent onshore area, showing total organic carbon contents of sediments obtained from vibracore samples. Results are core-integrated mean values.

Figure 34. Photomicrographs of example sediments from selected vibracore samples in Silver Strand Littoral Cell (see fig. 32 for locations), showing vibracore sample number and distance along core, as well as sample mean grain size, sorting, and associated grain-size class of sediments. *A*, Sample SD-1, at 53–55 centimeters (cm). *B*, Sample SD-2, at 83–85 cm. *C*, Sample SD-5, at 100 cm. Abbreviations: cm, centimeter; mm, millimeter; µm, micrometer.





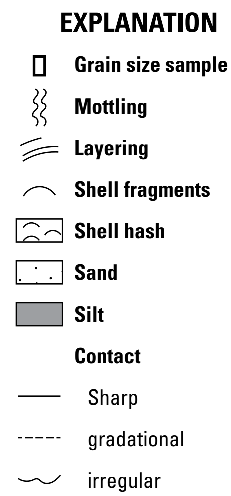


Figure 35. Core logs of selected vibracore samples from Silver Strand Littoral Cell study area. Logs consist of (from left to right) photograph of split core; core description, showing distance along core (on left, in centimeters [cm]), grain-size classes (along top: c, coarse sand; f, fine sand; med, medium sand; vc, very coarse sand; vf, very fine sand), and core descriptions and colors (on right; see explanation for lithology symbols) (large X indicates missing core material); velocity, in meters per second (m/s); and density, in grams per cubic centimeter (g/cm3). Density values from multisensor logger. Complete set of logs is provided in appendix 1. *A*, Sample MSCL SD-2. *B*, Sample MSCL SD-5.

Discussion and Conclusions

Summary of Findings—Geological Descriptions of Sites

The compilation of geophysical and sediment grain-size data allows for an improved understanding of the three study areas. Here these observations are combined with the general geologic understanding of the areas to provide summary descriptions of the spatial patterns of the sediment, including beach-nourishment-quality sand, in combined Federal and California State Waters for each area.

San Francisco Littoral Cell

The San Francisco Littoral Cell study area is underlain by metamorphosed sedimentary and volcanic rocks of the Jurassic and Cretaceous (Cochrane and others, 2015). In places, these rocks are intruded by Cretaceous granitic rocks and are overlain by younger Tertiary sedimentary rocks. These rocks are displaced by the San Andreas Fault and by strands of the San Gregorio Fault Zone.

Modern depositional patterns are dominated by sediment from the Sacramento–San Joaquin River system that is carried out the Golden Gate (Barnard and others, 2013b). Tidal currents have reworked these sediments into a shallow, crescent-shaped bar, known as the ebb-tidal delta, which lies about 3 to 10 km offshore of the mouth of San Francisco Bay and is largely sandy (Warrick and others, 2022). Additionally, the relative movements on the San Andreas and San Gregorio Faults have created a shallow basin, or graben, within the study area, which has been filled with unconsolidated sediments that exceed 50 m in thickness in places (fig. 17; Ryan and others, 2008; Cochrane and others, 2015). Evidence of tectonic-controlled sediment deposition extends beyond the graben, however, as shown by variable sediment thicknesses across several of the active faults in the region (fig. 16). Combined, these two factors—tectonic history and sediment supply—have resulted in an extensive deposit of sediment offshore of the mouth of the San Francisco Bay, represented by sandy to coarse, silty sediments across most of the seafloor; these sediments generally thin and fine with distance from the Golden Gate.

Oceanside Littoral Cell

The Oceanside Littoral Cell study area extends along the relatively narrow continental shelf between San Mateo Point and Oceanside Harbor. The region is underlain by marine sedimentary rocks primarily of the Miocene and younger that are displaced by the active north-northwest-striking Newport-Inglewood Fault Zone (Ryan and others, 2009). This fault zone extends along the outer shelf, structurally controlling the location of the shelf edge.

The shelf bulges westward slightly along this part of the coast, likely owing to a component of compression across the Newport-Inglewood Fault Zone that has resulted in uplift on the west side of the fault (fig. 23) (Ryan and others, 2009). This uplift exposes Miocene bedrock on the seafloor along the outer shelf, which has only a thin veneer of sandy, unconsolidated sediment. However, an elongate sediment depocenter has formed east of the fault on the midshelf, roughly parallel to the trend of the shelf (fig. 24). This unconsolidated sediment has distinct thicker and thinner areas, which are likely a result of the variable sediment supply from the area’s rivers. Additionally, drowned, relict channels associated with some of the major coastal drainages (San Mateo Creek, Santa Margarita River) incise the bedrock across the shelf, forming basins that are filled with unconsolidated sediment (Sea Surveyor, Inc., 1999).

The sandy sediments of the Oceanside Littoral Cell 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 region, conducted from 15- to 27-m water depths, that commonly found silty sand on the seafloor surface. These finer grained surficial sediments on the inner shelf ranged in thickness from 1 to 4 m and they lie over sandier sediments that were determined to be suitable for beach nourishment (Sea Surveyor, Inc., 1999).

Additionally, sandy sediment also exists near the shelf edge in the Oceanside Littoral Cell study area, and the combined evidence of grain-size distributions, microscope observations of sand grains, and the geographic setting of these deposits all point toward an interpretation that these offshore sands represent former beach deposits that were formed during lower sea levels of the Pleistocene or early Holocene but were stranded on the outer shelf during Holocene sea-level rise.

Silver Strand Littoral Cell

The Silver Strand Littoral Cell study area encompasses the continental shelf along the southernmost part of California, near the United States–Mexico border. The study area is underlain by Cretaceous and early Tertiary sedimentary and volcanic rocks that have been intruded by granitic rocks (Kennedy and Tan, 1977). These rocks are cut by numerous faults, most of which are strands of the active, north-south-striking Rose Canyon Fault Zone, part of the Newport-Inglewood Fault Zone. Movement on this fault has resulted in uplift on the west side of the study area, exposing bedrock that has a mostly thin veneer of unconsolidated sediment on the seafloor in the western part of the study area, offshore of Point Loma (Ryan and others, 2009). In the southeastern part of the study area, motion on strands of the Rose Canyon Fault Zone has created a shallow basin in the bedrock that is filled with as much as 20 m of unconsolidated sandy sediment (Ryan and others, 2009).

Sediment offshore of the entrance of the San Diego Bay is contained in Zuniga Shoal, which is the terminal depositional zone for the littoral cell and is influenced by the strong ebb currents from San Diego Bay, by the jetty on the east side of the inlet, and by dredging to maintain the shipping channel (Inman, 1976). The area offshore of the Tijuana River mouth was characterized by mapping and sampling by Sea Surveyor, Inc. (1999), Warrick and others (2012), and Dartnell and others (2020). Outside of the 5.6-km (3-nmi) limit of California State Waters, the sediment generally is less than 4 m thick and includes significant areas of rock outcrop. One exception is at the south end of the study area where deposits can reach 16 m in thickness (Warrick and others, 2022).

Exploratory geophysical measurements and sediment coring of the Silver Strand Littoral Cell study area indicate that unconsolidated sediment deposits exist and that these deposits generally are sandy. Additionally, the data indicate that large areas of rock crop out on the shelf and that sediments offshore of these outcrops are the coarsest samples gathered in this study (figs. 31, 33). The sediment deposits cored on the inner shelf are considerably finer than the offshore deposits, which generally is consistent with inner shelf sampling by Warrick and others (2012) and the vibracore results of Sea Surveyor, Inc. (1999). Sea Surveyor, Inc. (1999), found that the exposure of suitable beach-nourishment sand on the seafloor surface is limited and that “most of the suitable beach-replenishment sand within the area is buried under a 2 to 6 ft (0.6–2 m) layer of silty sand that is not suitable for beach replenishment” (Sea Surveyor, Inc., 1999, their p. 52–57).

Synthesis of Study Areas

The three study areas investigated in this project provide evidence that sediment distributions offshore of the California coast are strongly related to tectonic history and sediment supplies. Tectonic history will define the geographic setting in which sediment settles, and it can strongly dictate sediment deposition patterns and thicknesses. For example, the fault-controlled geologic structures of the San Francisco Littoral Cell study area have allowed for tens of meters of sedimentation within the subsiding graben landforms, although sediment thicknesses outside of these landforms is markedly lower (figs. 16, 17). Similarly, the fault-controlled outer shelf platform of the Oceanside Littoral Cell study area and the geologically controlled rocky outcrops of the Silver Strand Littoral Cell study area both influence the patterns of sedimentation, and they are also related to sandy deposits on the outer shelves of each area (figs. 23, 24, 30, 31).

Sediment supply provides another first-order control on sedimentation patterns on the continental shelf. Areas of increased sedimentation were evident in San Francisco and Oceanside Littoral Cell study areas where the San Francisco Bay and the Santa Margarita River, respectively, are dominant sources of sediment to these systems (figs. 17, 24). For both systems, the geometry of the modern shelf sediment deposits was directly related to the source and transport of these sediment supplies. In the southern part of the Silver Strand Littoral Cell study area, sediment supply from the Tijuana River is likely related to the high rates of sedimentation in the area (fig. 31), although a more comprehensive survey would provide more information to evaluate this.

Although modern sediment supply is important to the sedimentation patterns of the three study areas, ancient sources (or relict sediments), which are derived from processes or landforms that are no longer in existence, also are an important defining characteristic of these areas. For example, the sandy deposits on the outer shelves of the Oceanside and Silver Strand Littoral Cell study areas have grain-size, shape, and mineralogical characteristics that are similar to littoral systems, which is consistent with the interpretation that they are relict beach sediments (figs. 26, 28, 32, 34). These coarse sediments likely exist on the outer continental shelf because they were formerly beach or coastal-dune systems from the late Pleistocene or early Holocene when relative sea level was much lower and the shoreline was near the modern-day midshelf to outer shelf area. During sea-level rise in the Holocene, these sandy sediments were left in place, perhaps owing to the evolving landscape geometry or the volume of the sediment deposits that limited reworking, and they are now preserved in these midshelf to outer shelf settings. These hypotheses are consistent with the long-standing understanding of relict marine sediments and observations of relict sands along the continental shelf of California (Emery, 1968; Swift and others, 1971; Nordstrom and Margolis, 1972).

Although the importance of tectonics and sediment supplies are clear from the sedimentation patterns of all three study areas, these factors have produced distinctly different sedimentation patterns in these areas. Although the controlling factors for sedimentation were the same, they combined to produce different results. Perhaps this is best reflected in the differences in the relationship between sediment grain size and water depth for the three study areas (fig. 36). In the Oceanside Littoral Cell study area, grain size fines with depth between the shallowest samples (about 20-m water depth) and the midshelf (about 50-m water depth; fig. 36). This fining is consistent with other river-dominated shelf settings of California such as near the mouths of the Eel and Russian Rivers, in northern California, where fine-grained sediments from the rivers dominate midshelf sedimentation (Hill and others, 2007; Sommerfield and Wheatcroft, 2007; George and Hill, 2008). However, sediment is observed to coarsen from coarse silt to very fine sand for parts of the outer continental shelf (65–85-m water depth), which is related to relict littoral sands, as is noted in figure 36.

The grain-size patterns with water depth of the Silver Strand Littoral Cell study area also are substantially different from the other two areas. The limited sampling of the Silver Strand Littoral Cell study area reveals a coarsening trend with water depth (fig. 36). The shallowest samples (about 30-m water depth) are very fine to fine sand, whereas the deeper samples (50–60-m water depth) are medium sand. The San Francisco Littoral Cell study area, in contrast, has a relatively uniform grain size with water depth (fig. 36), largely owing to the strong influence of the San Francisco Bay sediment supply and grain size in the region (fig. 19) (Barnard and others, 2013a).

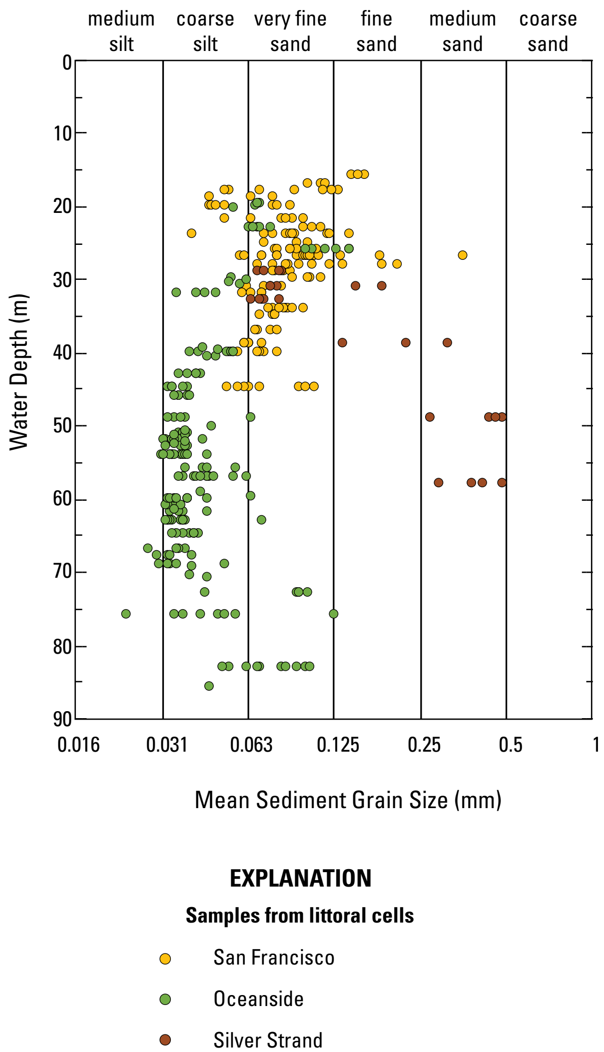


Figure 36. Plot showing water depth versus mean sediment grain size of sediment from vibracore samples, showing patterns of sizes at various depths of the core from San Francisco, Oceanside, and Silver Strand Littoral Cell study areas. All independent grain-size analyses are shown.

Future Work and Next Steps

Sediment in all three study areas of the Sand Resources Study was suitable for beach nourishment, as reflected by their grain-size distributions and sediment thicknesses. For example, sandy sediment in the San Francisco Littoral Cell study area was on and immediately outside of the "San Francisco Bar," a landform that has had a strong influence on grain-size patterns of the region (fig. 19). However, the thick sediment deposits in the graben north of the Golden Gate were siltier than those of the remaining study area, which likely limits the use of these sediments for shoreline nourishment on the outer coast. Sandy sediment in the Oceanside Littoral Cell may be useful for nourishment on the inner and outer parts of the continental shelf, whereas the midshelf area between these sandy areas was dominated by silty sediments (figs. 26, 28). The Silver Strand Littoral Cell, which was only sampled selectively, has the greatest potential for beach-nourishment sediment, especially in the more distal and deeper areas where medium sand is found (figs. 32, 34).

The potential use of these sediments for coastal-nourishment projects will largely be related to the locations, depths, and sediment characteristics of the deposits, as well as the locations and grain-size distributions of the receiver sites. Beach-receiver sites in California have grain-size distributions that have littoral cutoff diameters that are typically between 100 and 120 µm, but they may be as low as 90 µm or as high as 180 µm (Limber and others, 2008). Coastal wetlands will have much finer grain sizes, and receiver sites within the wetland landform types may be able to use the areas that have finer sediments sampled in this project. Thus, it will be imperative to have a detailed understanding of potential receiver sites to compare with the offshore data presented herein to assess the future use of offshore sediments. The data tabulated in the reports associated with this study (Sliter and others, 2021a, b, c) will provide critical information for these comparisons.

The Sand Resources Project did identify several sandy parts of the continental shelf that are deeper than 30 m, which is deeper dredging technologies currently available in the United States would be able to reach. Sandy sediment exists in all three study areas in water depths of less than 30 m (fig. 36). However, if dredging technologies are expanded in the United States to incorporate depths of 60 m or deeper, additional sediment supplies—most of which are in Federal Waters—may be available to beach-nourishment projects (fig. 36). These deeper sandy sediments are primarily in the Oceanside and Silver Strand Littoral Cell study areas (figs. 26, 32).

The Silver Strand Littoral Cell study area was considerably replete in sand resources, especially as compared to the other study areas (fig. 36). Because these conclusions are based on limited sampling provided by the USGS outside of this Sand Resources Project, a more complete characterization of sediment resources in this area may be beneficial. To meet the needs of future leases of these sediment resources, additional data collection would likely need to include high-resolution bathymetric mapping in Federal Waters in this study area, as well as more detailed geophysics and additional coring within areas that have high potential of nourishment-grade sand. It will be especially important to map the distribution of rocky outcrops and sediment thicknesses in this area.

Sand resources of the San Francisco Littoral Cell were on, or were immediately adjacent to, the ebb-tidal bar of the San Francisco Bay, largely owing to the supply of sediment through the Golden Gate and also the sediment-transport mechanisms on the bar (Barnard and others, 2013a). However, outstanding questions remain about the potential geomorphic and oceanographic effects of mining the bar of sand for coastal nourishment that should be addressed before projects are initiated. For example, the bar induces wave shoaling and breaking, which in turn influences coastal waves, water levels, and sediment transport along the shoreline (Barnard and others, 2013a, b). Additionally, the bar has been shrinking over time because of the reduced sediment supply related to sand mining and smaller tidal prism from bay filling, and the history and trajectories of these processes should be considered before the size of the bar is reduced further by sediment mining.

In conclusion, the Sand Resources Project has shown that several areas of sand resources are present in Federal and California State Waters in places where they were previously unknown. The presence of these marine sands and their thicknesses generally is related to the geologic setting and sediment supplies of each study area. Because these conditions vary greatly along the California coast, the locations, thicknesses, and grain-size distributions of sands as determined in this study also vary greatly. Combined with other studies of the California continental shelf (for example, on Santa Monica Bay sand and gravel; Noble and Xu, 2003), new evidence exists that marine sand and gravel resources may be present in Federal and California State Waters in areas that were previously undocumented. As such, this project will provide important data for future coastal sediment management decisions in California, and it may provide a model for future investigations of sediment resources in other areas of California.

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Appendix 1. Graphical Logs of the Vibracores Collected from the San Francisco, Oceanside, and Silver Strand Littoral Cells for the Sand Resources Project along the Continental Shelf of California

Summary

For the Sand Resources Project, 74 vibracore samples were collected from the San Francisco, Oceanside, and Silver Strand Littoral Cell study areas along the California continental shelf. These cores were photographed, described, sampled, and characterized using a multisensor logger. These observations have been presented as graphical logs for each core.

The core logs are organized by core number, each of which contains a study-area label and a sample number. The study-area labels are as follows:

- SF—San Francisco Littoral Cell,
- OC—Oceanside Littoral Cell, and
- SD—Silver Strand Littoral Cell.

Each core log includes the following elements (from left to right): a photograph of the split core; a core description of the core, showing the distance along the core (on left, in centimeters [cm]), the grain-size classes (along the top: c, coarse sand; f, fine sand; med, medium sand; vc, very coarse sand; vf, very fine sand), and the core descriptions and colors (on right; see the explanation for the lithology symbols) (large X, where present, indicates missing core material); and the output of the multisensor core logger, which may include density (in grams per cubic centimeter [g/cm^3]), sound velocity (in meters per second [m/s]), and (or) magnetic susceptibility (Mag. Susc.) (dimensionless), depending on the sample date.

Raw data and photographs and their associated metadata are available in Sliter and others (2021a, c).

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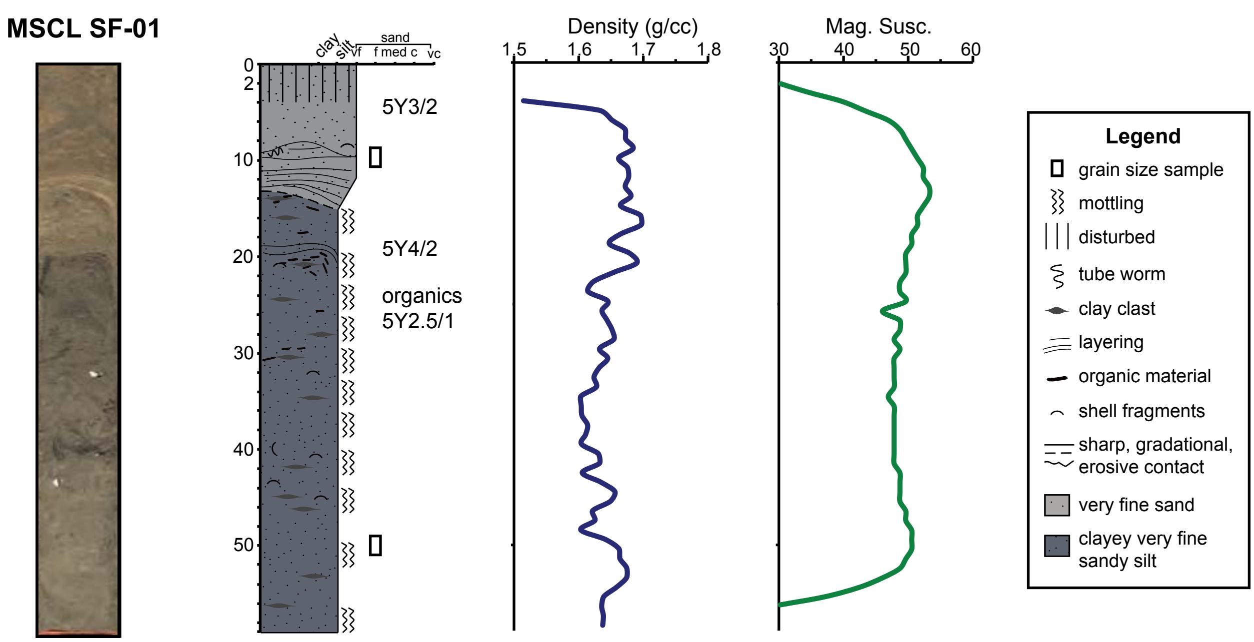

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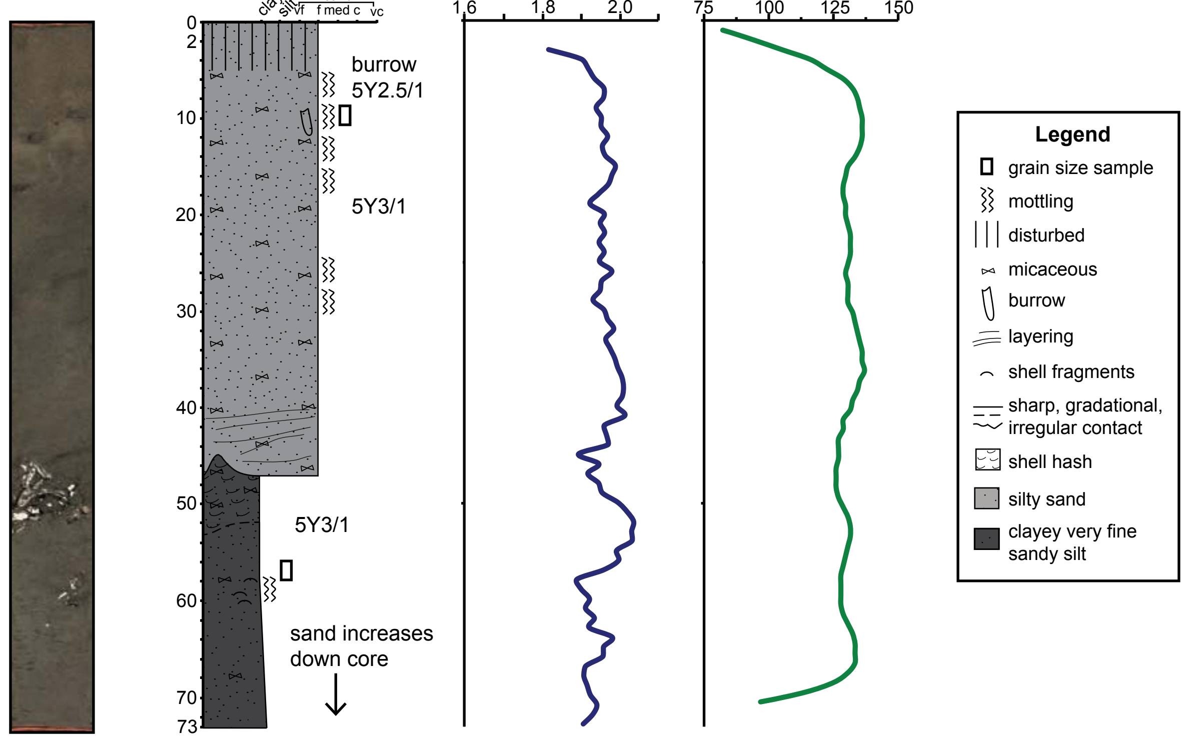

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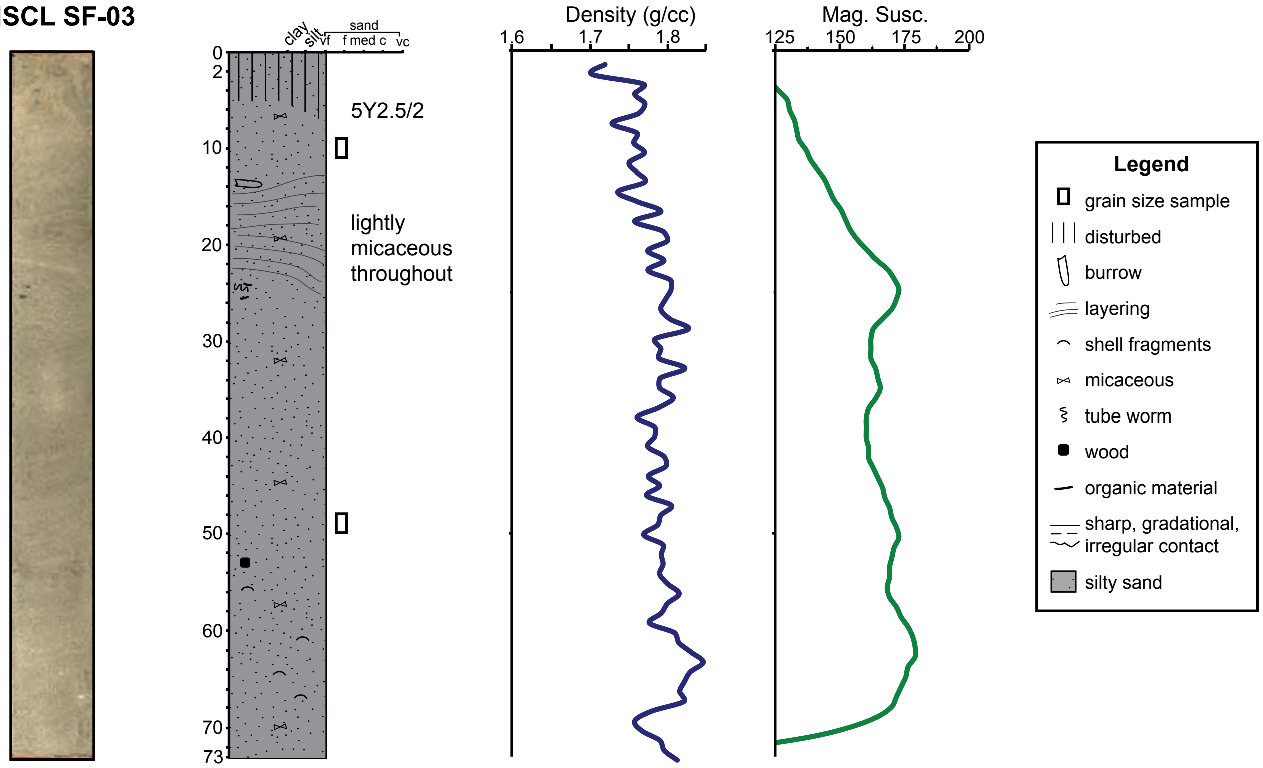
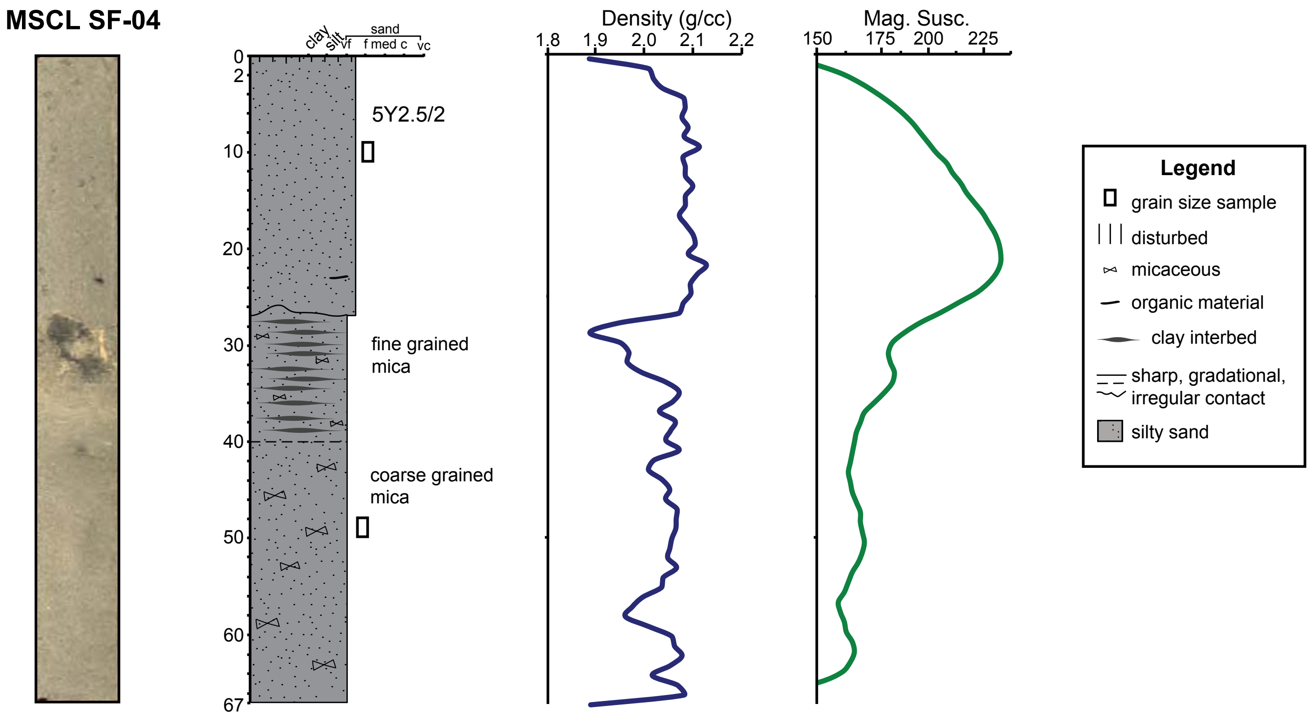
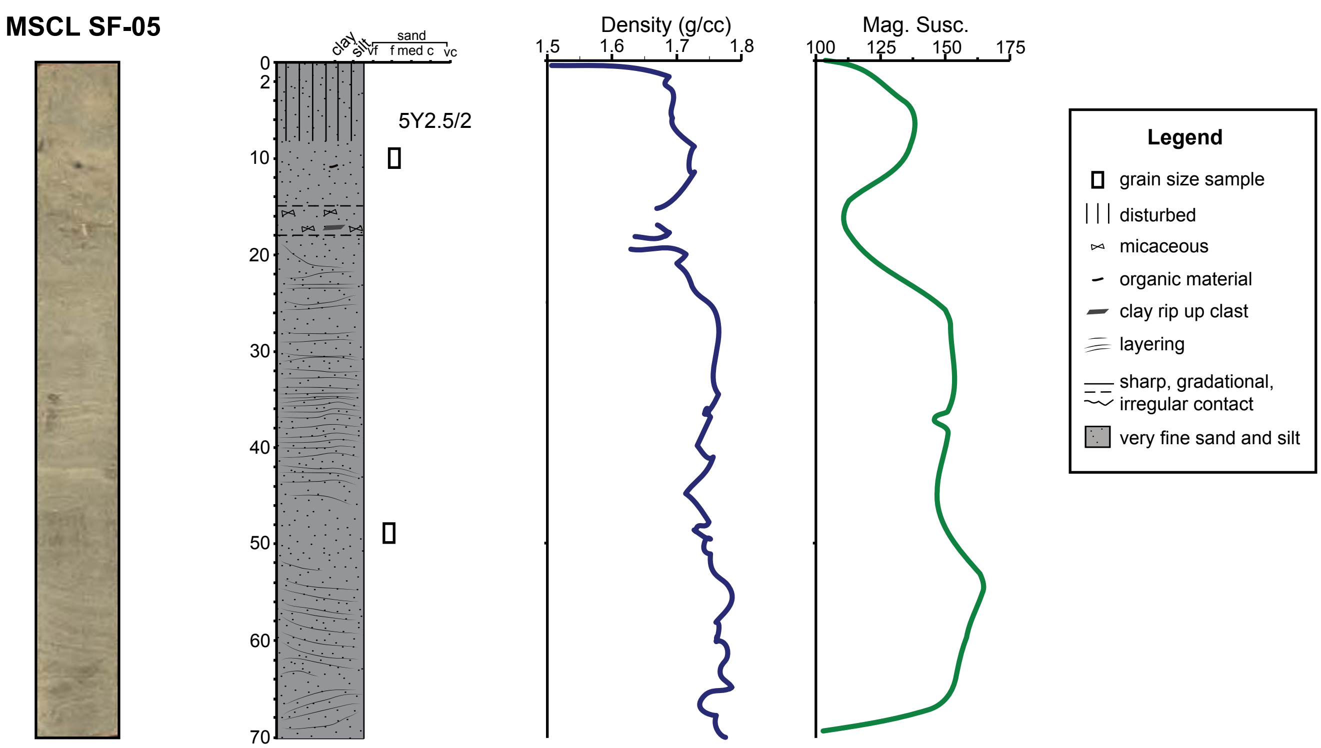
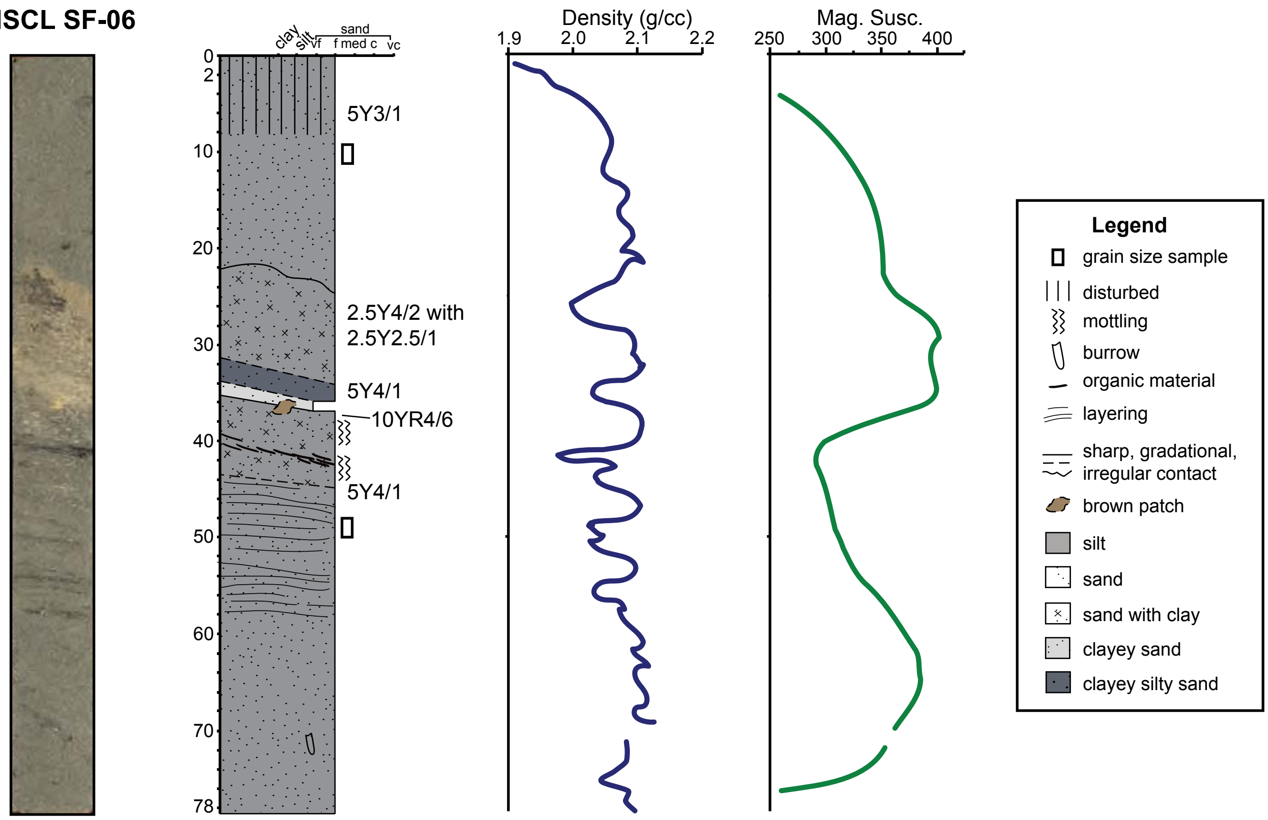


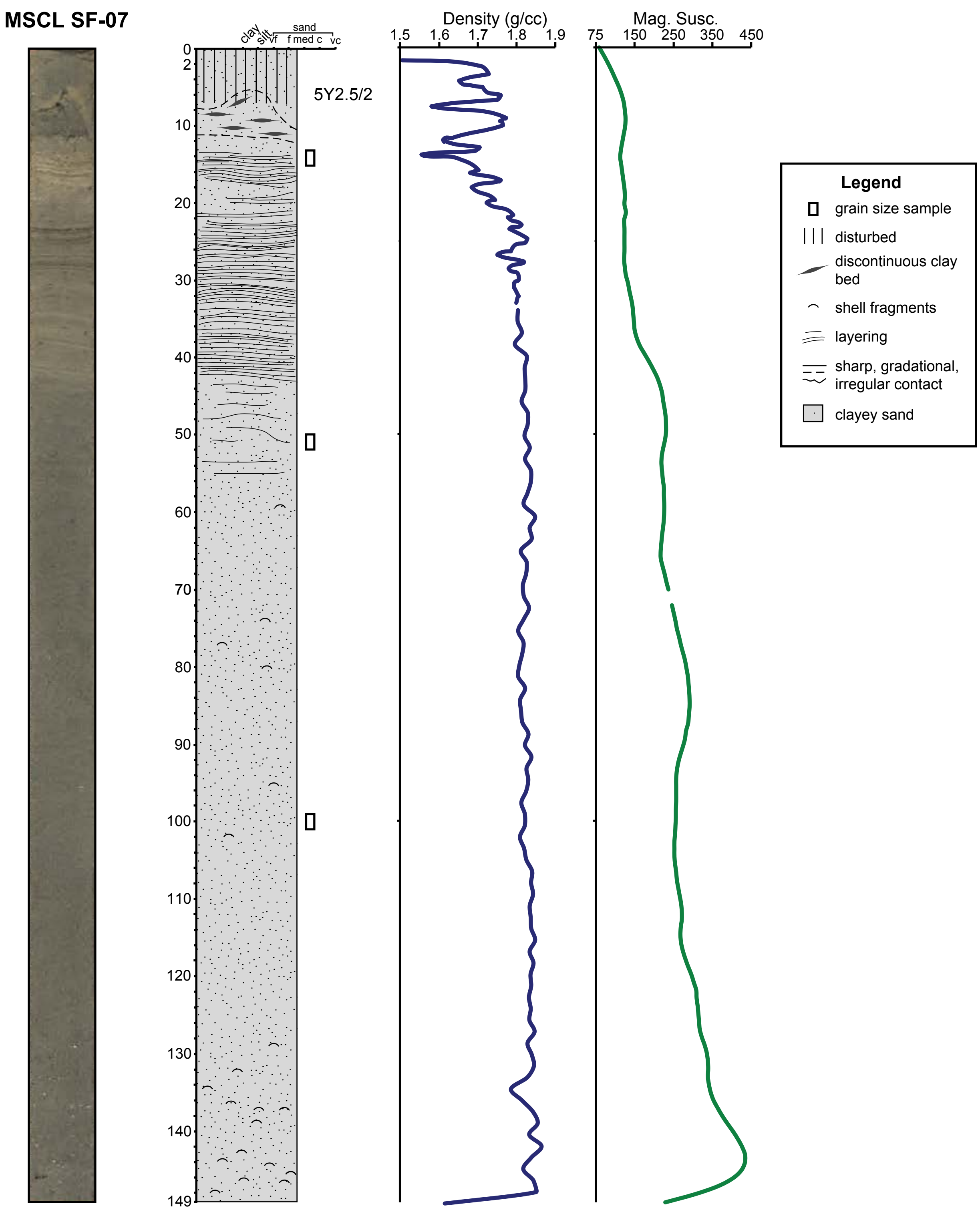

MSCL SF-04
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
67
5Y2.5/2
fine grained
mica
coarse grained
mica
Density (g/cc)
1.8 1.9 2.0 2.1 2.2
Mag. Susc.
150 175 200 225
Legend
grain size sample
disturbed
micaceous
organic material
clay interbed
sharp, gradational,
irregular contact
silty sand


MSCL SF-05
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
5Y2.5/2
Density (g/cc)
1.5 1.6 1.7 1.8
Mag. Susc.
100 125 150 175
Legend
grain size sample
disturbed
micaceous
organic material
clay rip up clast
layering
sharp, gradational,
irregular contact
very fine sand and silt

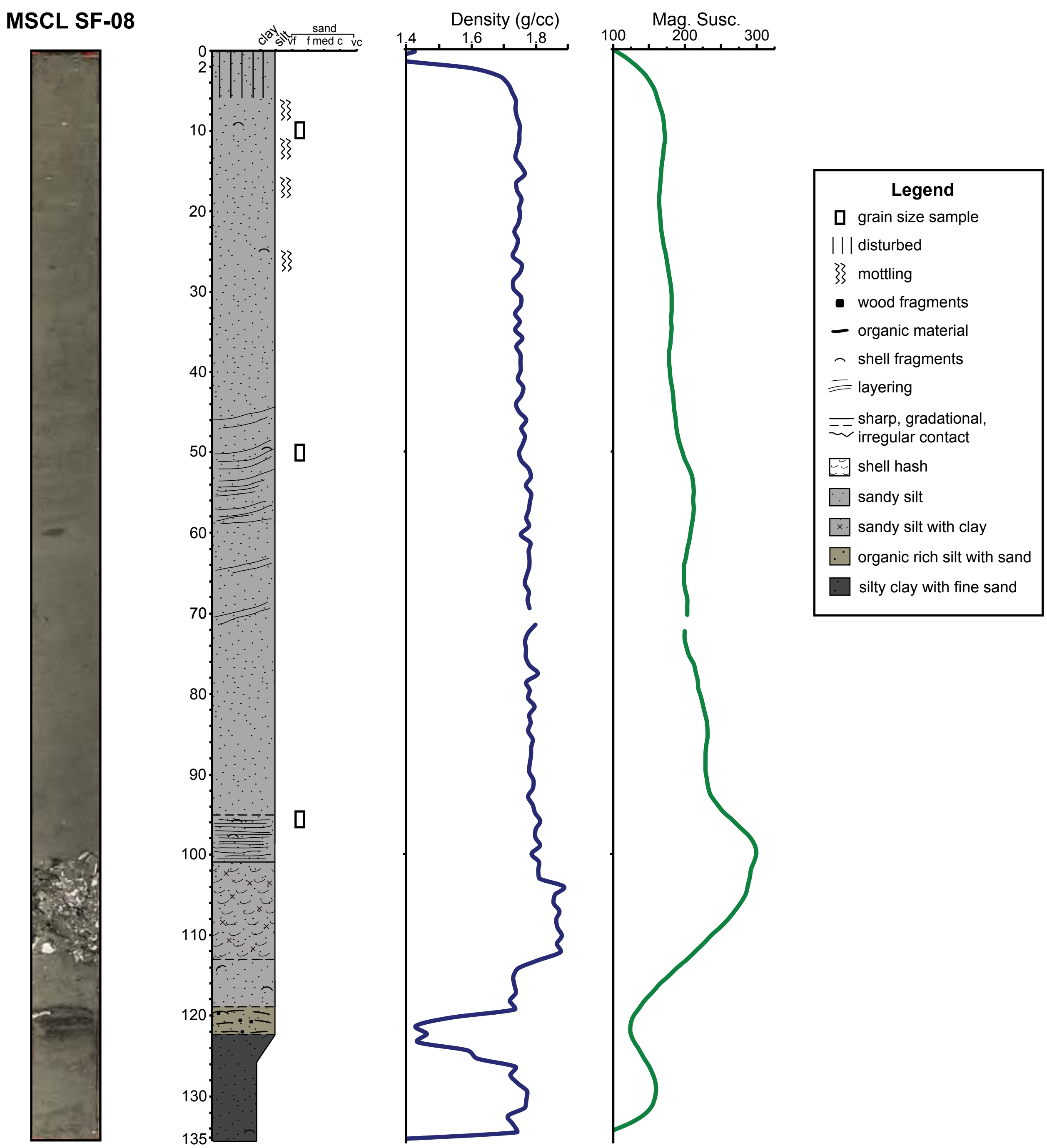
MSCL SF-06



clay
silt
vf
sand
f med c
vc
0
2
10
20
30
40
50
60
70
78
5Y3/1
2.5Y4/2 with
2.5Y2.5/1
5Y4/1
10YR4/6
5Y4/1
Density (g/cc)
1.9
2.0
2.1
2.2
Mag. Susc.
250
300
350
400
Legend
grain size sample
disturbed
mottling
burrow
organic material
layering
sharp, gradational,
irregular contact
brown patch
silt
sand
sand with clay
clayey sand
clayey silty sand



MSCL SF-07
clay
silt
sand
vf
f med c
vc
5Y2.5/2
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
149
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Mag. Susc.
75
150
250
350
450
Legend
grain size sample
disturbed
discontinuous clay bed
shell fragments
layering
sharp, gradational, irregular contact
clayey sand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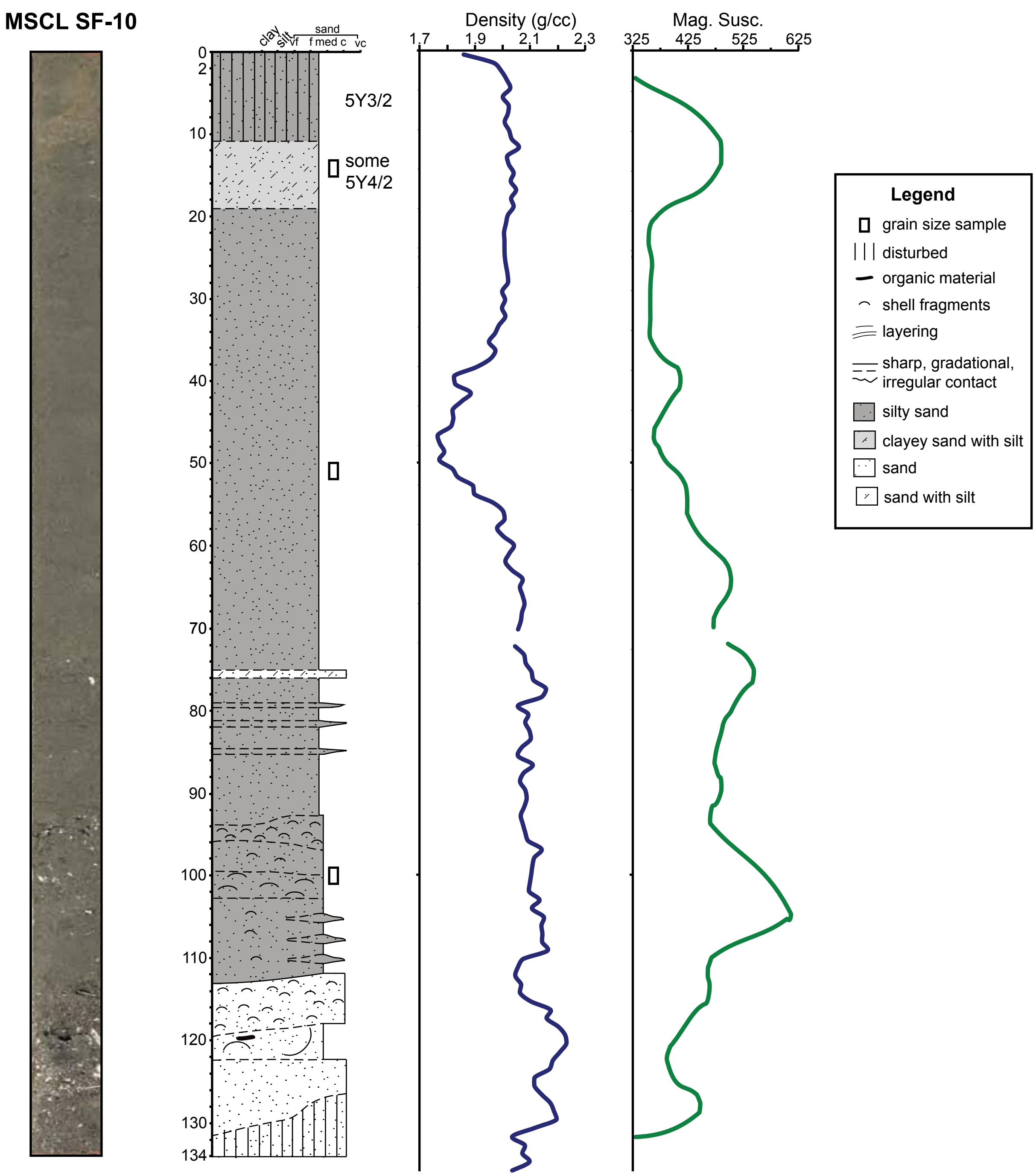
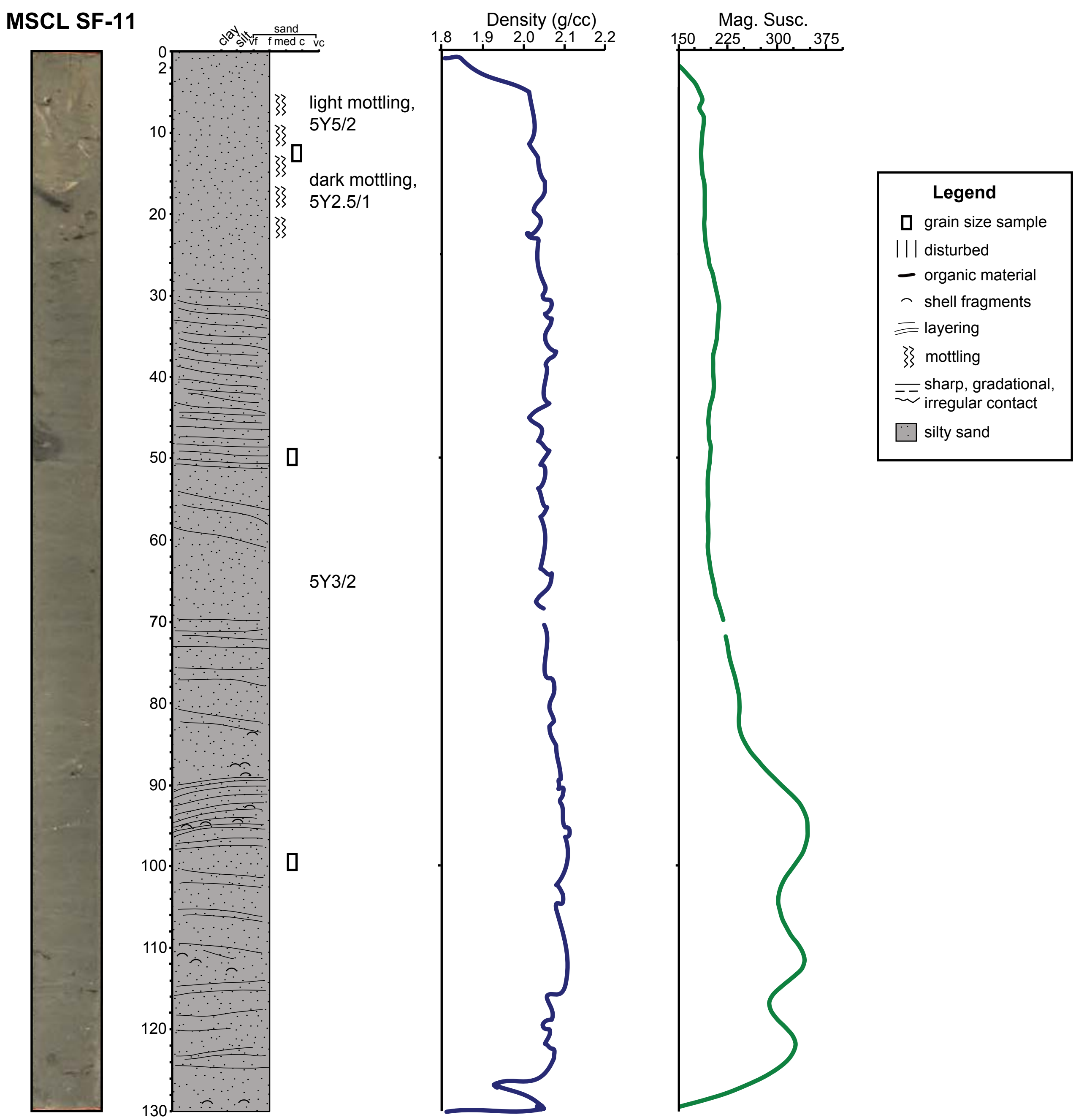
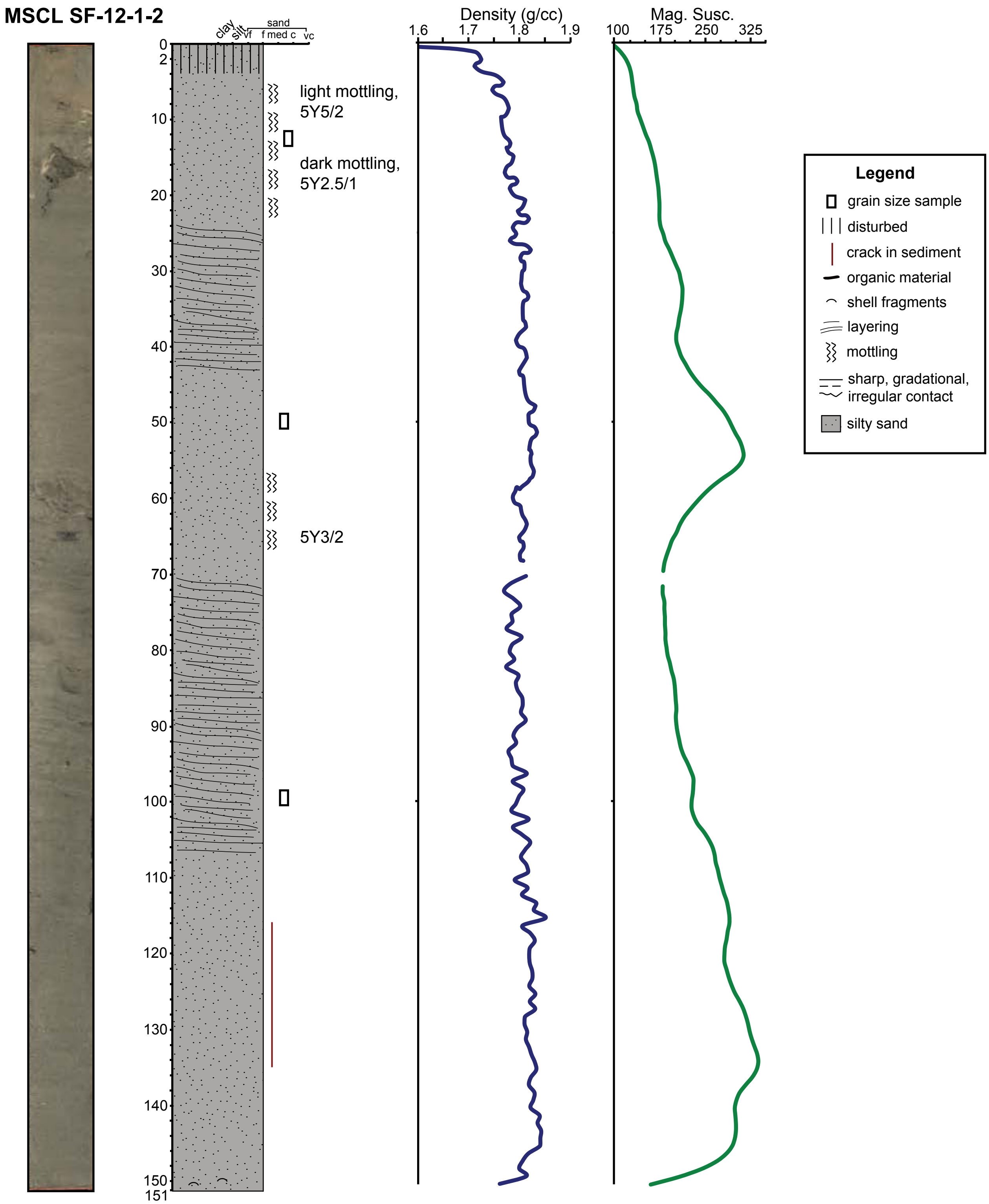
clay
silt
vf
sand
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
135
Density (g/cc)
1.4
1.6
1.8
Mag. Susc.
100
200
300
Legend
grain size sample
disturbed
mottling
wood fragments
organic material
shell fragments
layering
sharp, gradational, irregular contact
shell hash
sandy silt
sandy silt with clay
organic rich silt with sand
silty clay with fine sand

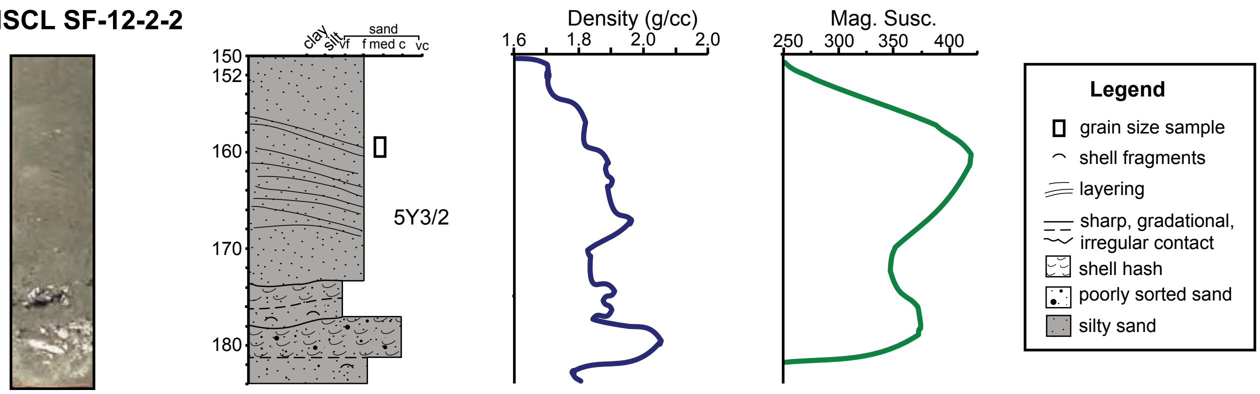

MSCL SF-10
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
134
5Y3/2
some
5Y4/2
Density (g/cc)
1.7 1.9 2.1 2.3
Mag. Susc.
325 425 525 625
Legend
grain size sample
disturbed
organic material
shell fragments
layering
sharp, gradational, irregular contact
silty sand
clayey sand with silt
sand
sand with silt


MSCL SF-11
clay
silt
vf
sand
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
light mottling,
5Y5/2
dark mottling,
5Y2.5/1
5Y3/2
Density (g/cc)
1.8 1.9 2.0 2.1 2.2
Mag. Susc.
150 225 300 375
Legend
grain size sample
disturbed
organic material
shell fragments
layering
mottling
sharp, gradational,
irregular contact
silty sand

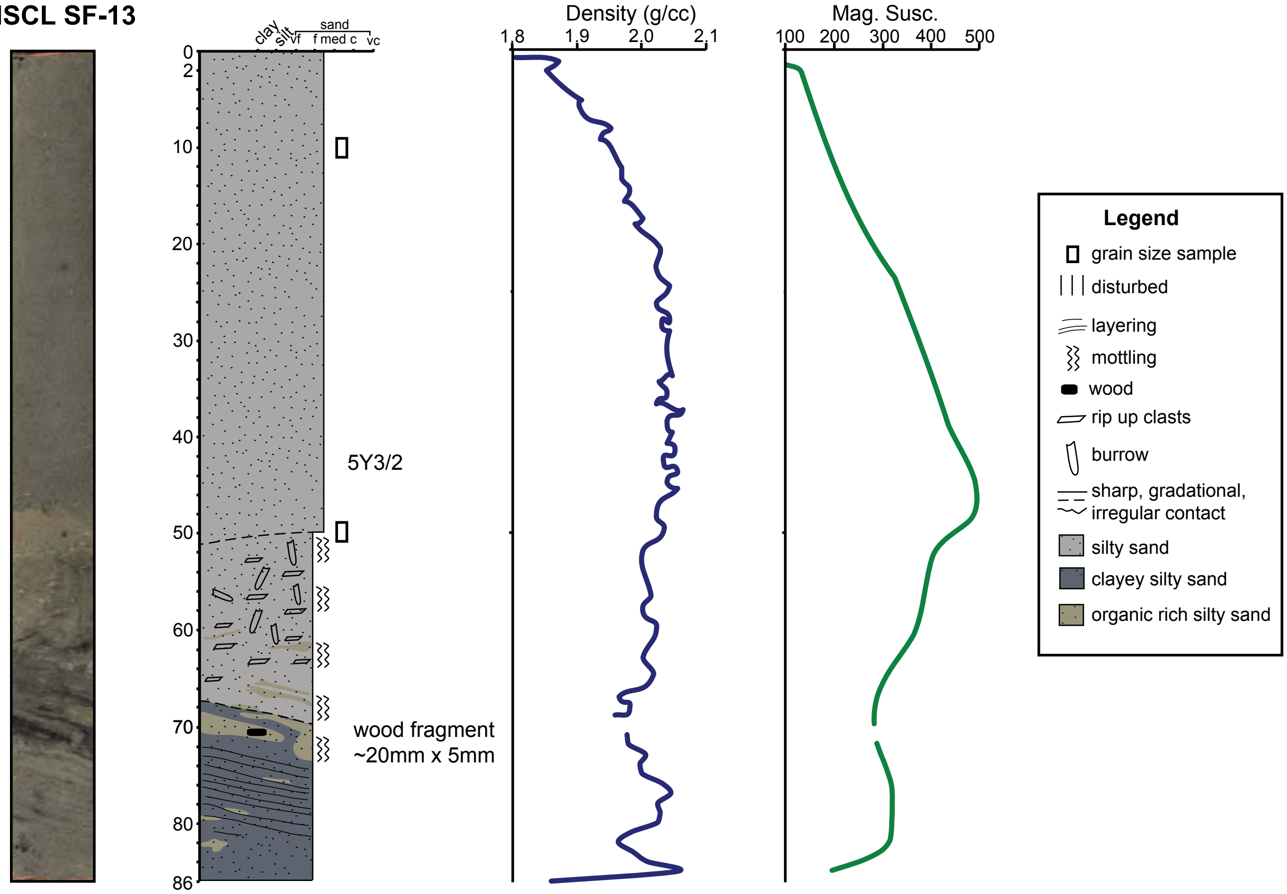


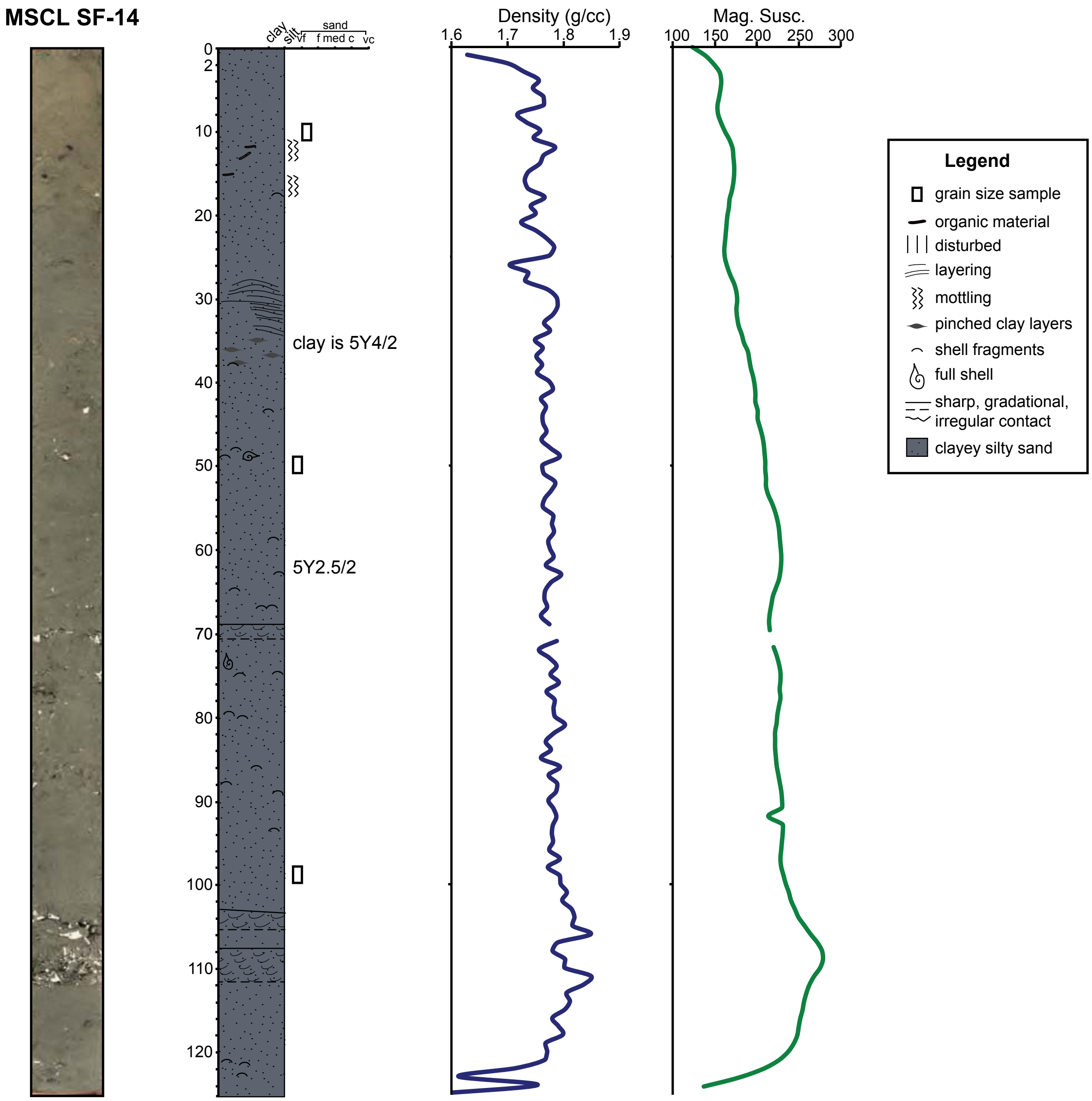
MSCL SF-12-1-2
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
151
light mottling, 5Y5/2
dark mottling, 5Y2.5/1
5Y3/2
Density (g/cc)
1.6
1.7
1.8
1.9
Mag. Susc.
100
175
250
325
Legend
grain size sample
disturbed
crack in sediment
organic material
shell fragments
layering
mottling
sharp, gradational, irregular contact
silty sand

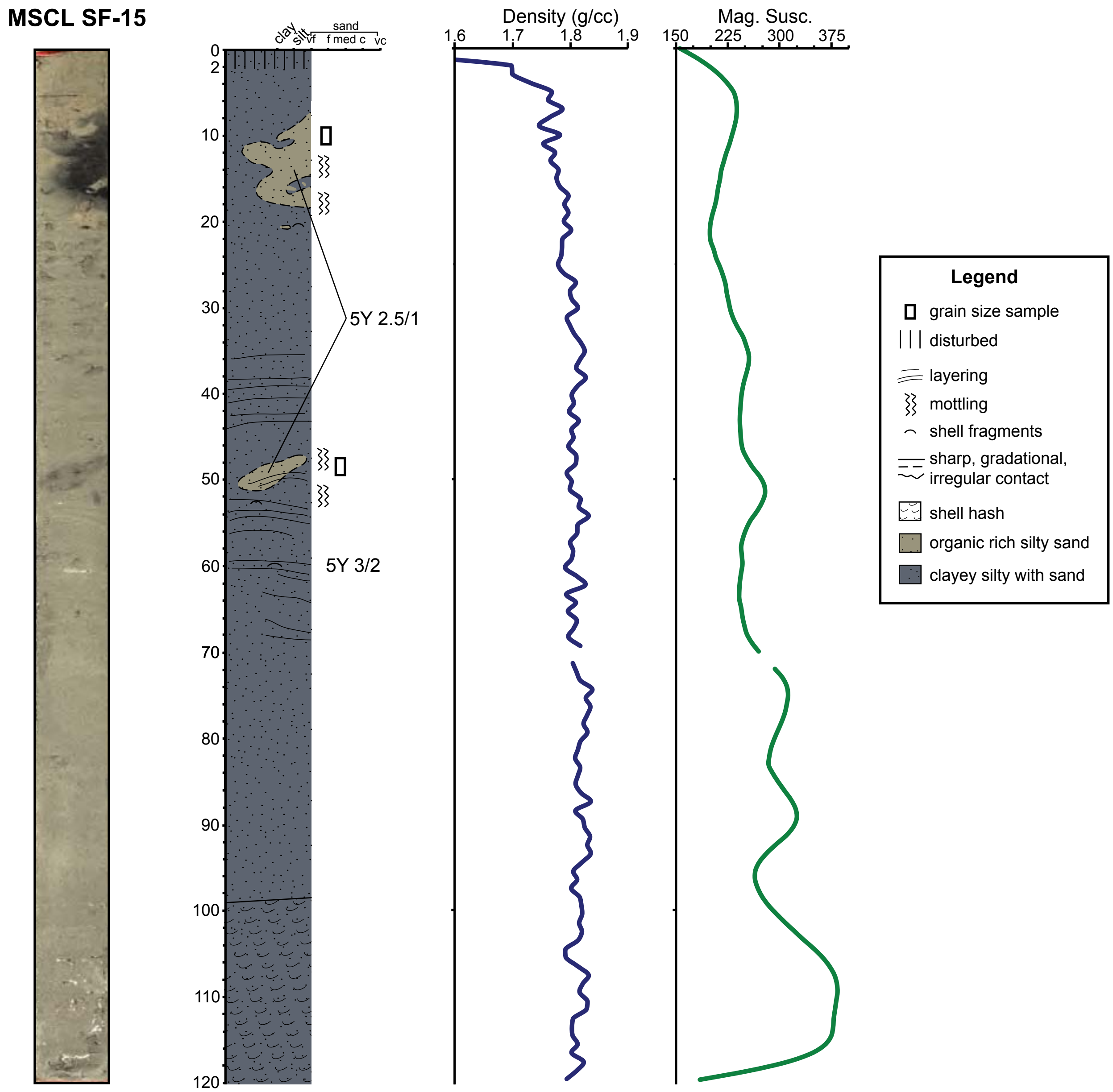
MSCL SF-12-2-2

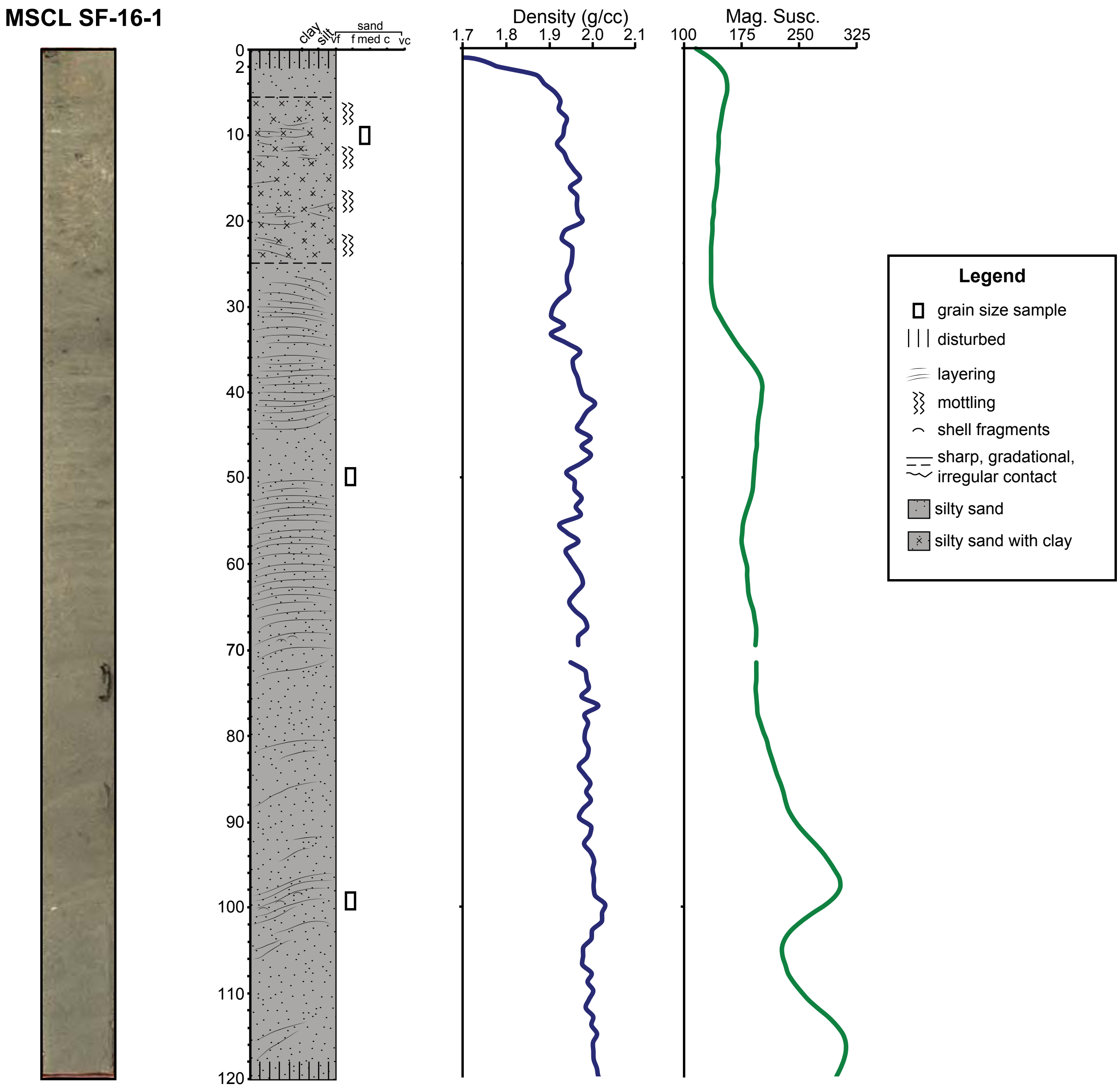


MSCL SF-13



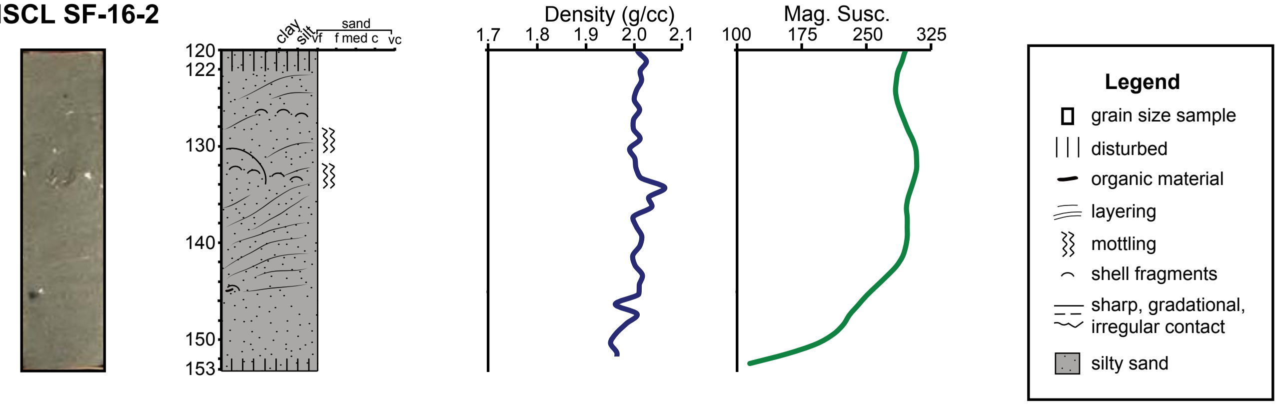

MSCL SF-14
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
clay is 5Y4/2
5Y2.5/2
Density (g/cc)
1.6
1.7
1.8
1.9
Mag. Susc.
100
150
200
250
300
Legend
grain size sample
organic material
disturbed
layering
mottling
pinched clay layers
shell fragments
full shell
sharp, gradational, irregular contact
clayey silty sand


MSCL SF-15
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
5Y 2.5/1
5Y 3/2
Density (g/cc)
1.6 1.7 1.8 1.9
Mag. Susc.
150 225 300 375
Legend
grain size sample
disturbed
layering
mottling
shell fragments
sharp, gradational, irregular contact
shell hash
organic rich silty sand
clayey silty with sand

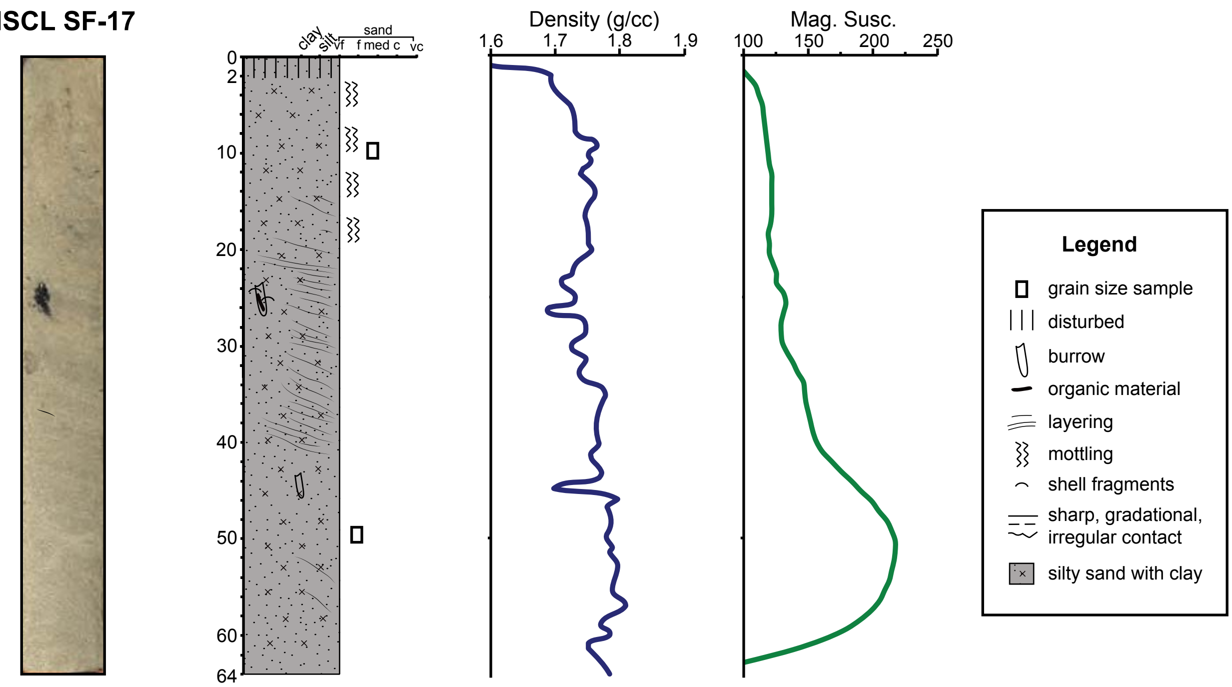


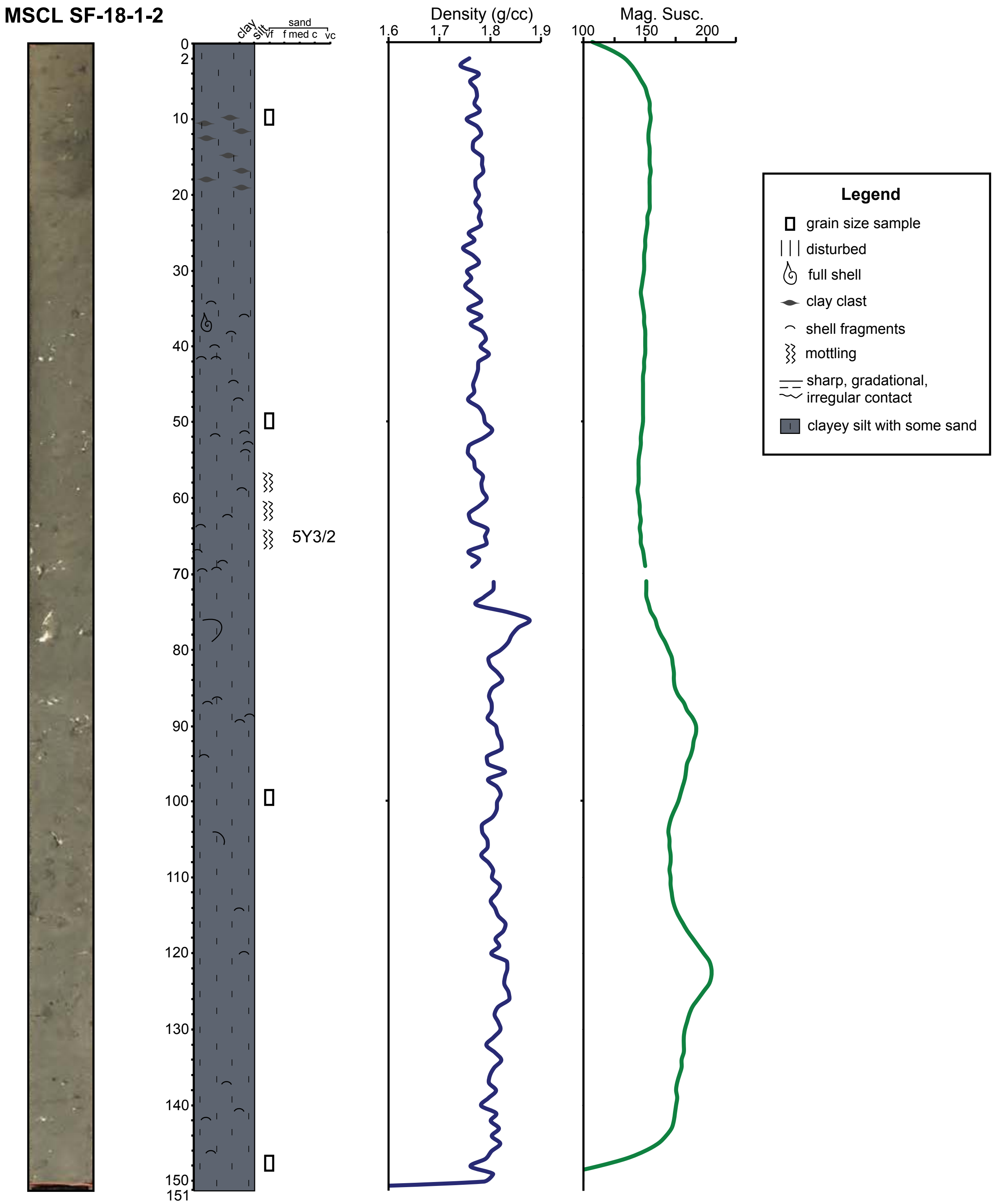
MSCL SF-16-1
clay
silt
vf
sand
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
Density (g/cc)
1.7
1.8
1.9
2.0
2.1
Mag. Susc.
100
175
250
325
Legend
grain size sample
disturbed
layering
mottling
shell fragments
sharp, gradational, irregular contact
silty sand
silty sand with clay

MSCL SF-16-2

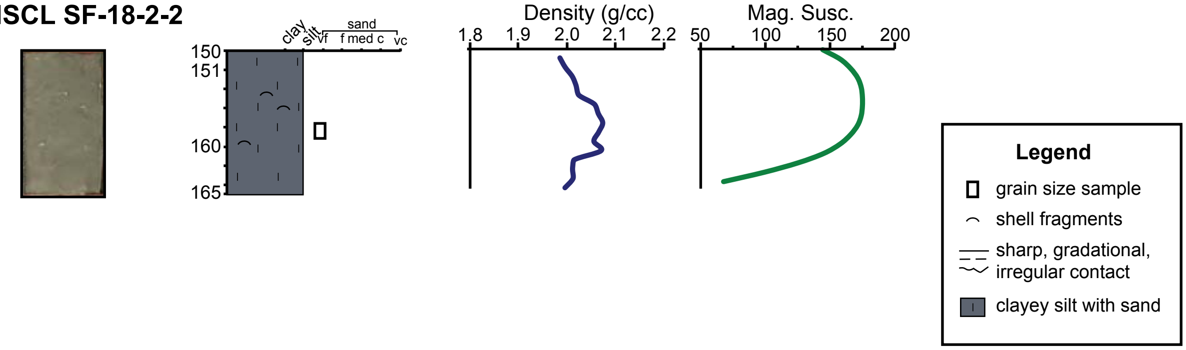


MSCL SF-17

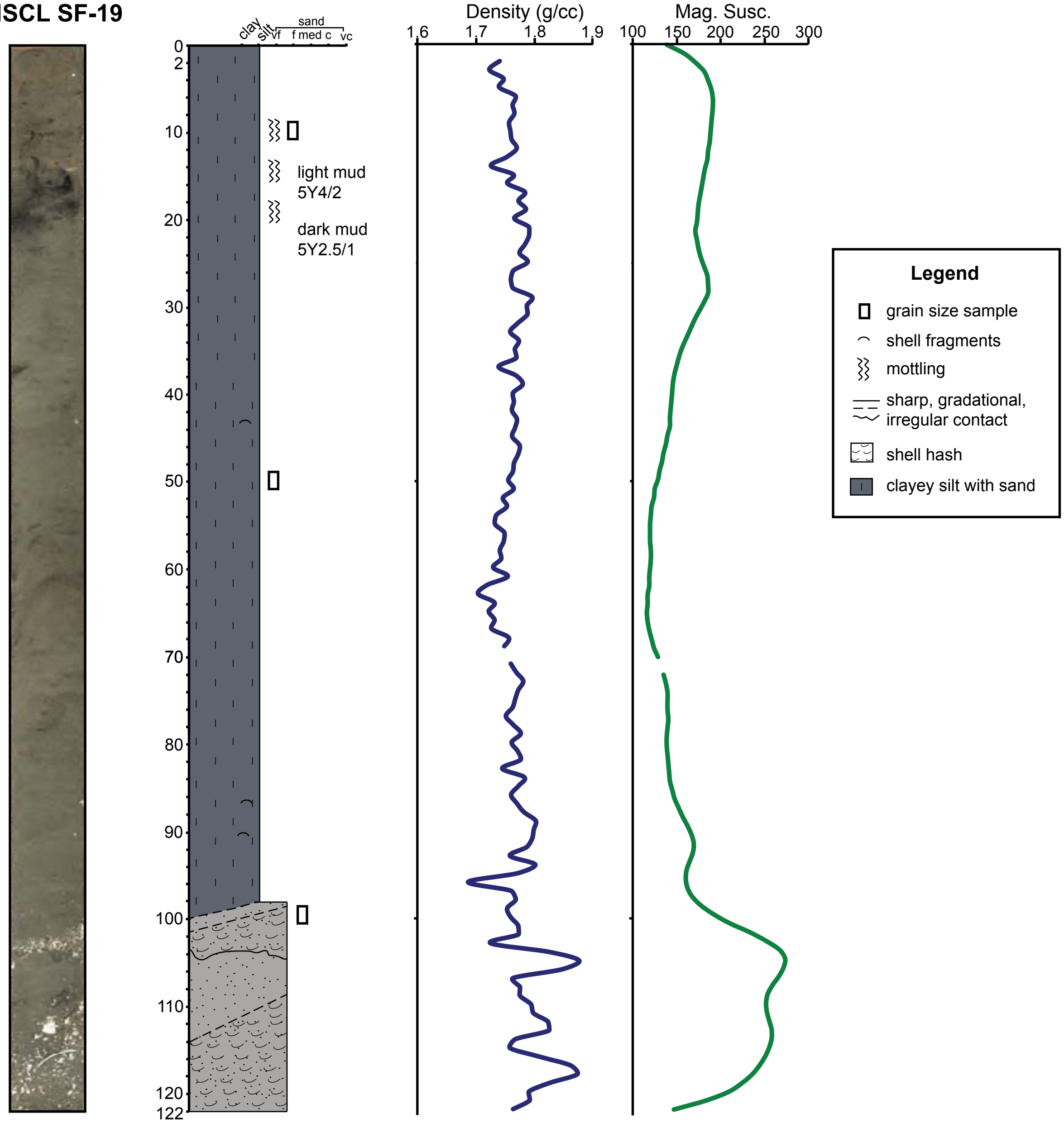


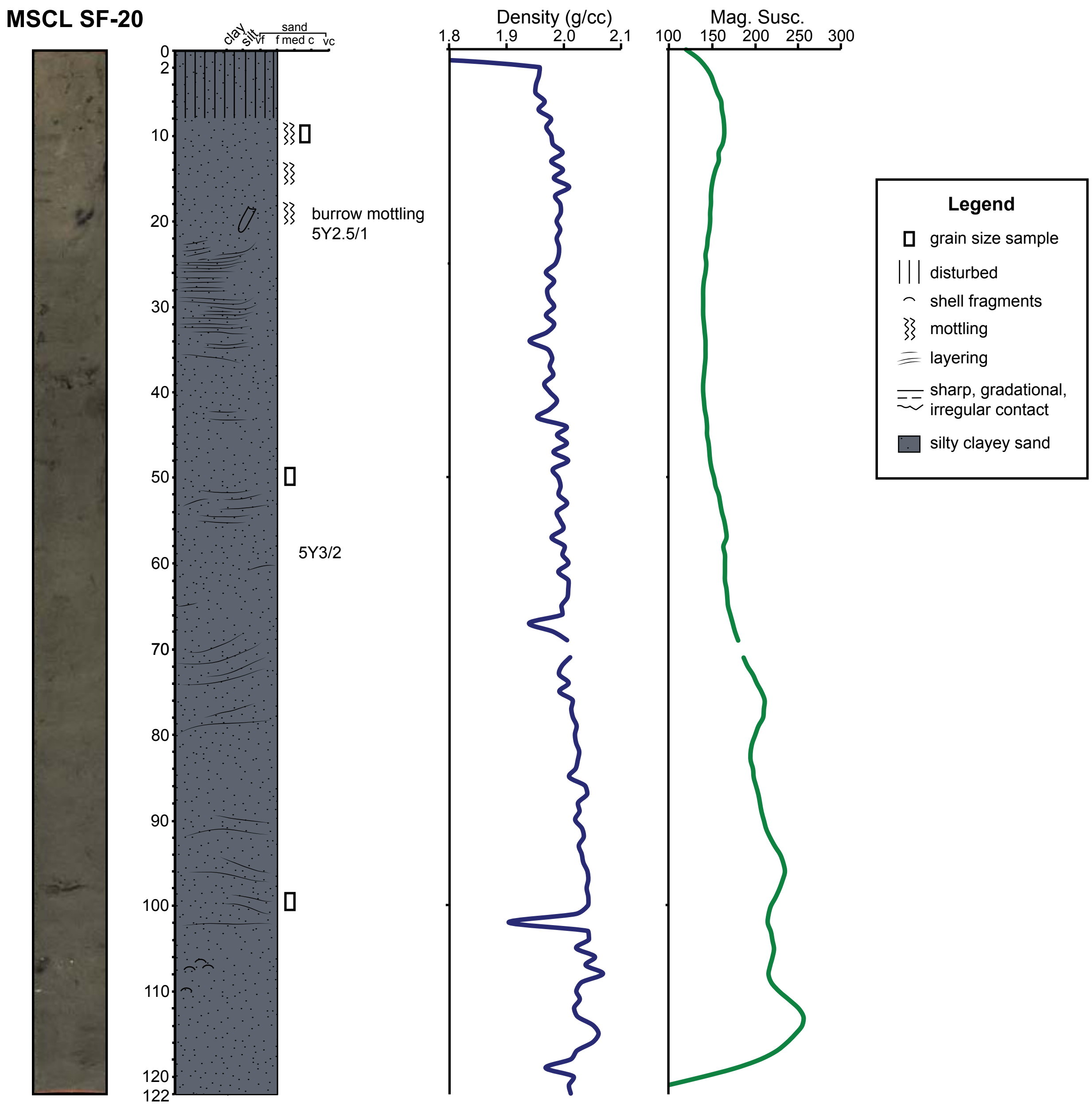

MSCL SF-18-1-2
clay
silt
sand
vf
f med c
vc
5Y3/2
Density (g/cc)
1.6
1.7
1.8
1.9
Mag. Susc.
100
150
200
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
151
Legend
grain size sample
disturbed
full shell
clay clast
shell fragments
mottling
sharp, gradational, irregular contact
clayey silt with some sand

MSCL SF-18-2-2

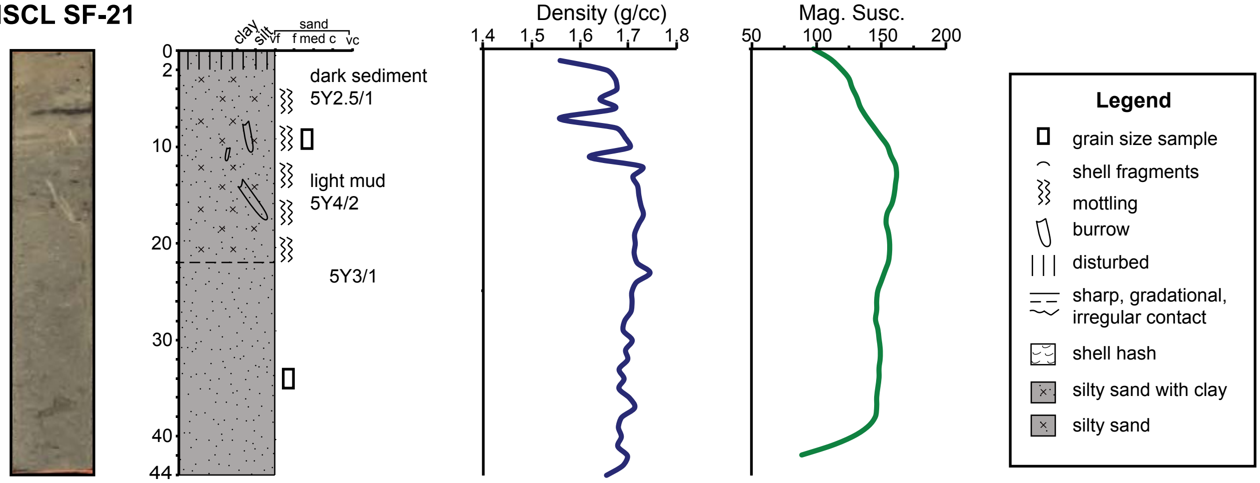


MSCL SF-19

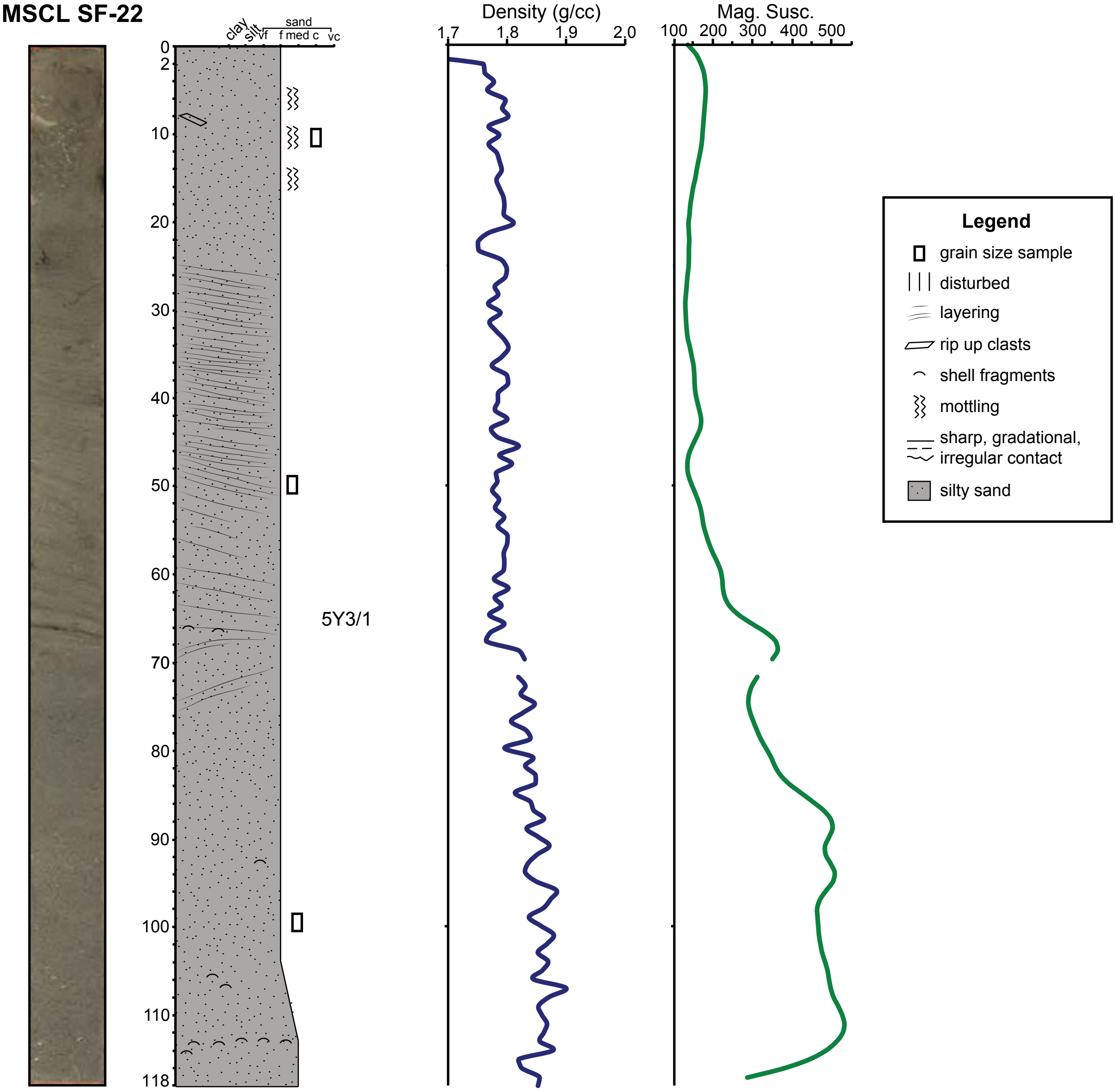


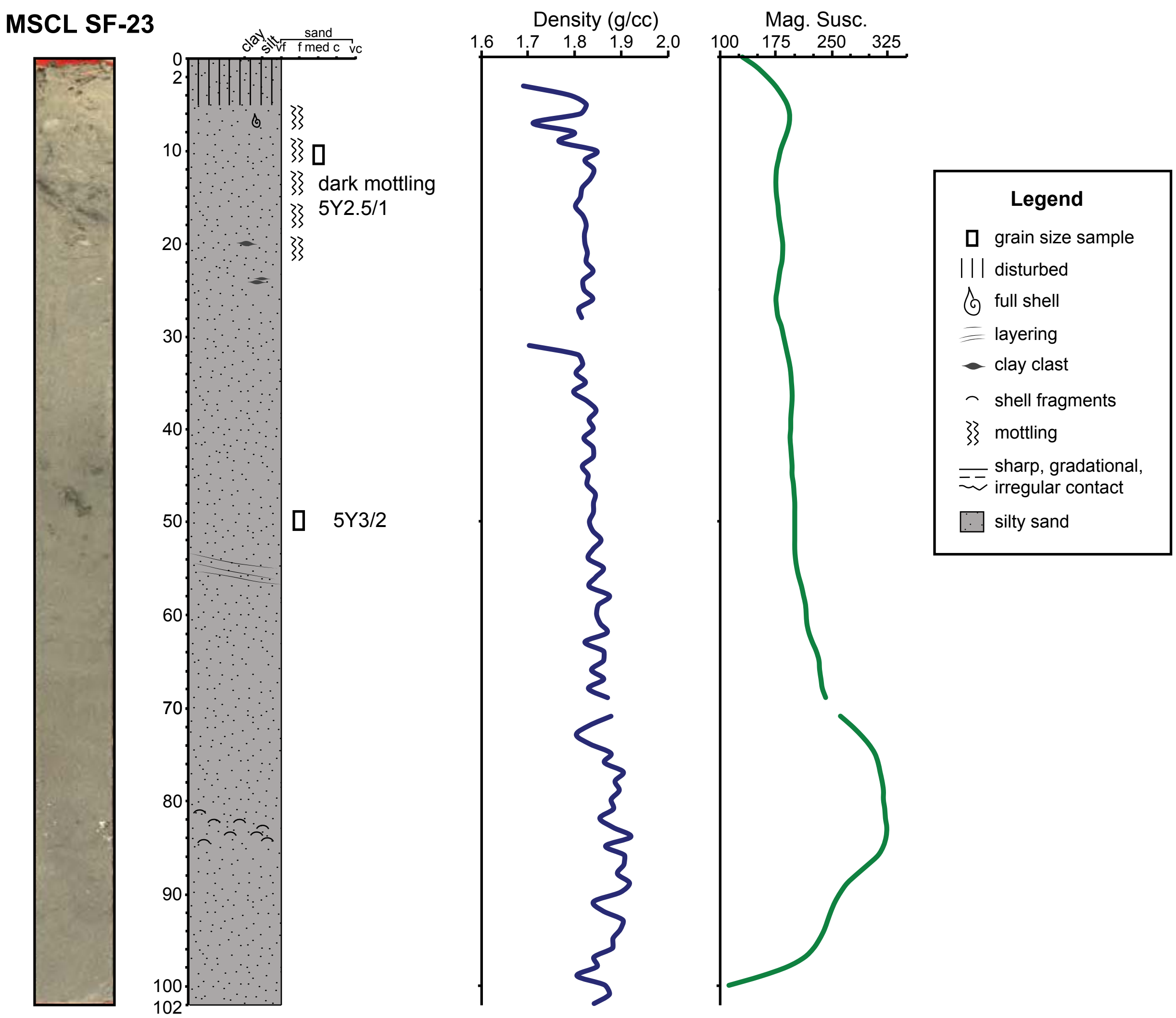

MSCL SF-20
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
122
burrow mottling
5Y2.5/1
5Y3/2
Density (g/cc)
1.8
1.9
2.0
2.1
Mag. Susc.
100
150
200
250
300
Legend
grain size sample
disturbed
shell fragments
mottling
layering
sharp, gradational, irregular contact
silty clayey sand

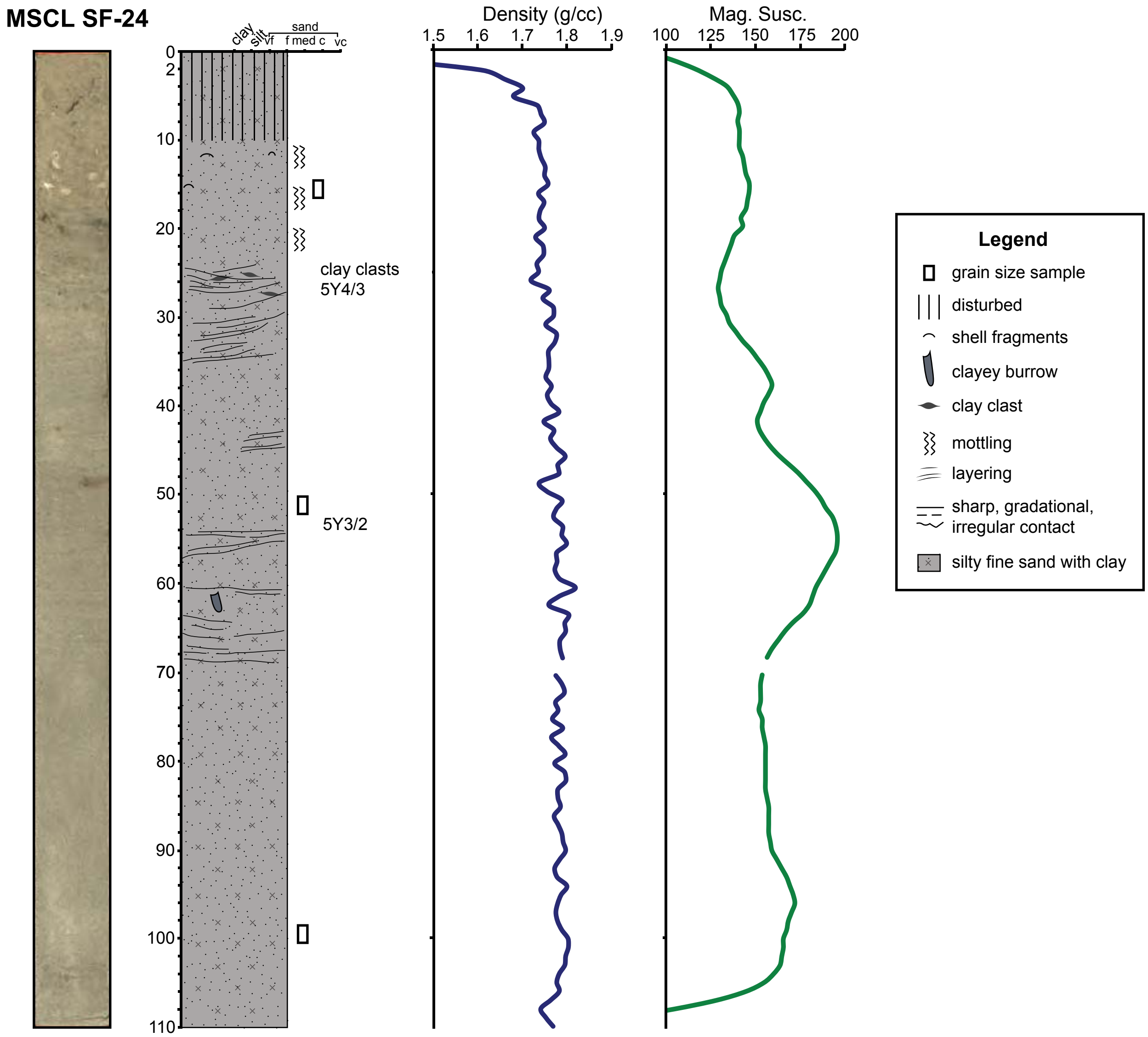
MSCL SF-21

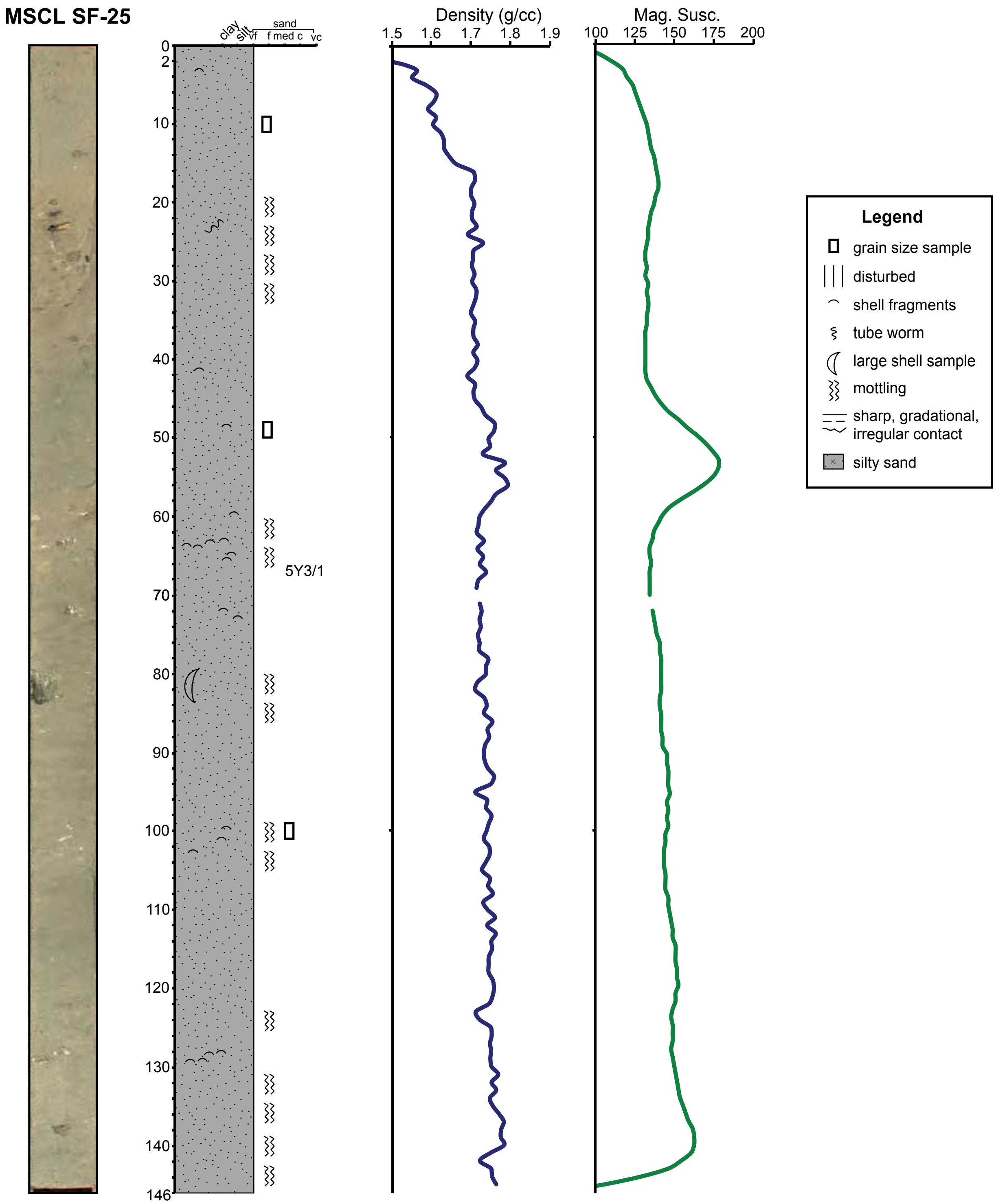


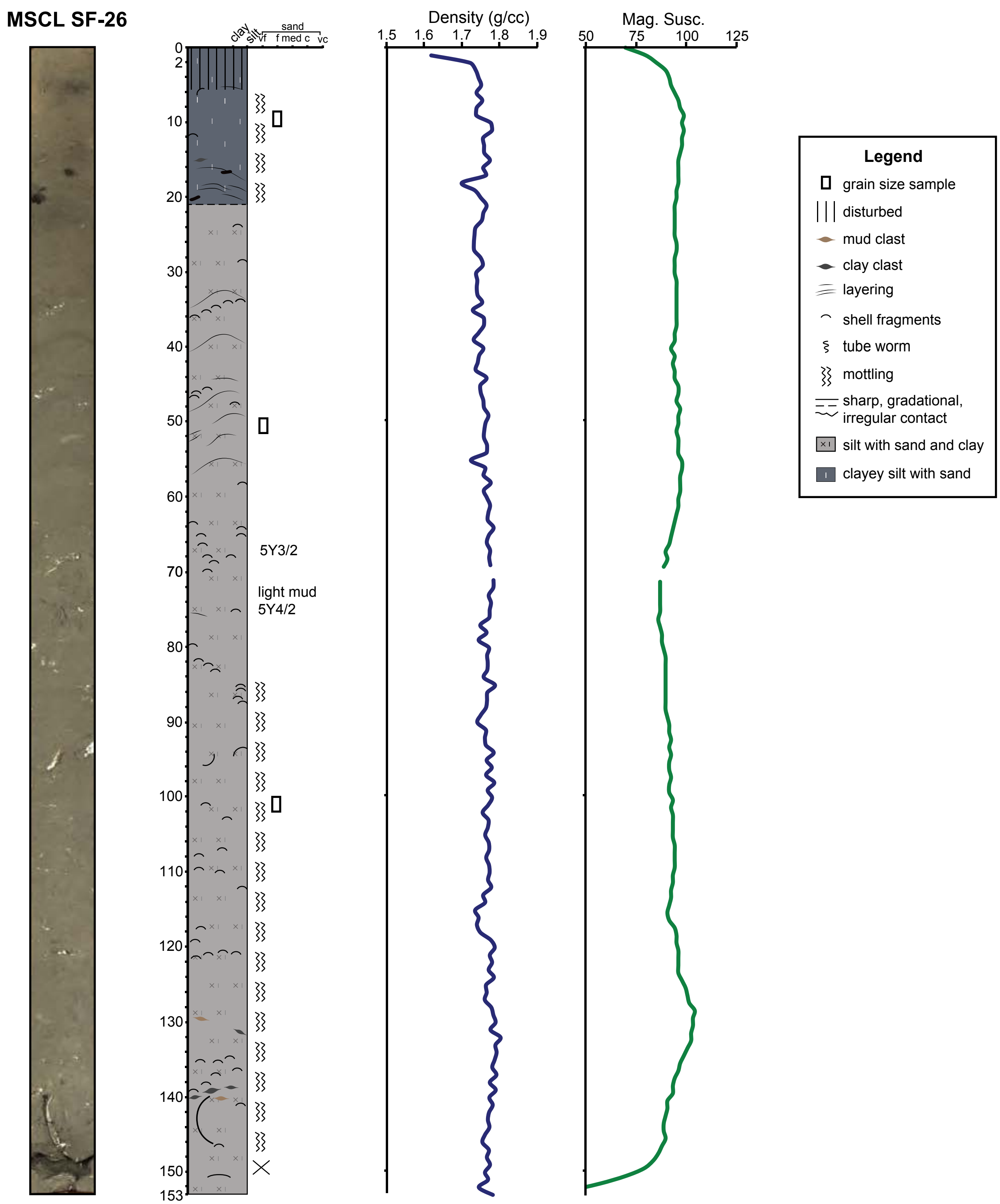
MSCL SF-22



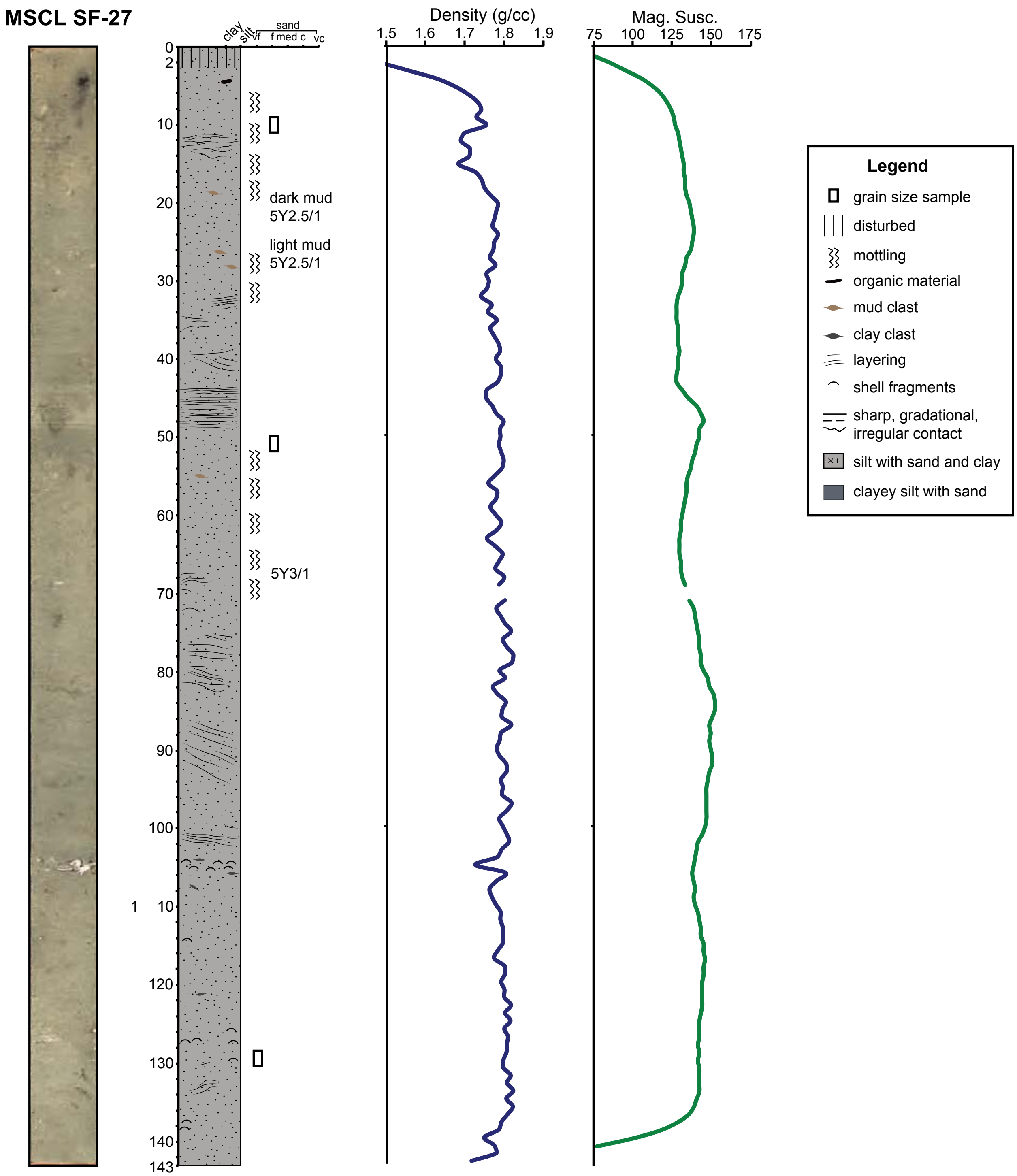

MSCL SF-23
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
102
dark mottling
5Y2.5/1
5Y3/2
Density (g/cc)
1.6
1.7
1.8
1.9
2.0
Mag. Susc.
100
175
250
325
Legend
grain size sample
disturbed
full shell
layering
clay clast
shell fragments
mottling
sharp, gradational,
irregular contact
silty sand

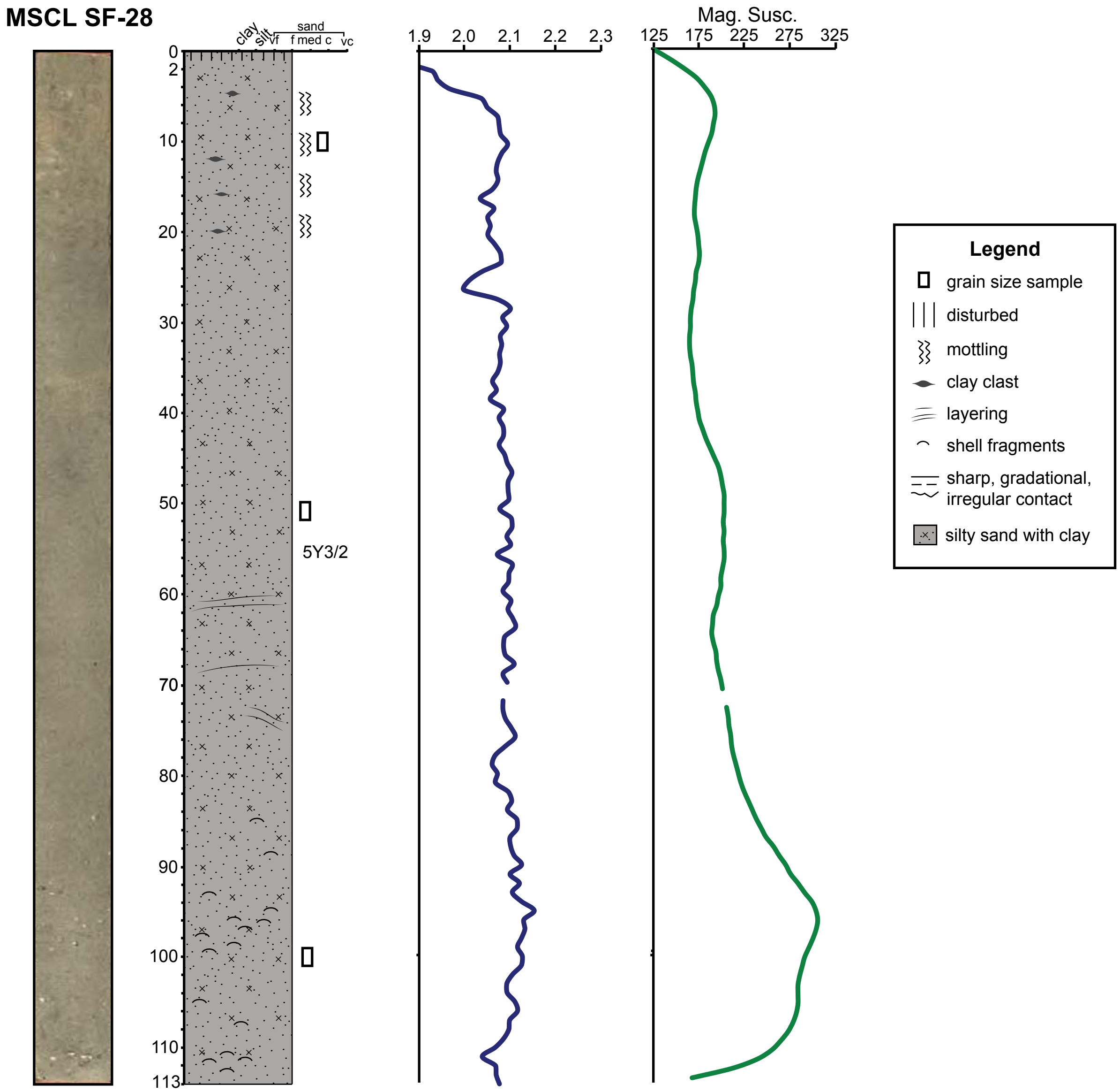

MSCL SF-24
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
clay clasts
5Y4/3
5Y3/2
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Mag. Susc.
100
125
150
175
200
Legend
grain size sample
disturbed
shell fragments
clayey burrow
clay clast
mottling
layering
sharp, gradational, irregular contact
silty fine sand with clay

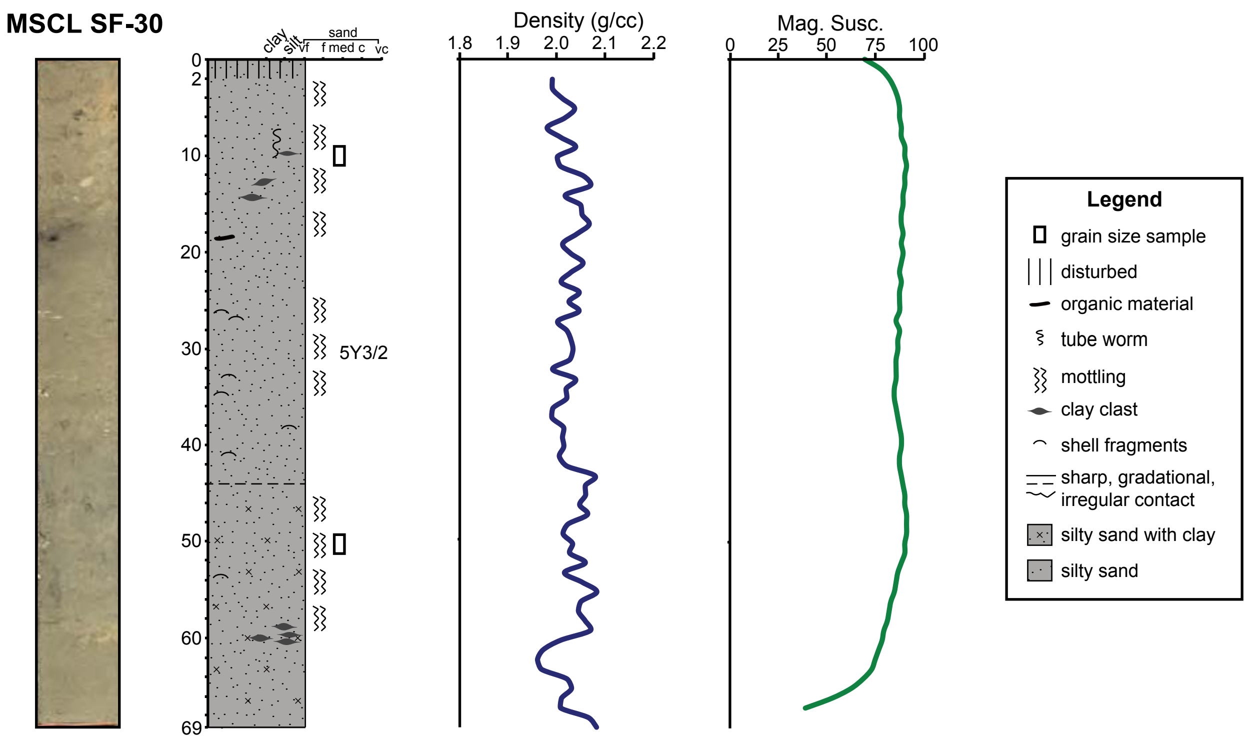

MSCL SF-25
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
146
5Y3/1
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Mag. Susc.
100
125
150
175
200
Legend
grain size sample
disturbed
shell fragments
tube worm
large shell sample
mottling
sharp, gradational, irregular contact
silty sand

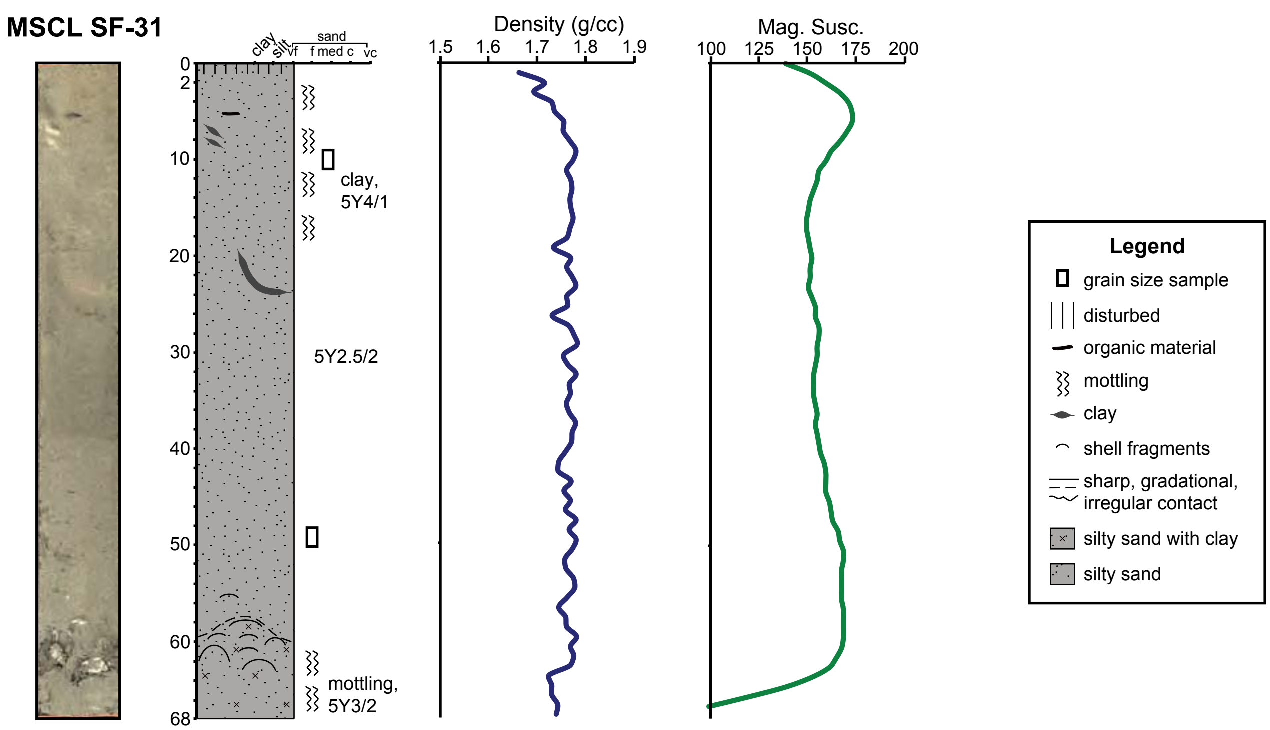


MSCL SF-26
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
153
5Y3/2
light mud
5Y4/2
Density (g/cc)
1.5 1.6 1.7 1.8 1.9
Mag. Susc.
50 75 100 125
Legend
grain size sample
disturbed
mud clast
clay clast
layering
shell fragments
tube worm
mottling
sharp, gradational, irregular contact
silt with sand and clay
clayey silt with sand

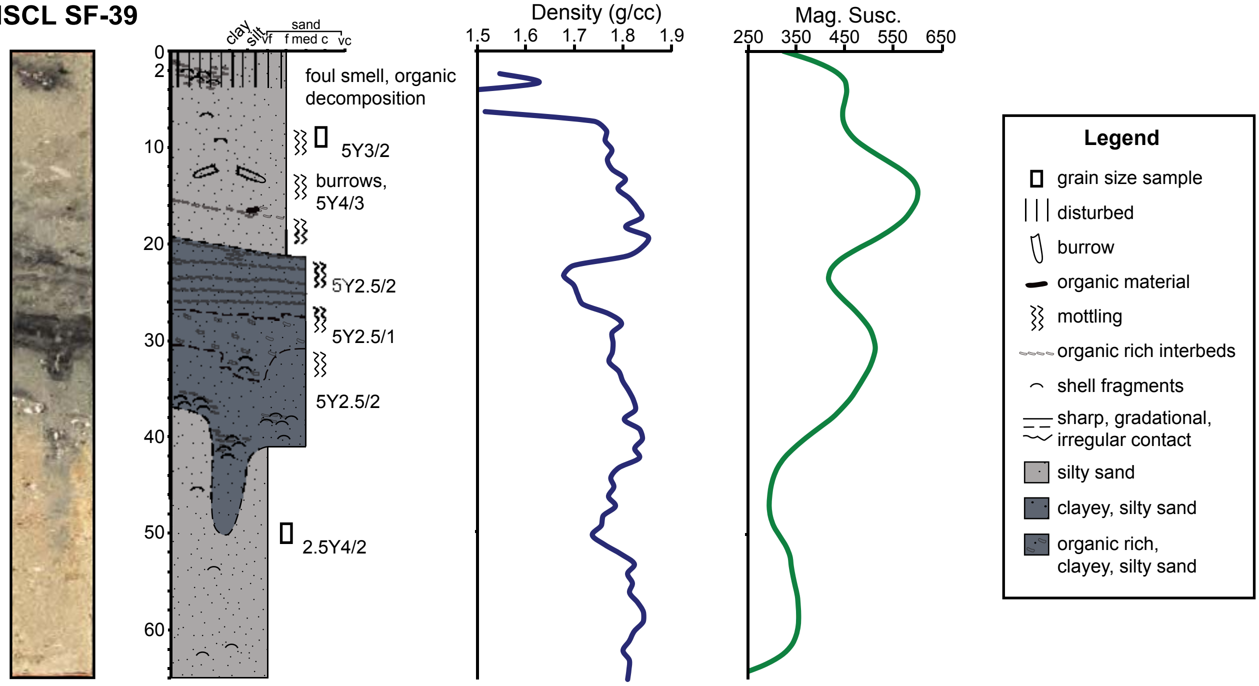

MSCL SF-27
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
1 10
120
130
140
143
dark mud
5Y2.5/1
light mud
5Y2.5/1
5Y3/1
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Mag. Susc.
75
100
125
150
175
Legend
grain size sample
disturbed
mottling
organic material
mud clast
clay clast
layering
shell fragments
sharp, gradational,
irregular contact
silt with sand and clay
clayey silt with sand


MSCL SF-28
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
113
5Y3/2
1.9
2.0
2.1
2.2
2.3
Mag. Susc.
125
175
225
275
325
Legend
grain size sample
disturbed
mottling
clay clast
layering
shell fragments
sharp, gradational, irregular contact
silty sand with clay

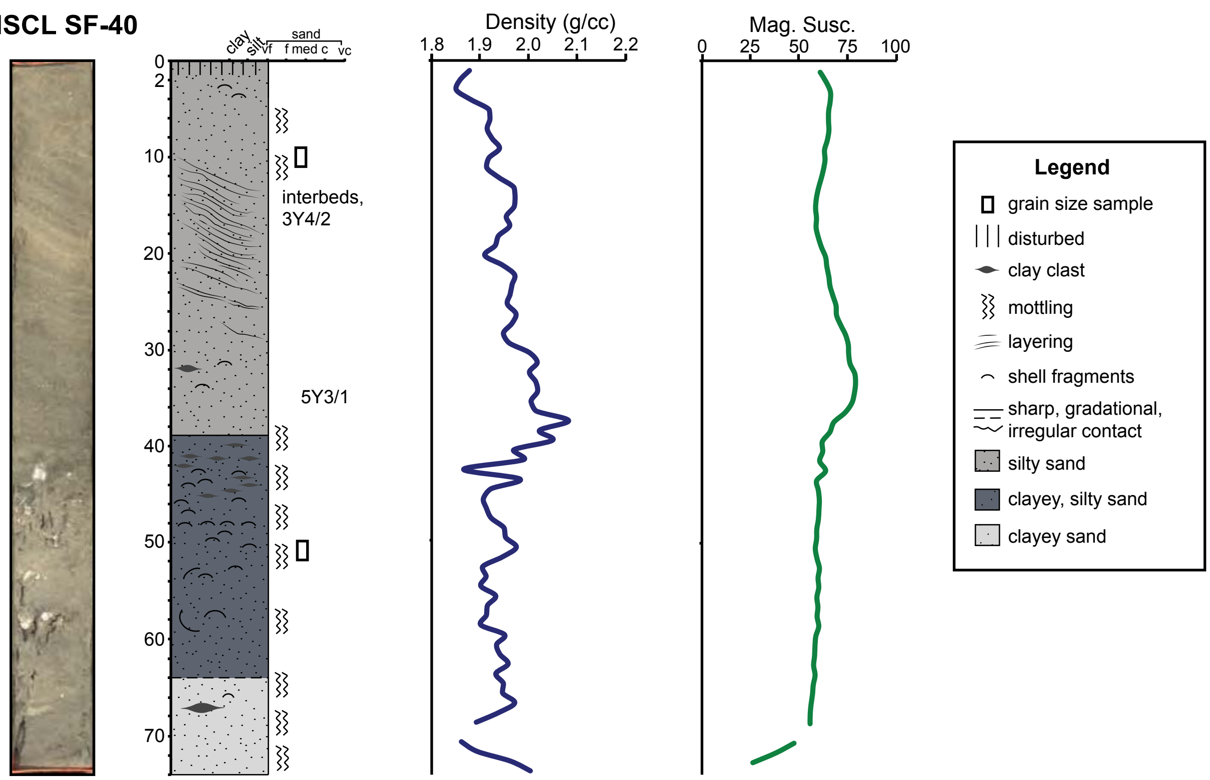

MSCL SF-30
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
69
5Y3/2
Density (g/cc)
1.8
1.9
2.0
2.1
2.2
Mag. Susc.
0
25
50
75
100
Legend
grain size sample
disturbed
organic material
tube worm
mottling
clay clast
shell fragments
sharp, gradational, irregular contact
silty sand with clay
silty sand

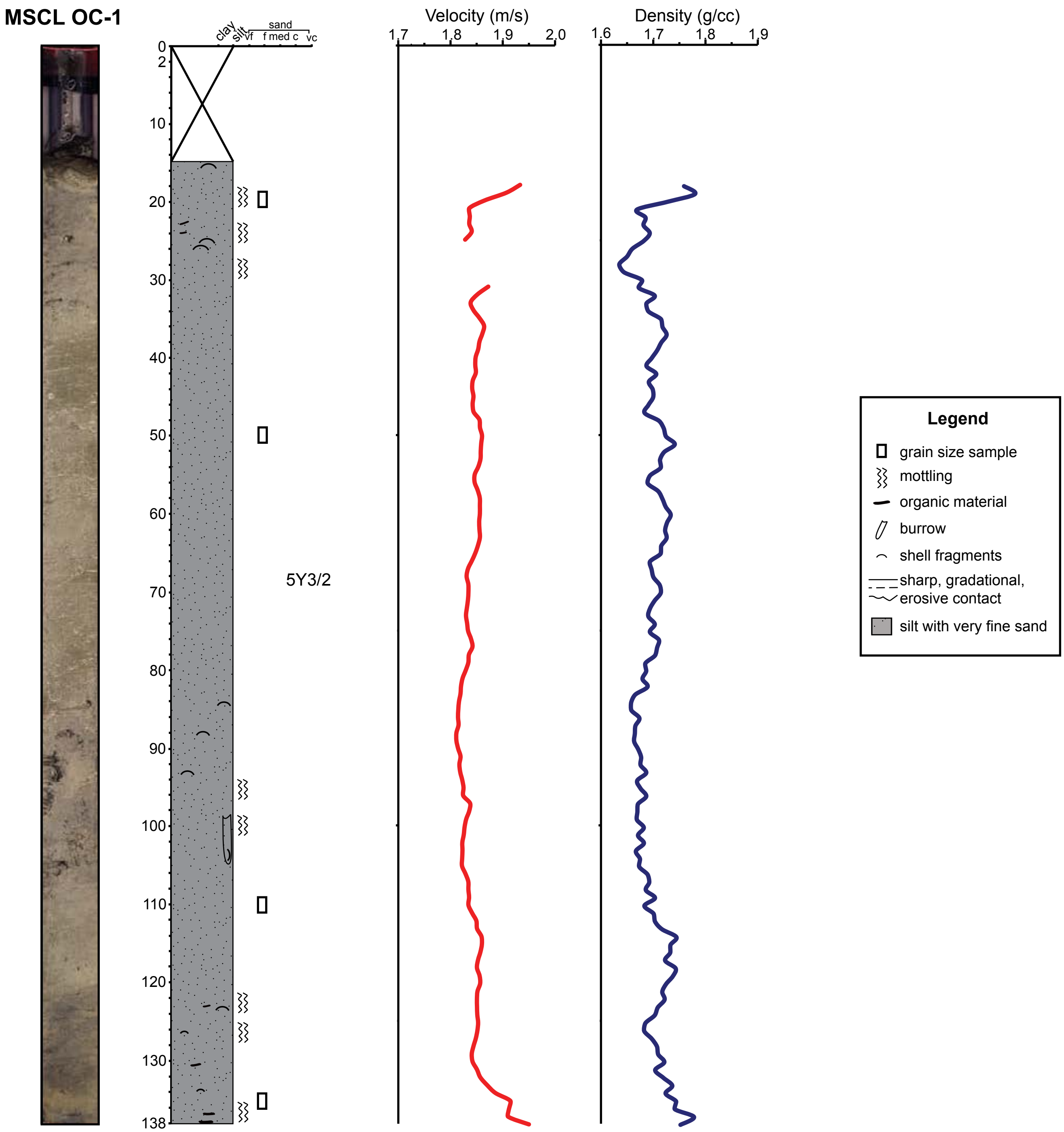

MSCL SF-31
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
68
clay, 5Y4/1
5Y2.5/2
mottling, 5Y3/2
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Mag. Susc.
100
125
150
175
200
Legend
grain size sample
disturbed
organic material
mottling
clay
shell fragments
sharp, gradational, irregular contact
silty sand with clay
silty sand

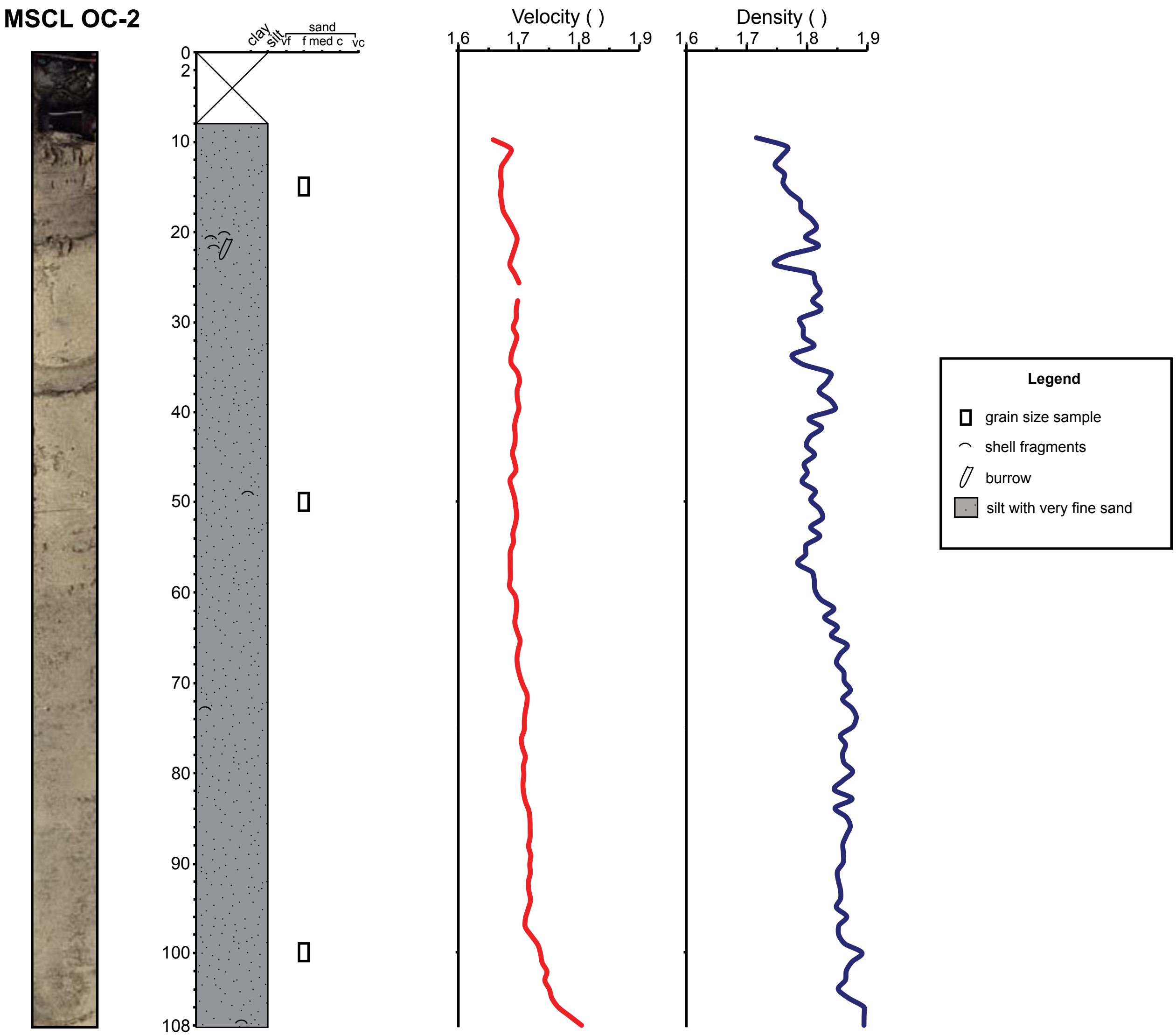
MSCL SF-39



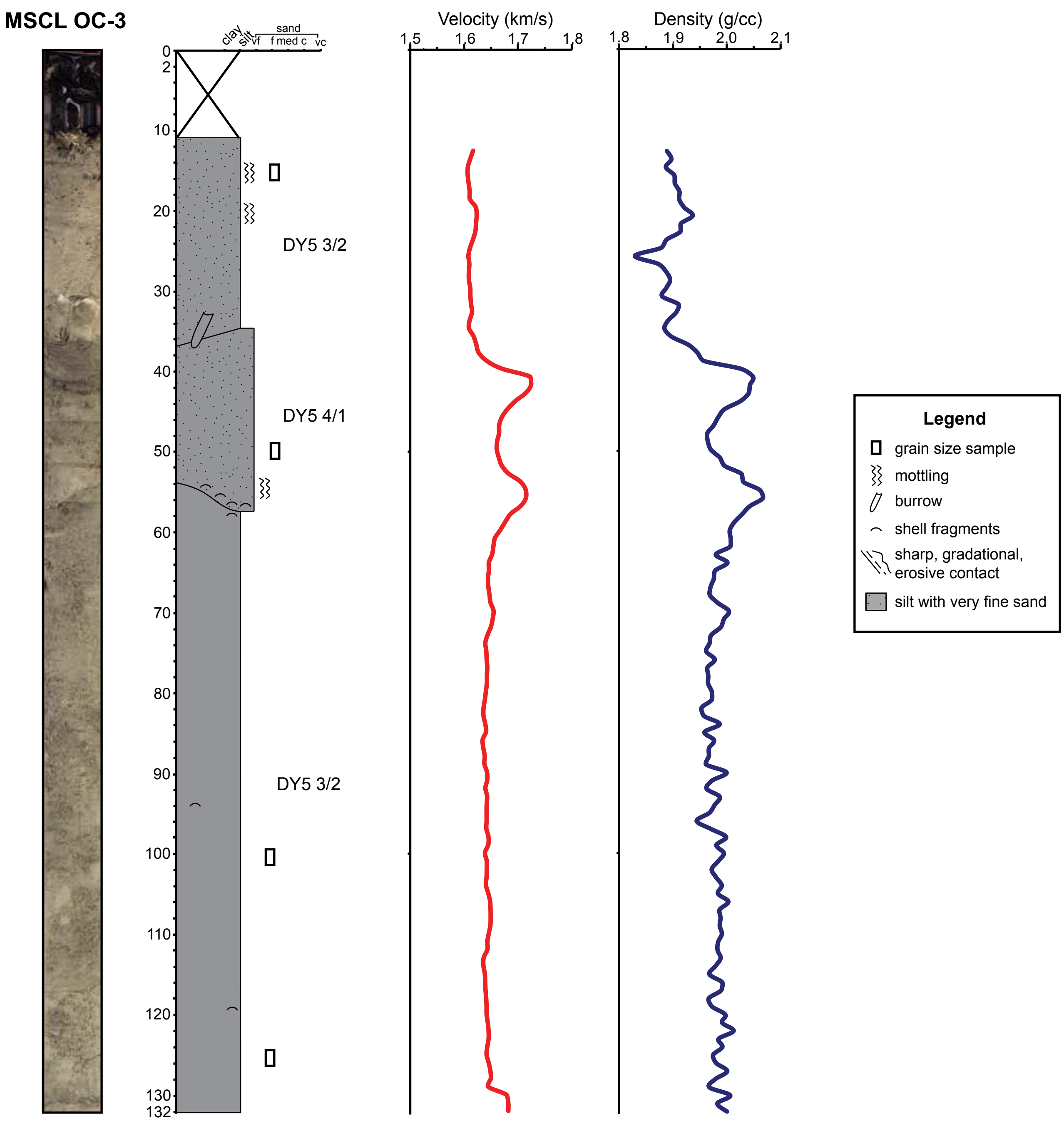
MSCL SF-40

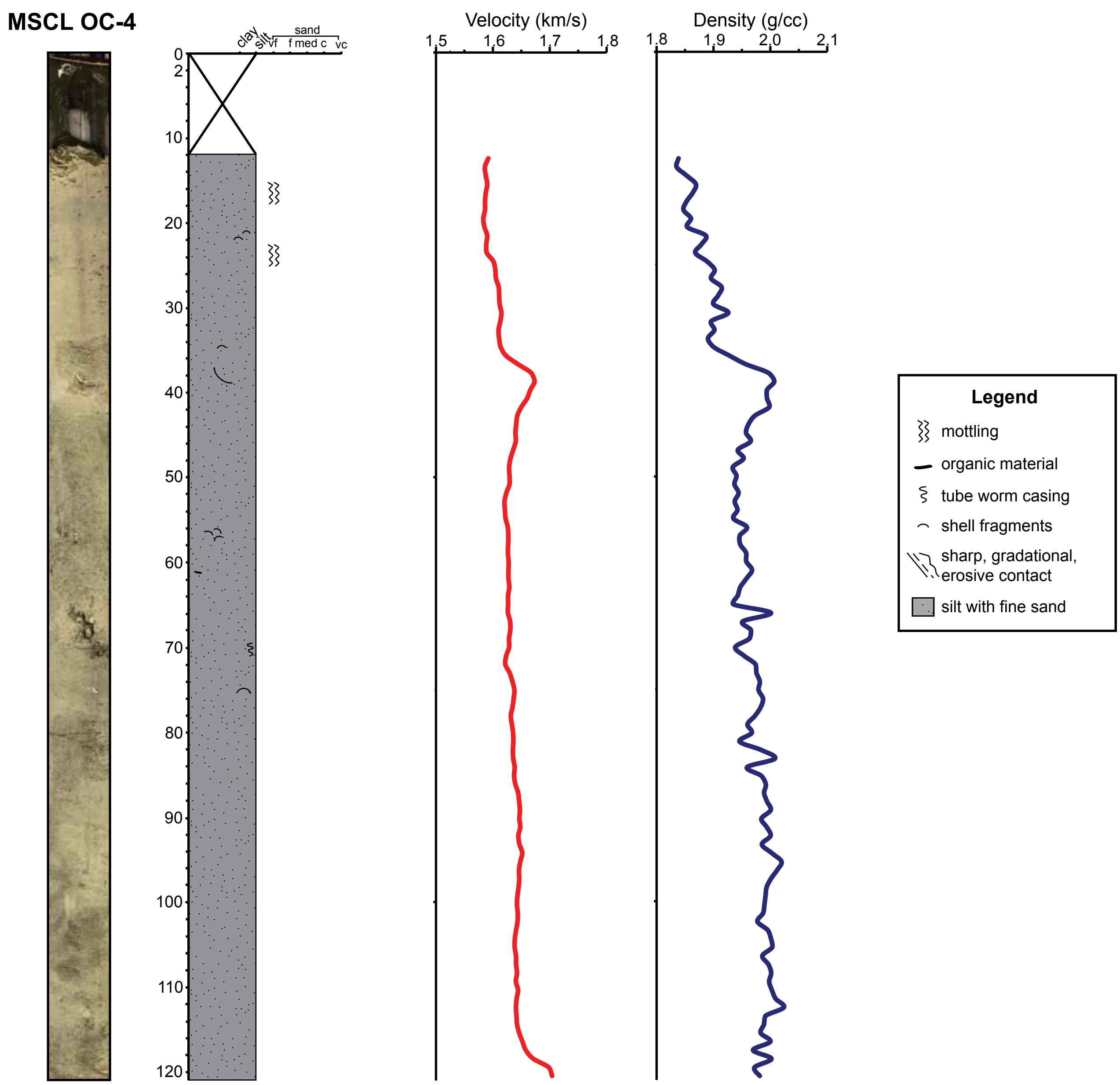


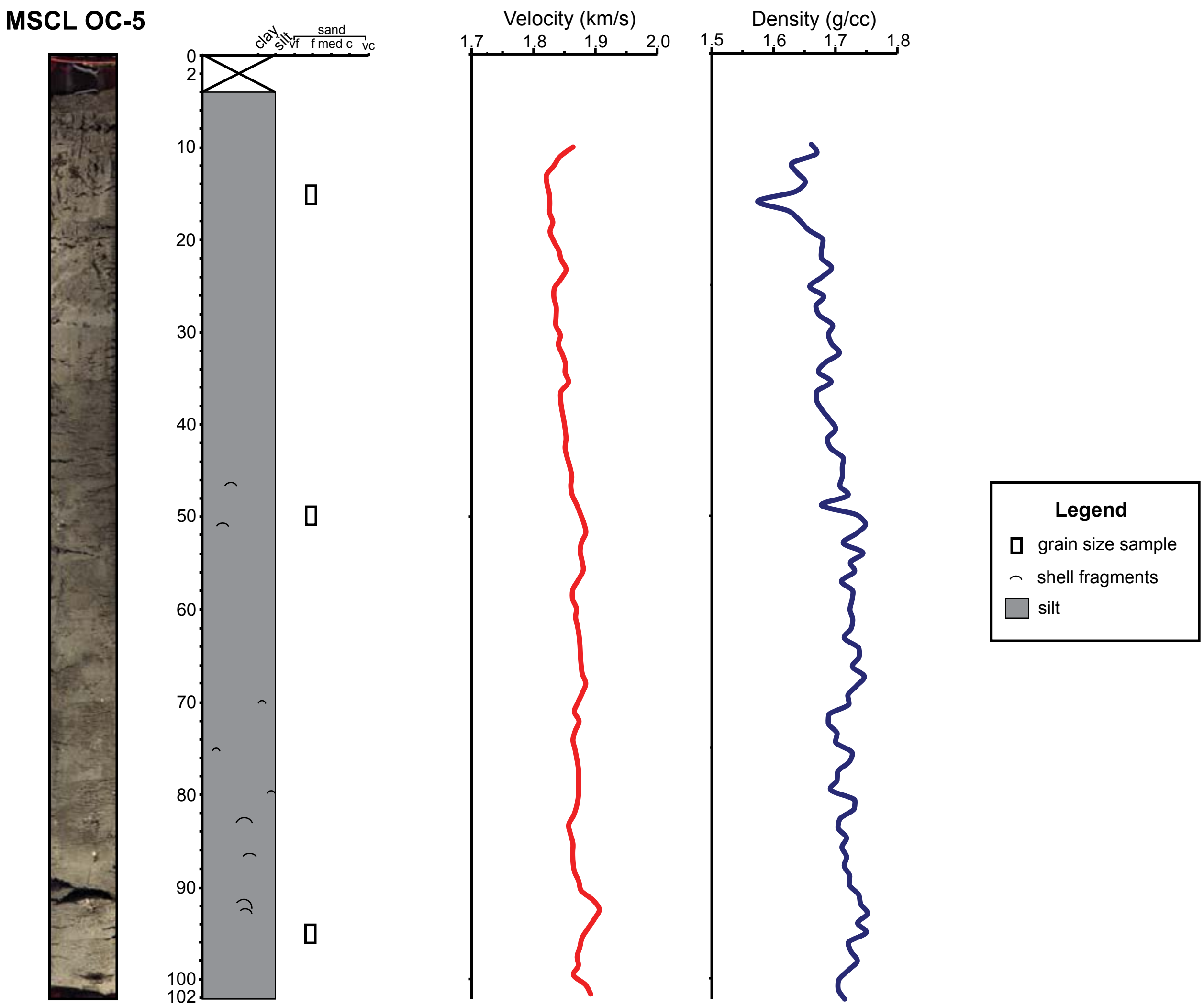

MSCL OC-1
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
138
5Y3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.6
1.7
1.8
1.9
Legend
grain size sample
mottling
organic material
burrow
shell fragments
sharp, gradational,
erosive contact
silt with very fine sand



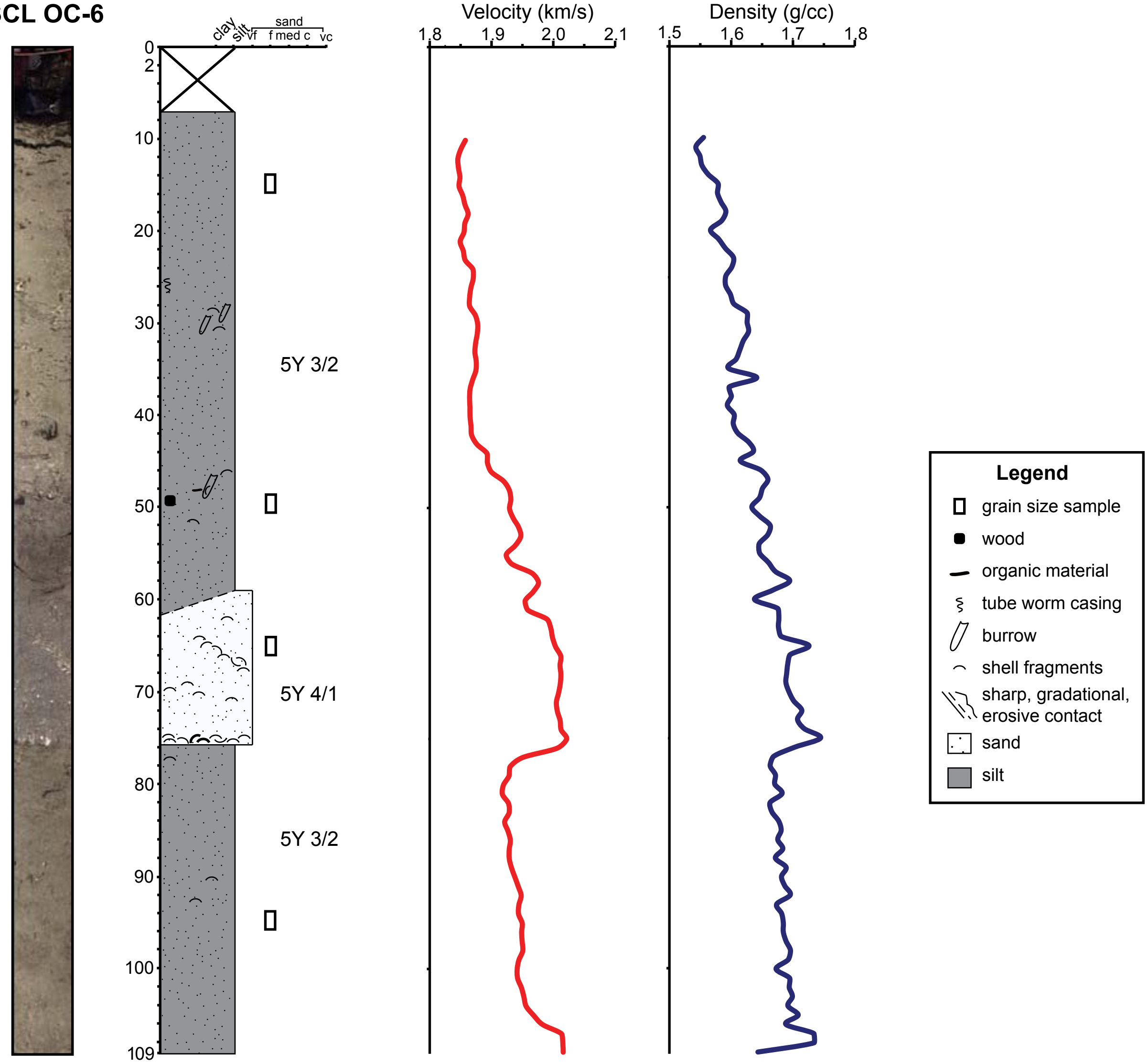
MSCL OC-2
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
108
Velocity ( )
1.6 1.7 1.8 1.9
Density ( )
1.6 1.7 1.8 1.9
Legend
grain size sample
shell fragments
burrow
silt with very fine sand

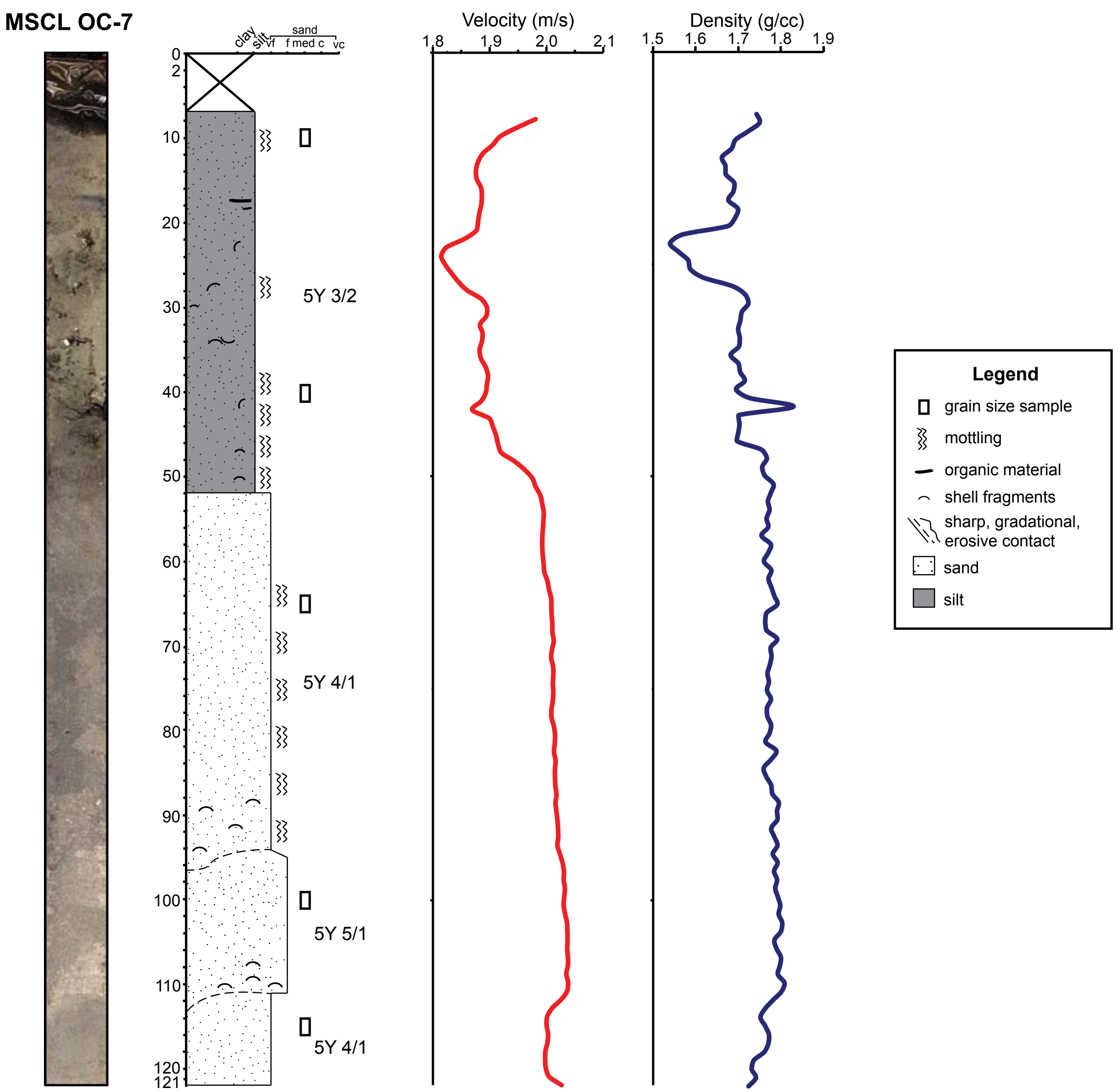

MSCL OC-3
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
132
DY5 3/2
DY5 4/1
DY5 3/2
Velocity (km/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.8
1.9
2.0
2.1
Legend
grain size sample
mottling
burrow
shell fragments
sharp, gradational, erosive contact
silt with very fine sand

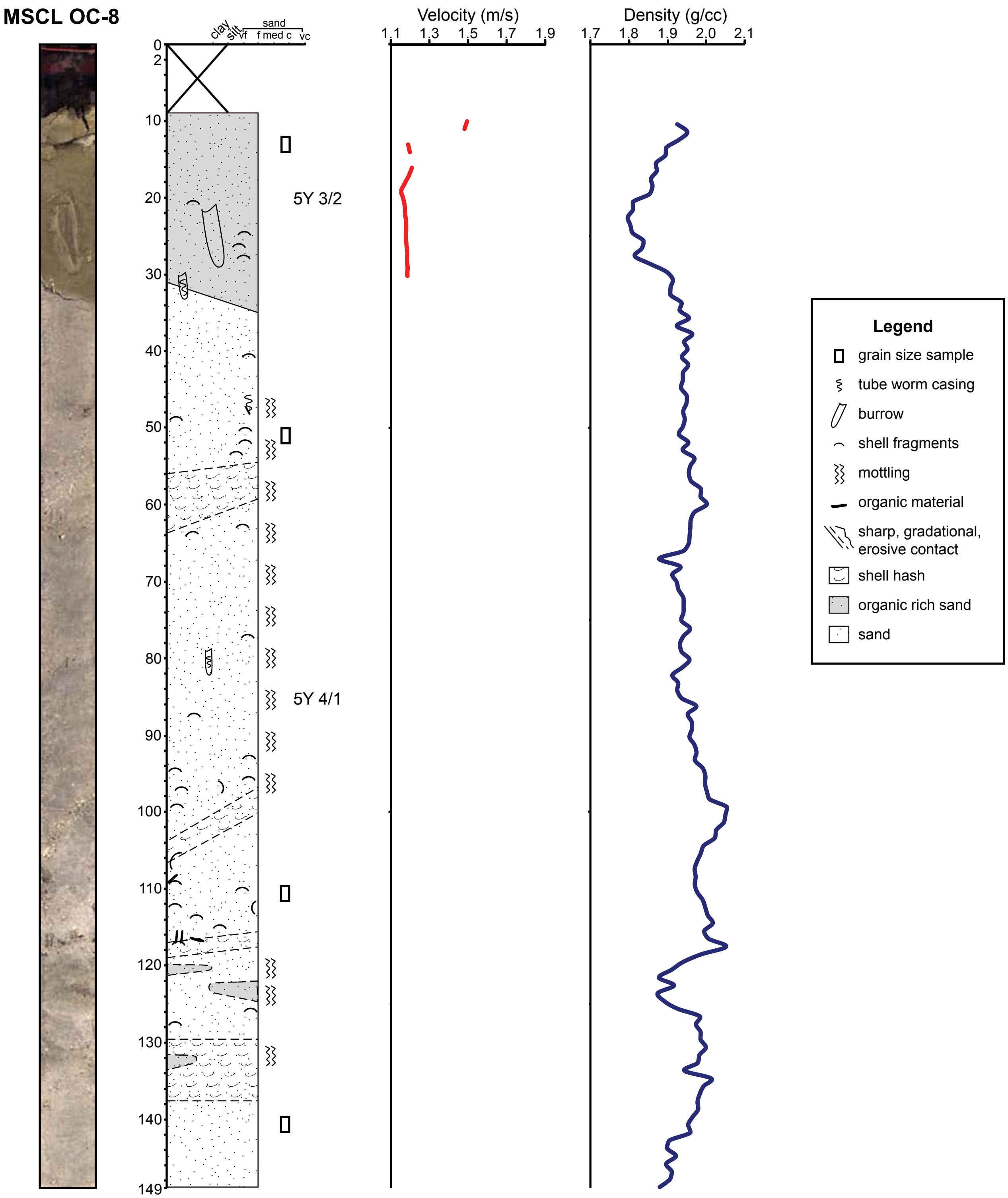

MSCL OC-4
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
Velocity (km/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.8
1.9
2.0
2.1
Legend
mottling
organic material
tube worm casing
shell fragments
sharp, gradational, erosive contact
silt with fine sand

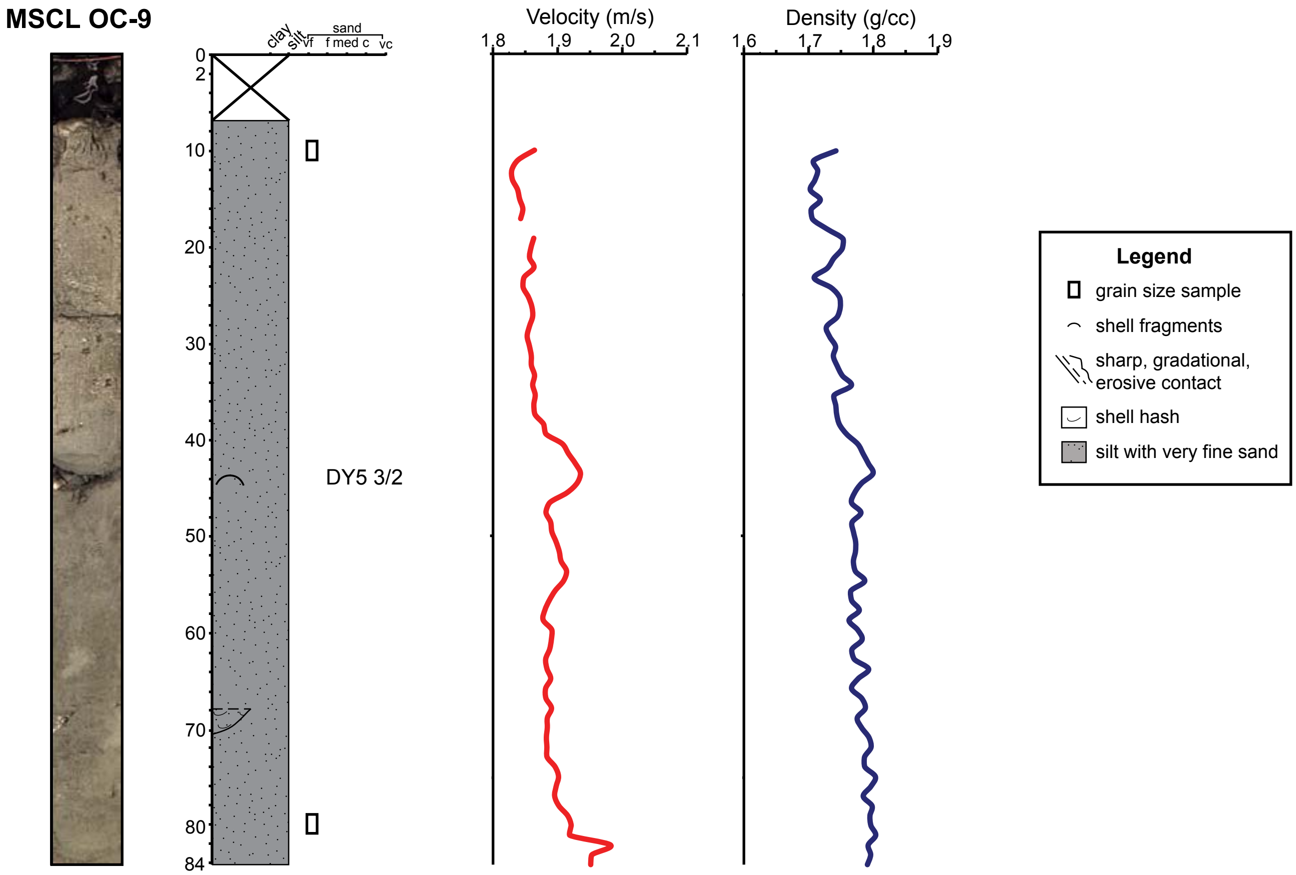

MSCL OC-5
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
102
Velocity (km/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
silt

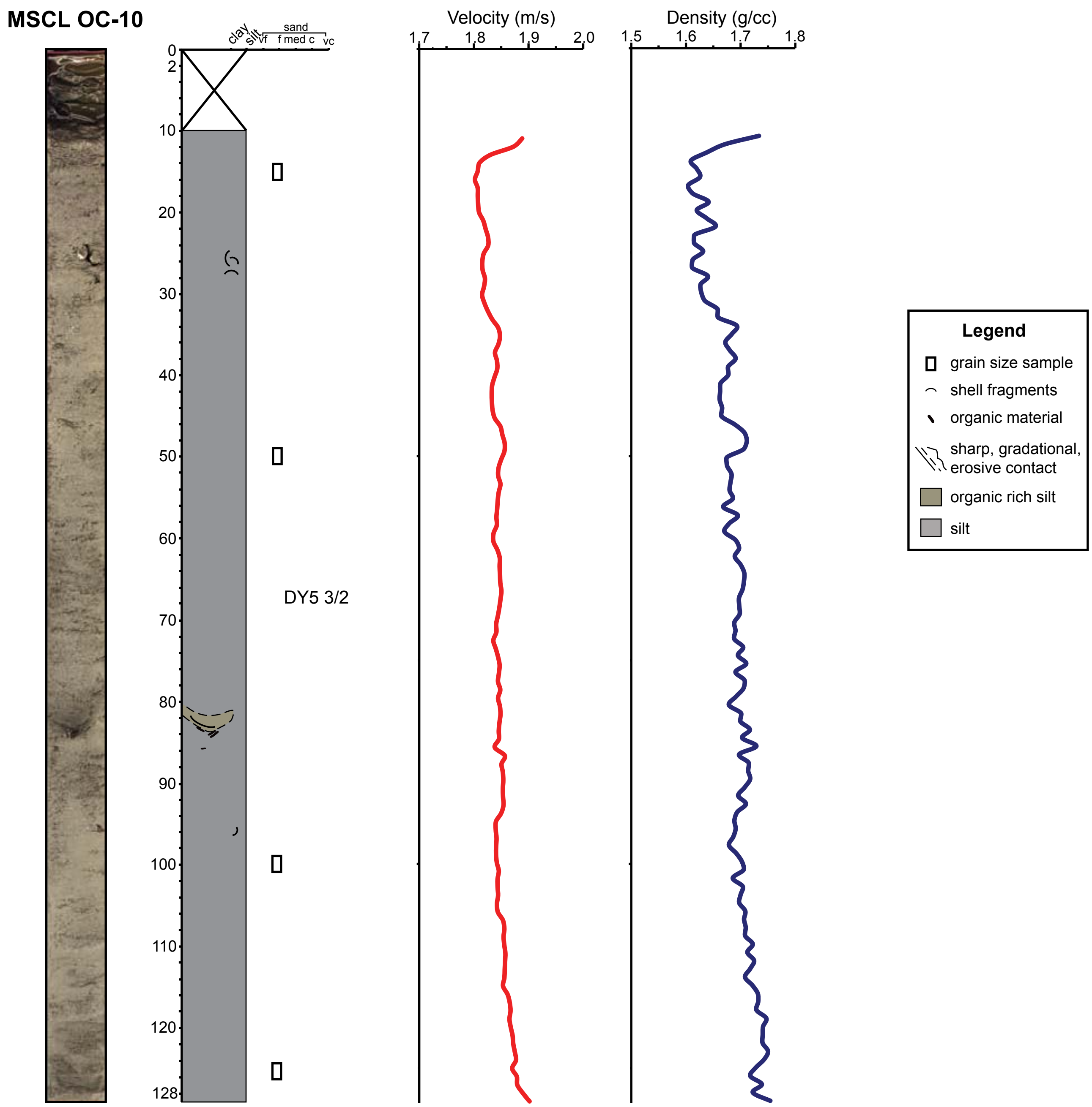
MSCL OC-6

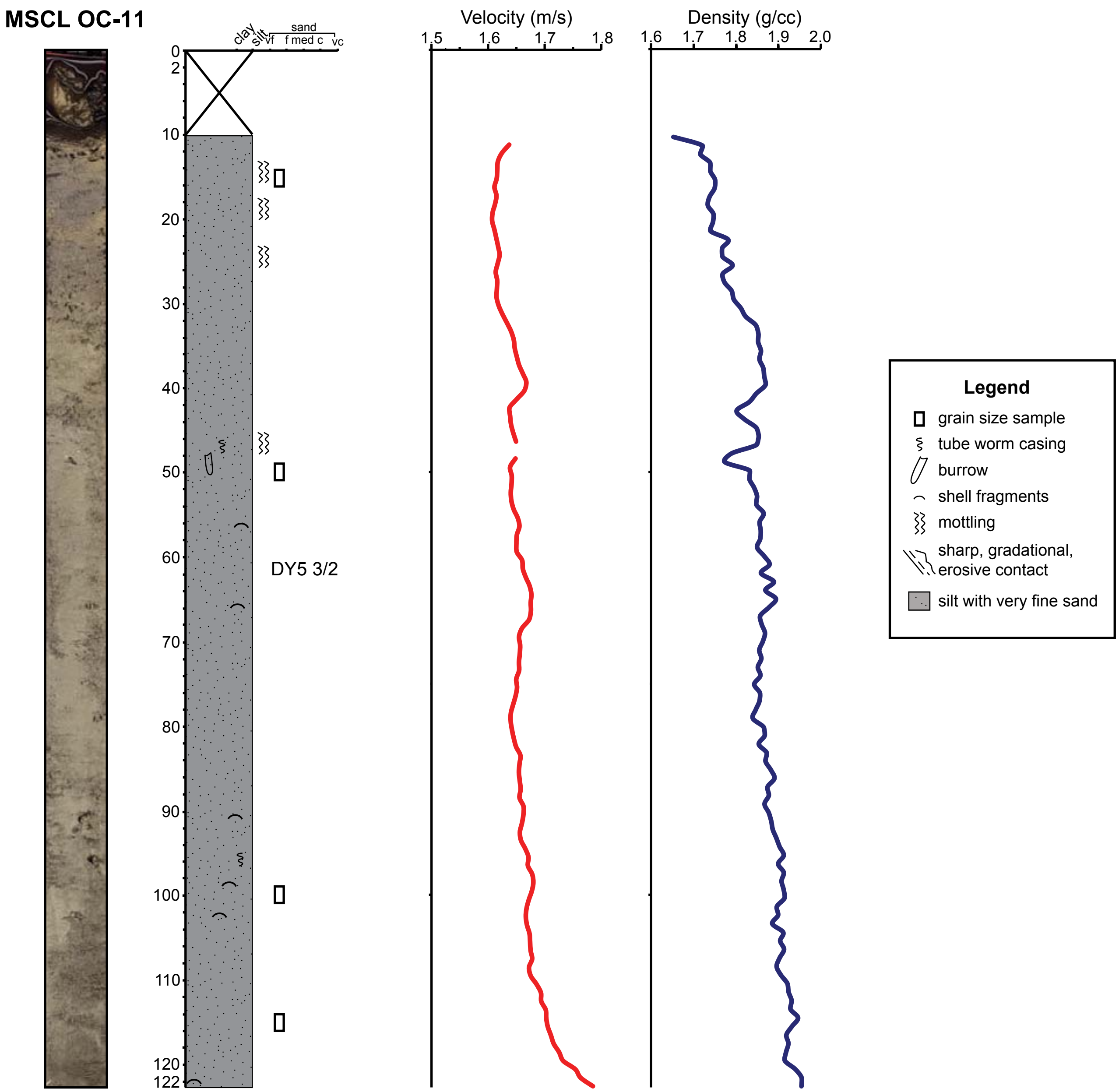

clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
109
5Y 3/2
5Y 4/1
5Y 3/2
Velocity (km/s)
1.8
1.9
2.0
2.1
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
wood
organic material
tube worm casing
burrow
shell fragments
sharp, gradational, erosive contact
sand
silt

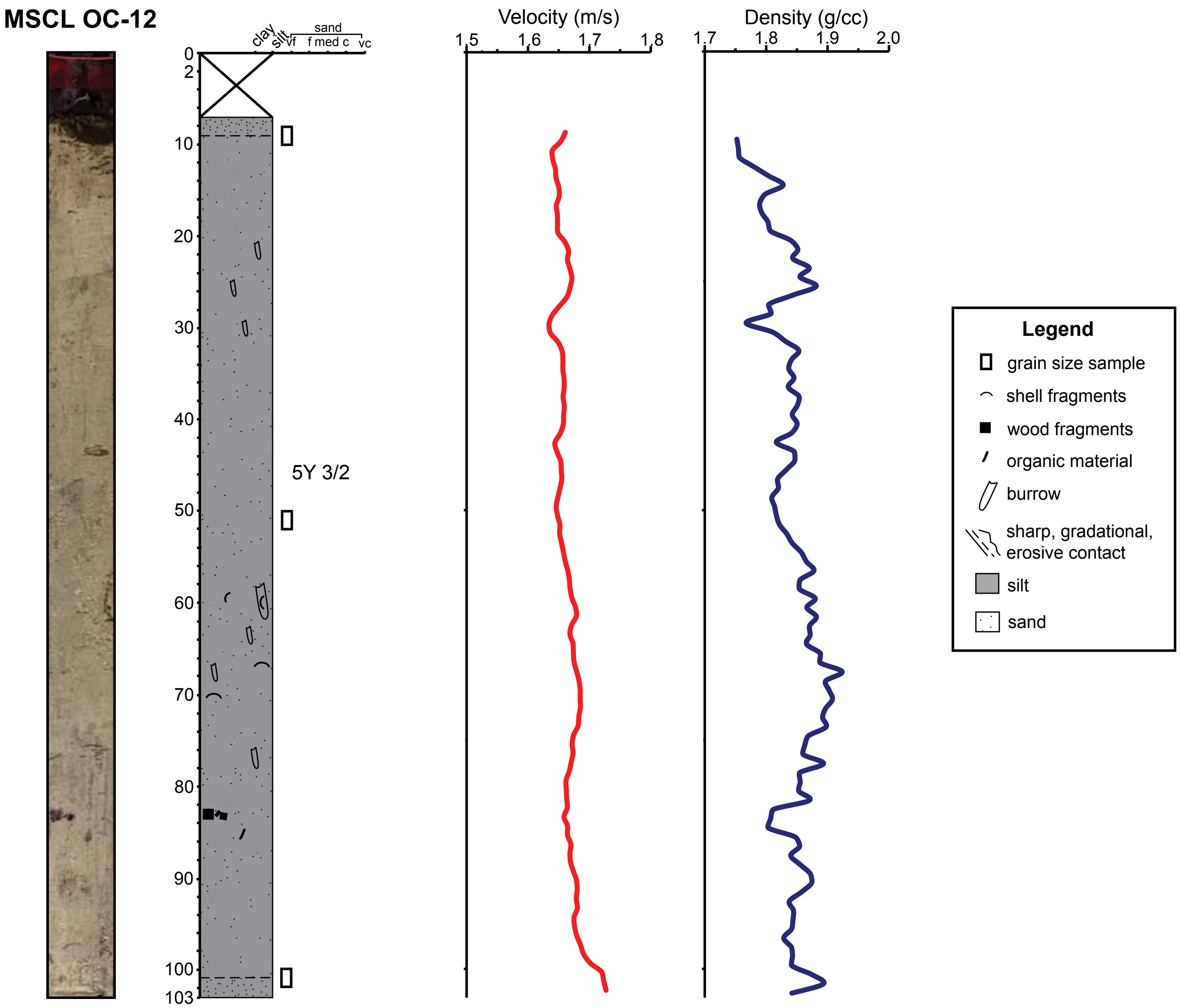

MSCL OC-7
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
121
5Y 3/2
5Y 4/1
5Y 5/1
5Y 4/1
Velocity (m/s)
1.8
1.9
2.0
2.1
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Legend
grain size sample
mottling
organic material
shell fragments
sharp, gradational, erosive contact
sand
silt

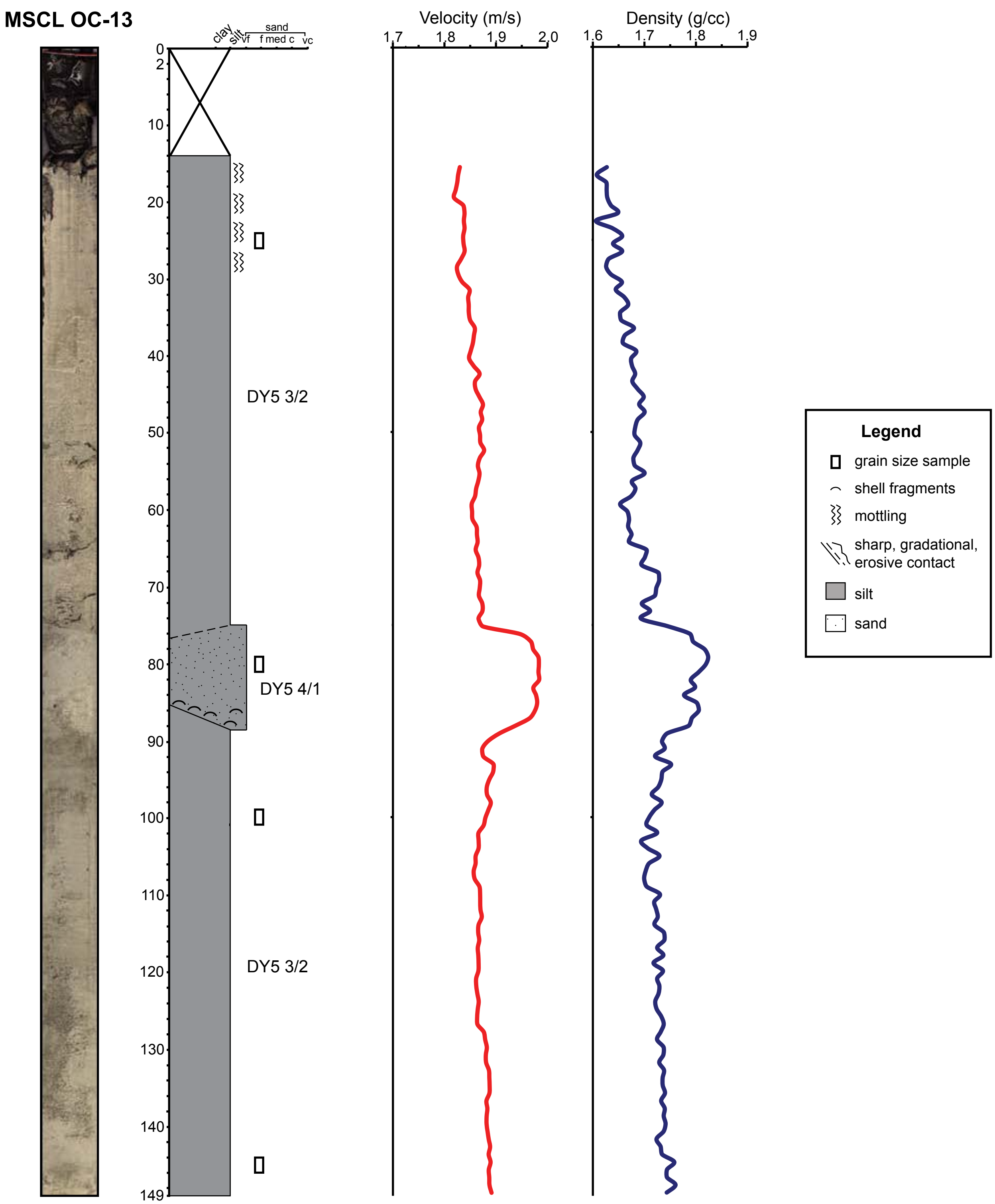

MSCL OC-8
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
149
5Y 3/2
5Y 4/1
Velocity (m/s)
1.1 1.3 1.5 1.7 1.9
Density (g/cc)
1.7 1.8 1.9 2.0 2.1
Legend
grain size sample
tube worm casing
burrow
shell fragments
mottling
organic material
sharp, gradational, erosive contact
shell hash
organic rich sand
sand

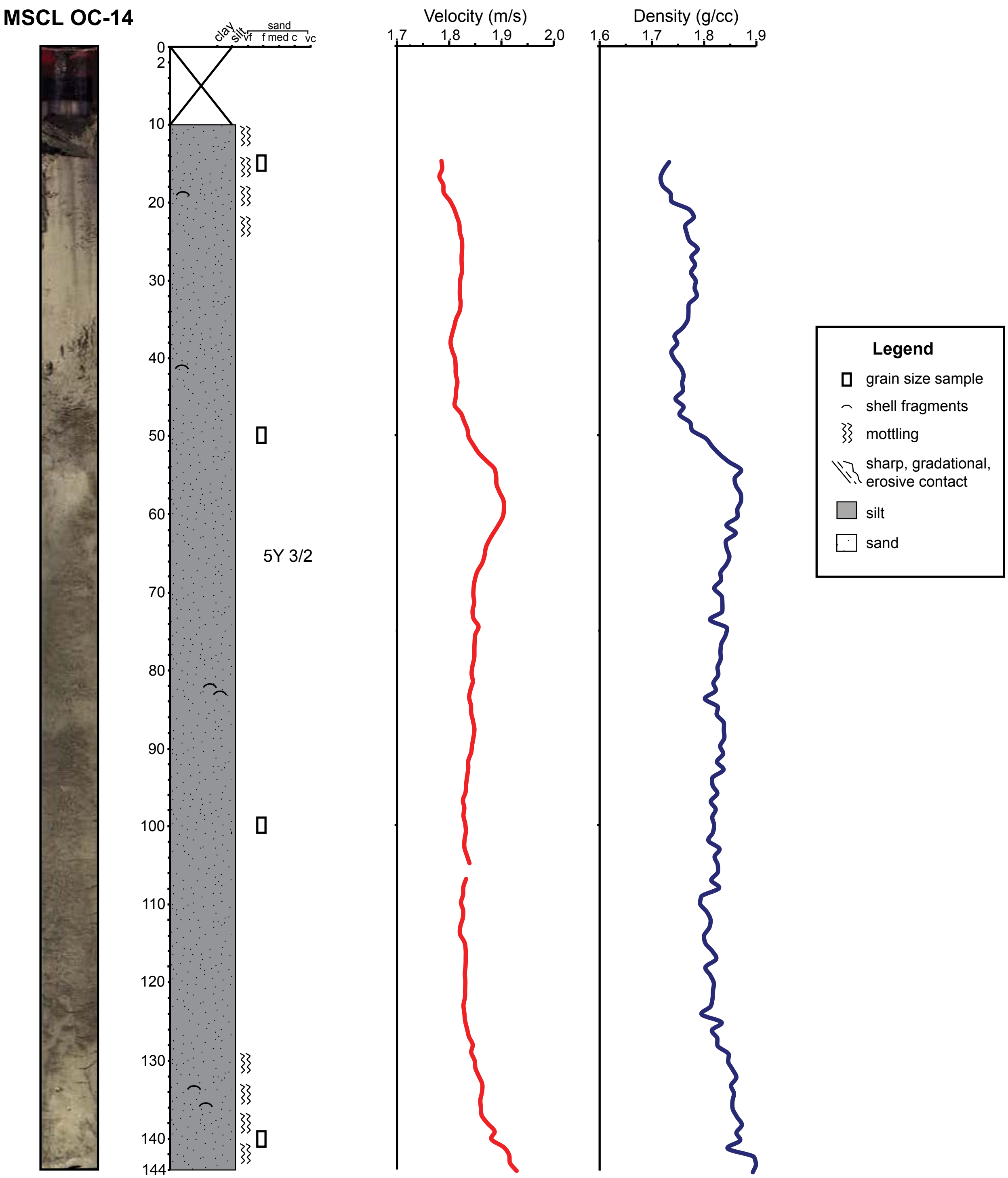

MSCL OC-9
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
84
DY5 3/2
Velocity (m/s)
1.8
1.9
2.0
2.1
Density (g/cc)
1.6
1.7
1.8
1.9
Legend
grain size sample
shell fragments
sharp, gradational, erosive contact
shell hash
silt with very fine sand


MSCL OC-10
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
128
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
organic material
sharp, gradational, erosive contact
organic rich silt
silt

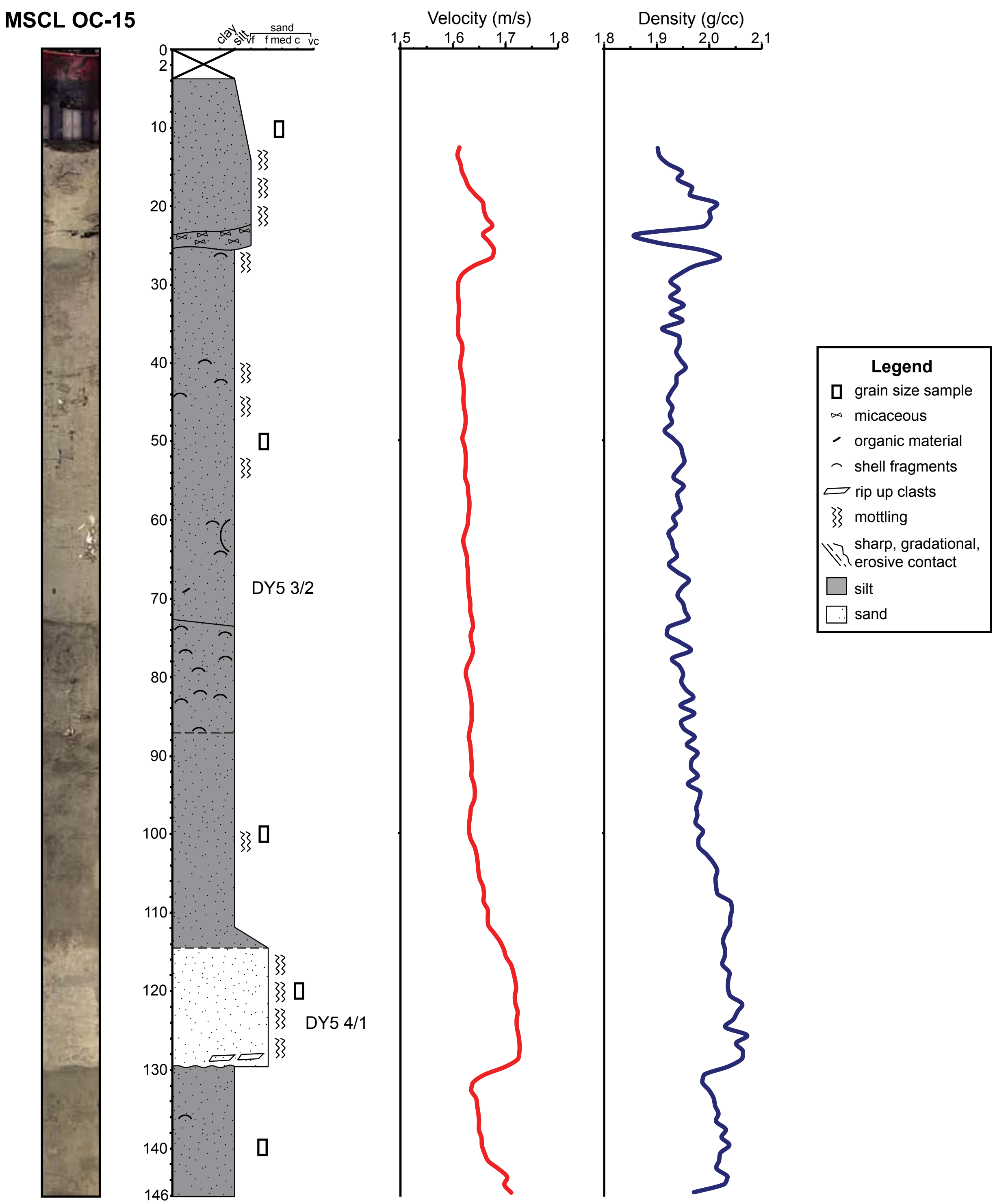

MSCL OC-11
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
122
DY5 3/2
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.6
1.7
1.8
1.9
2.0
Legend
grain size sample
tube worm casing
burrow
shell fragments
mottling
sharp, gradational, erosive contact
silt with very fine sand

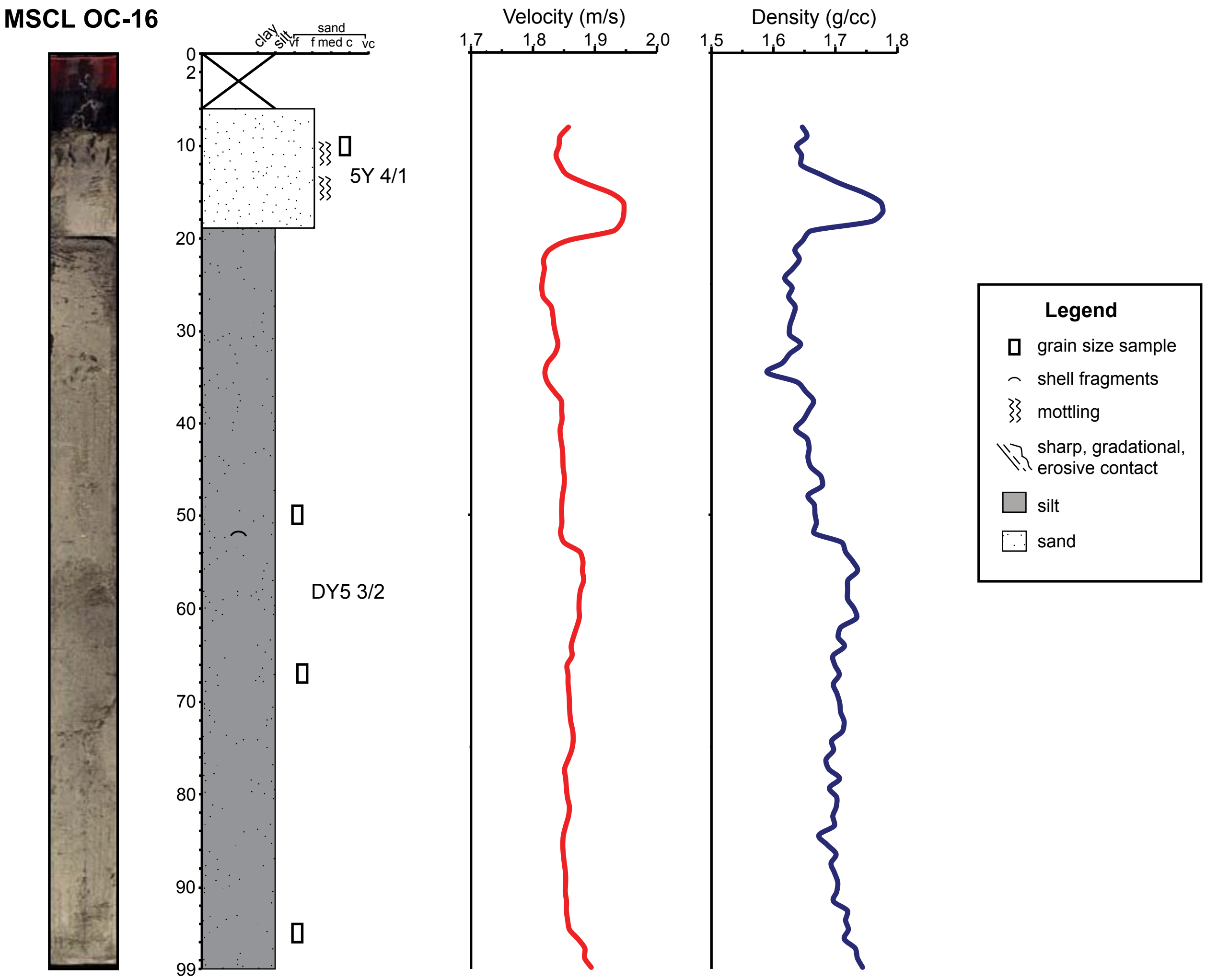

MSCL OC-12
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
103
5Y 3/2
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.7
1.8
1.9
2.0
Legend
grain size sample
shell fragments
wood fragments
organic material
burrow
sharp, gradational, erosive contact
silt
sand

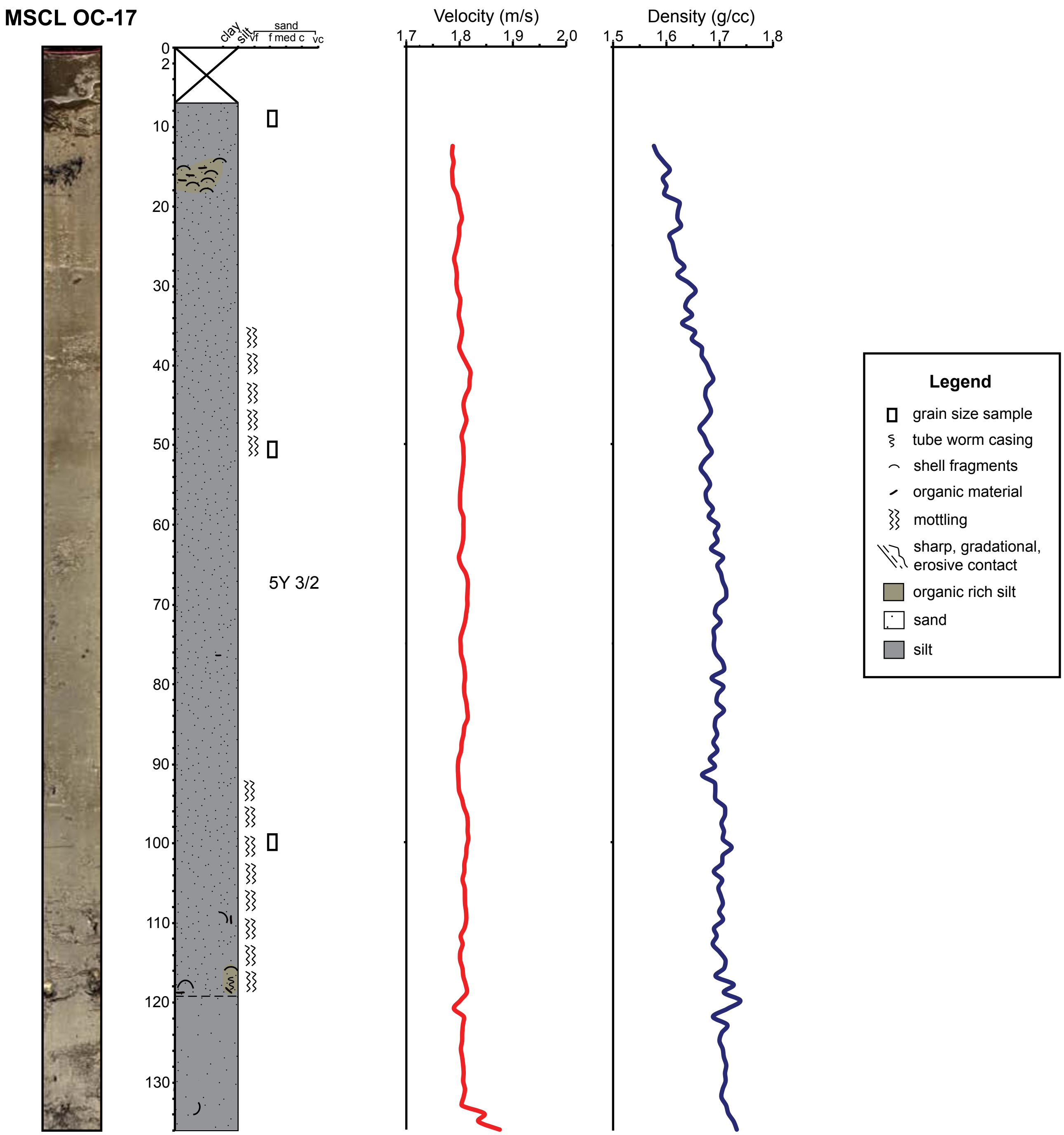

MSCL OC-13
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
149
DY5 3/2
DY5 4/1
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.6
1.7
1.8
1.9
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt
sand

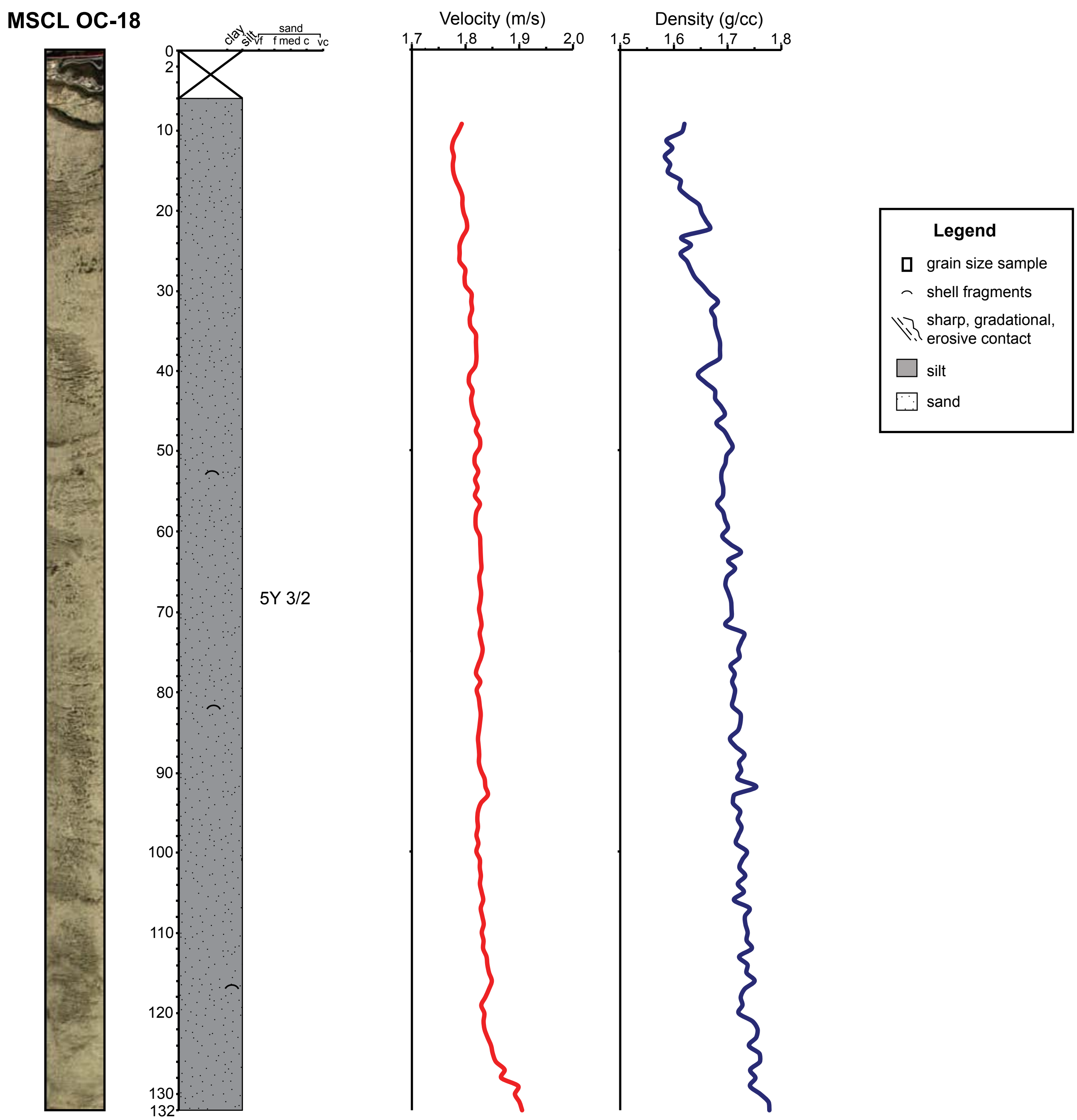


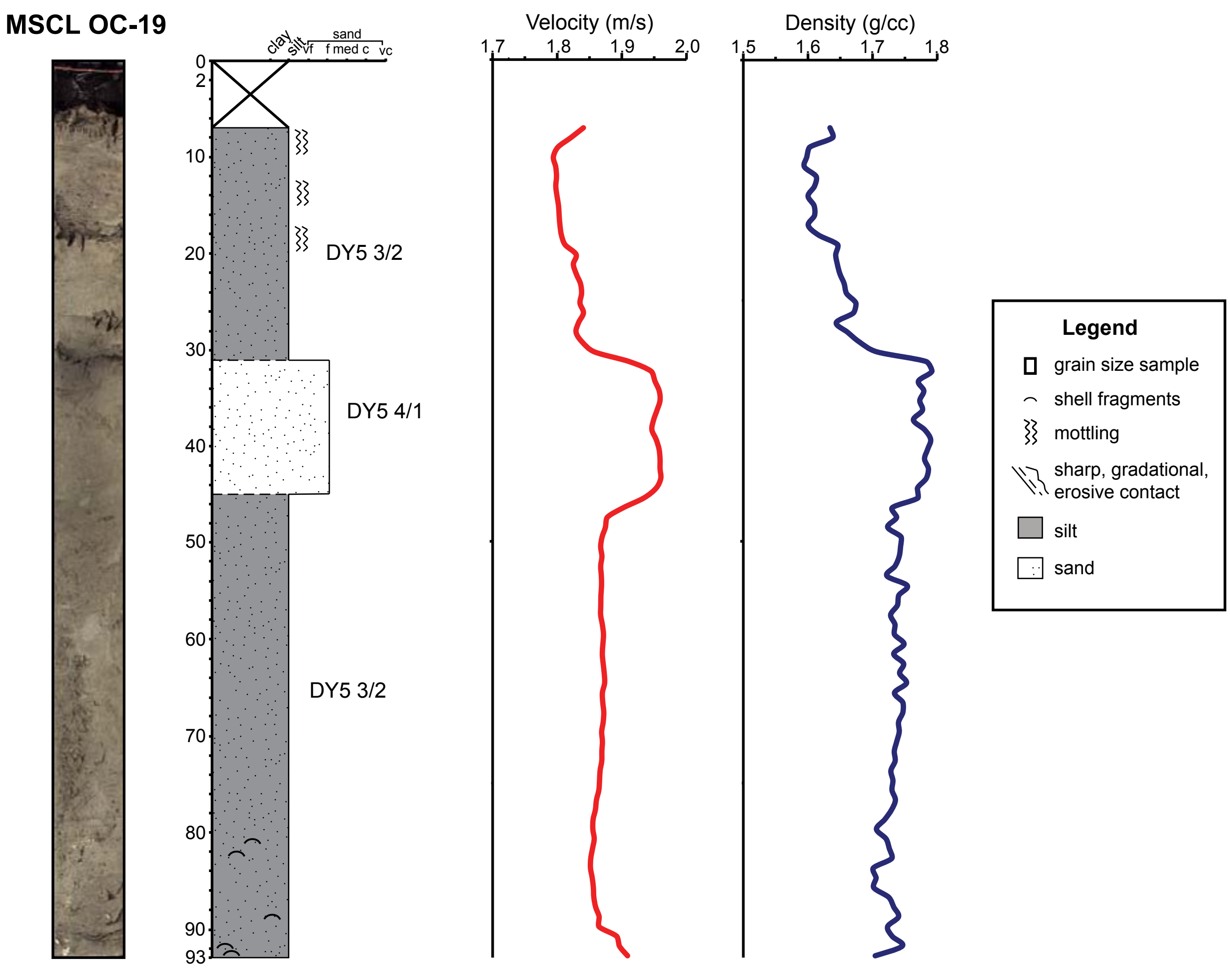
MSCL OC-14
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
144
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.6
1.7
1.8
1.9
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt
sand


MSCL OC-15
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
146
DY5 3/2
DY5 4/1
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.8
1.9
2.0
2.1
Legend
grain size sample
micaceous
organic material
shell fragments
rip up clasts
mottling
sharp, gradational, erosive contact
silt
sand

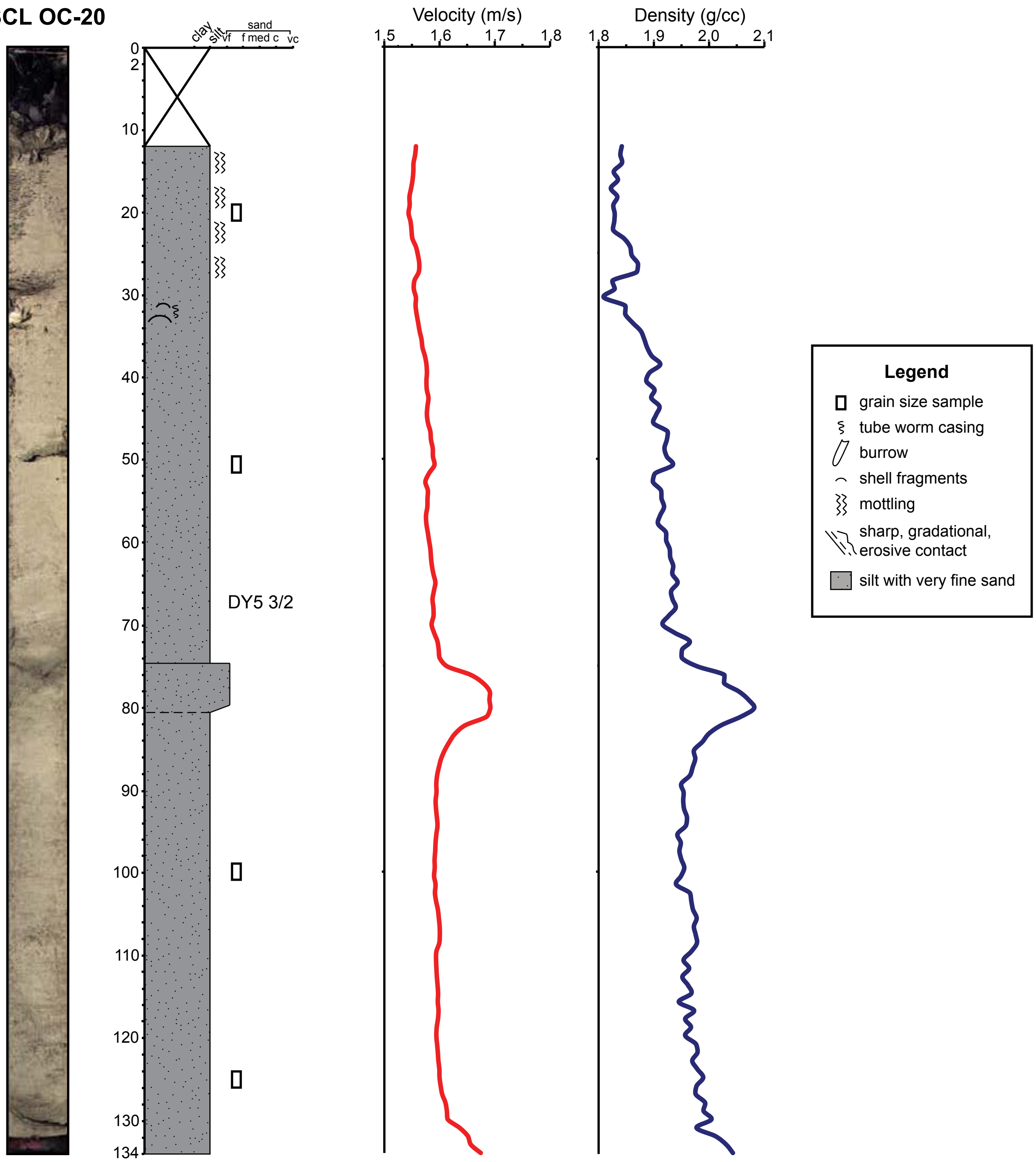

MSCL OC-16
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
99
5Y 4/1
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt
sand

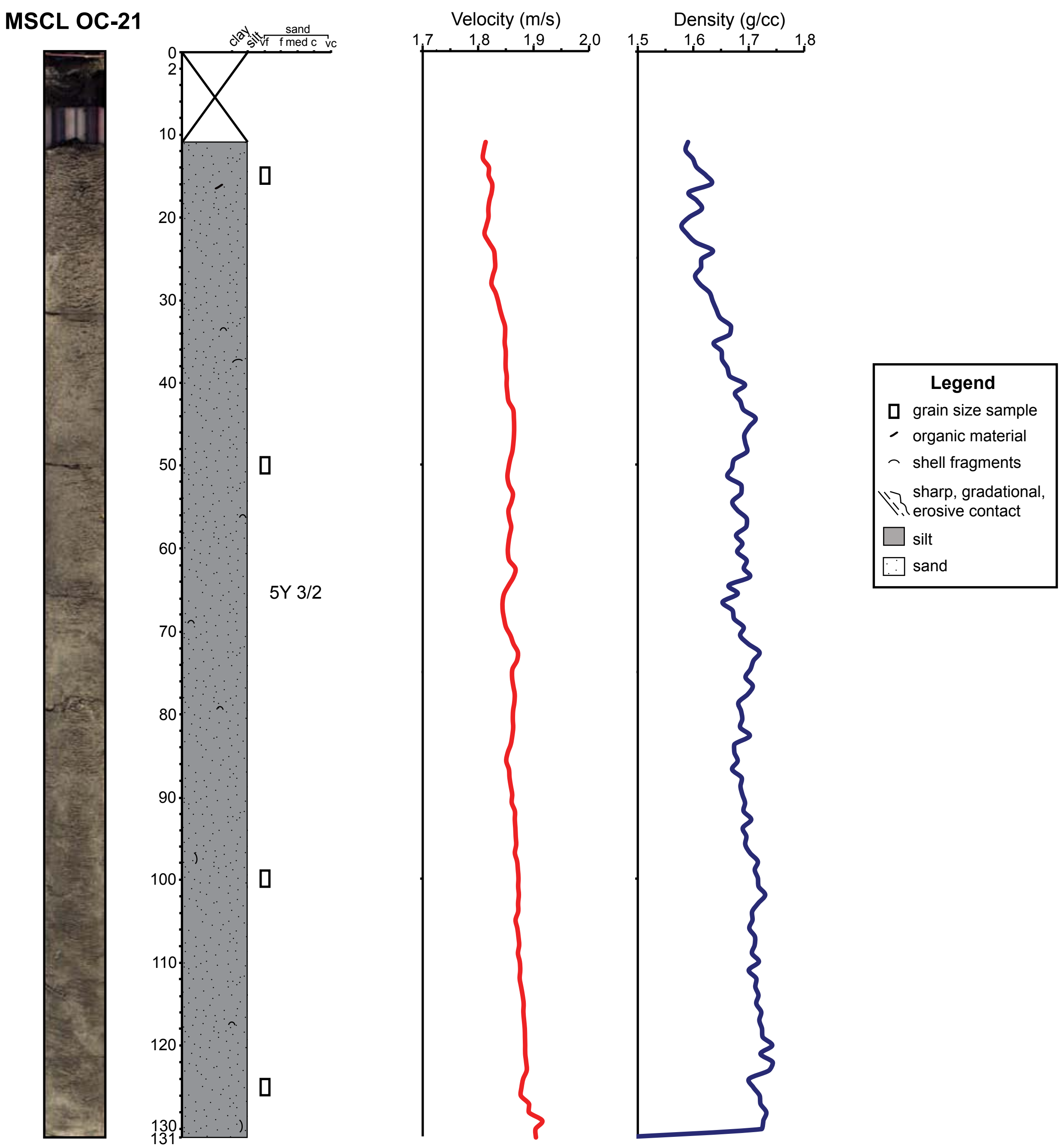

MSCL OC-17
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
tube worm casing
shell fragments
organic material
mottling
sharp, gradational, erosive contact
organic rich silt
sand
silt

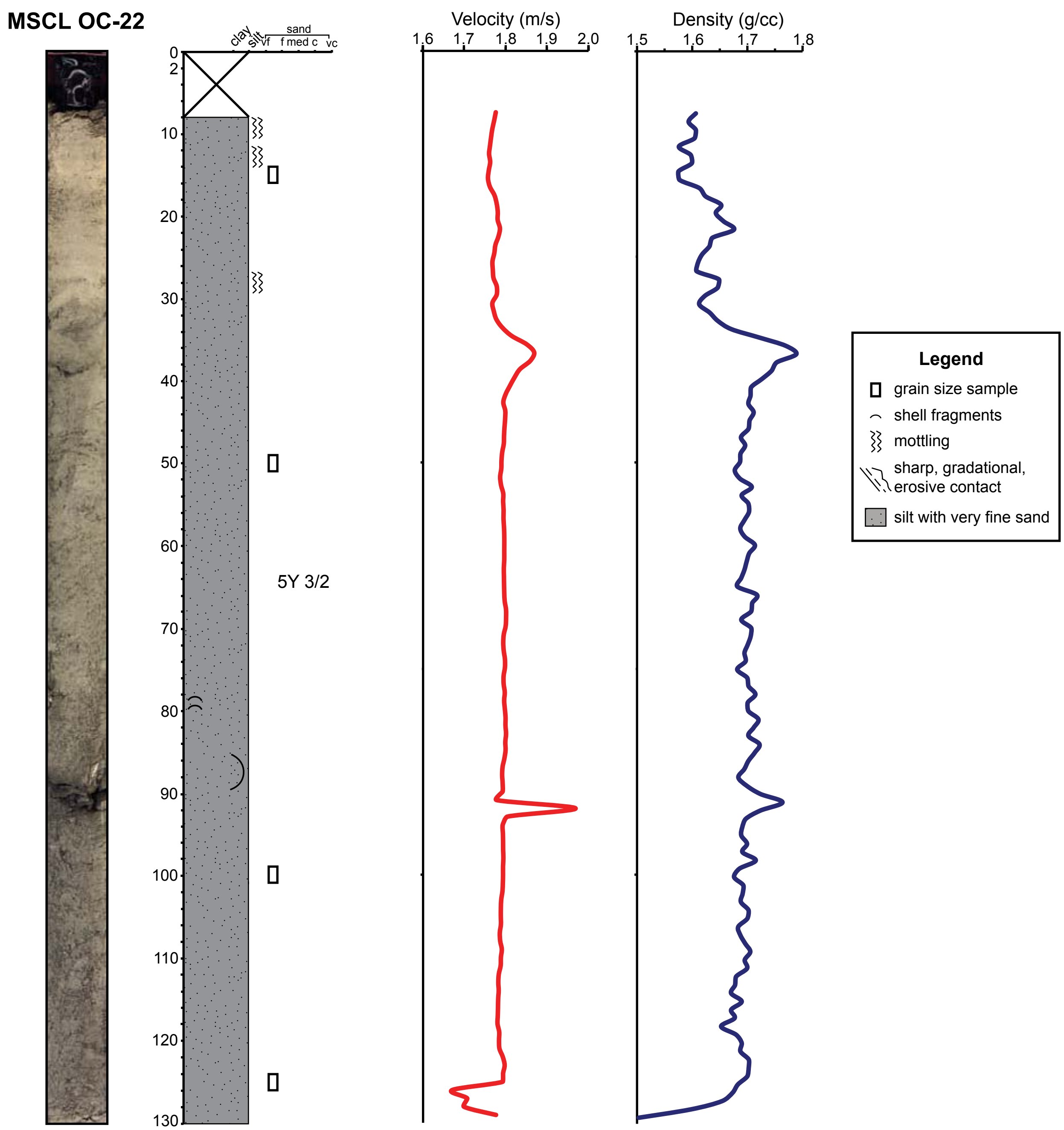

MSCL OC-18
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
132
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
sharp, gradational, erosive contact
silt
sand


MSCL OC-19
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
93
DY5 3/2
DY5 4/1
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt
sand

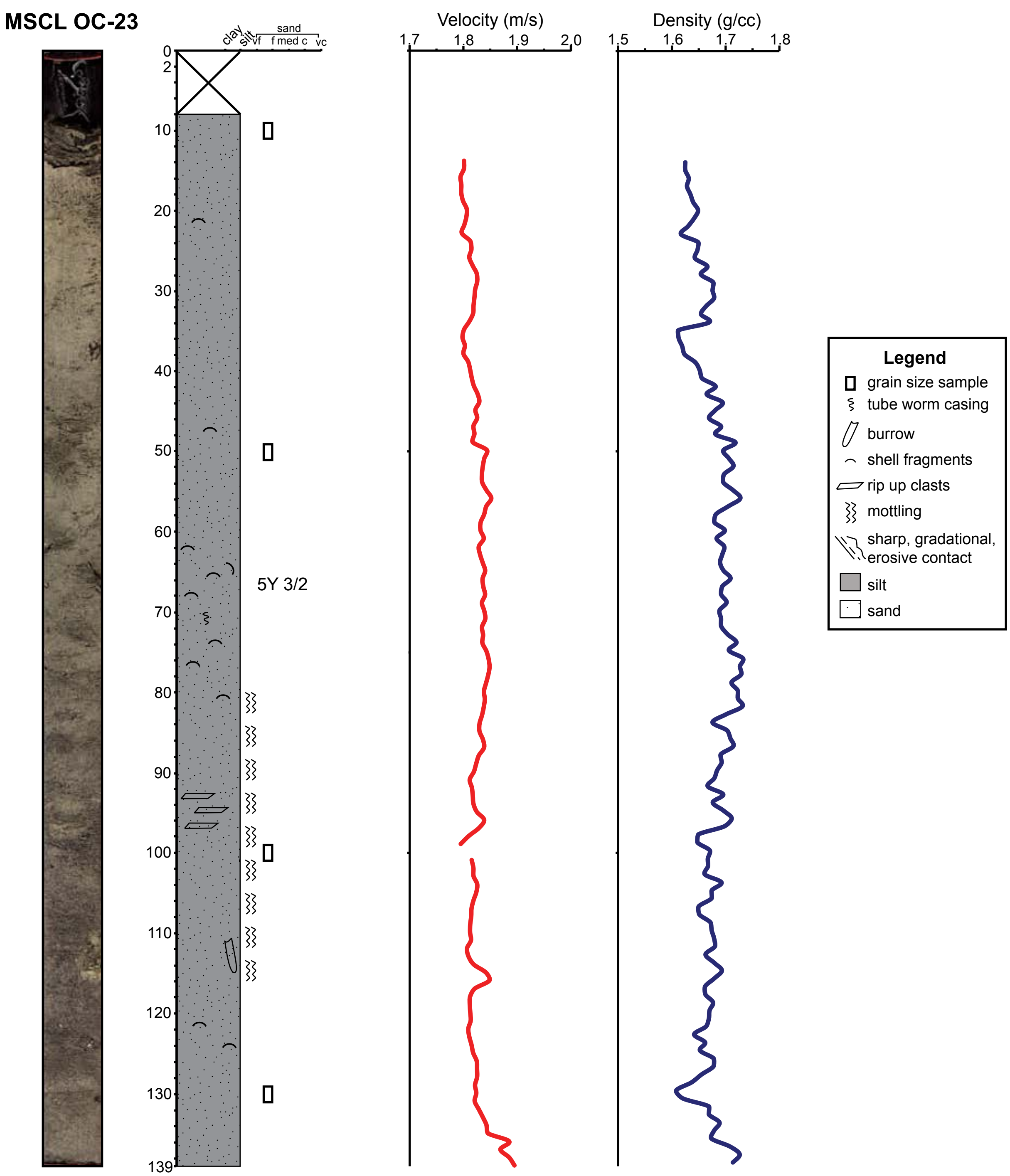
MSCL OC-20


clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
134
DY5 3/2
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.8
1.9
2.0
2.1
Legend
grain size sample
tube worm casing
burrow
shell fragments
mottling
sharp, gradational, erosive contact
silt with very fine sand

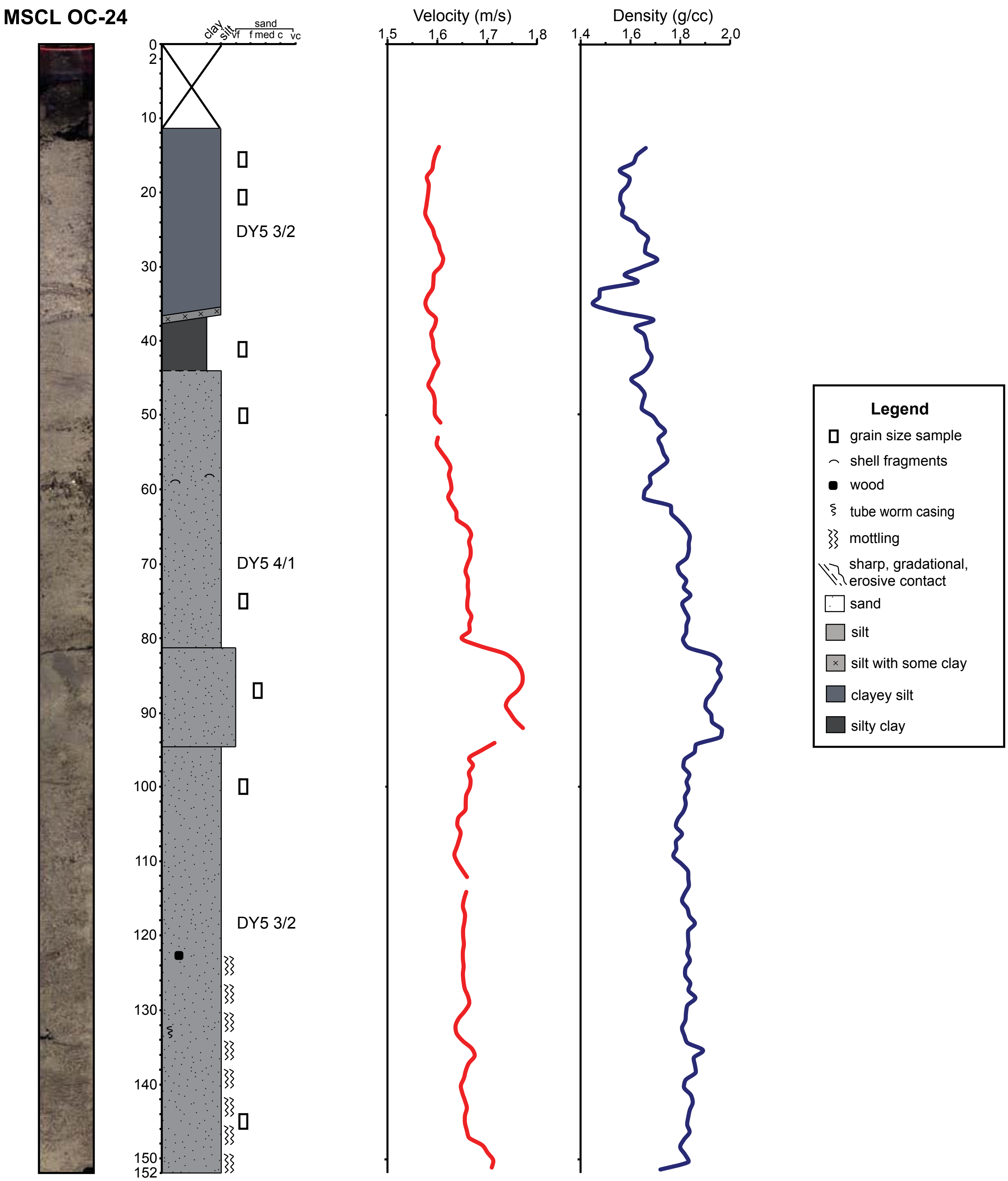

MSCL OC-21
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
131
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
organic material
shell fragments
sharp, gradational, erosive contact
silt
sand

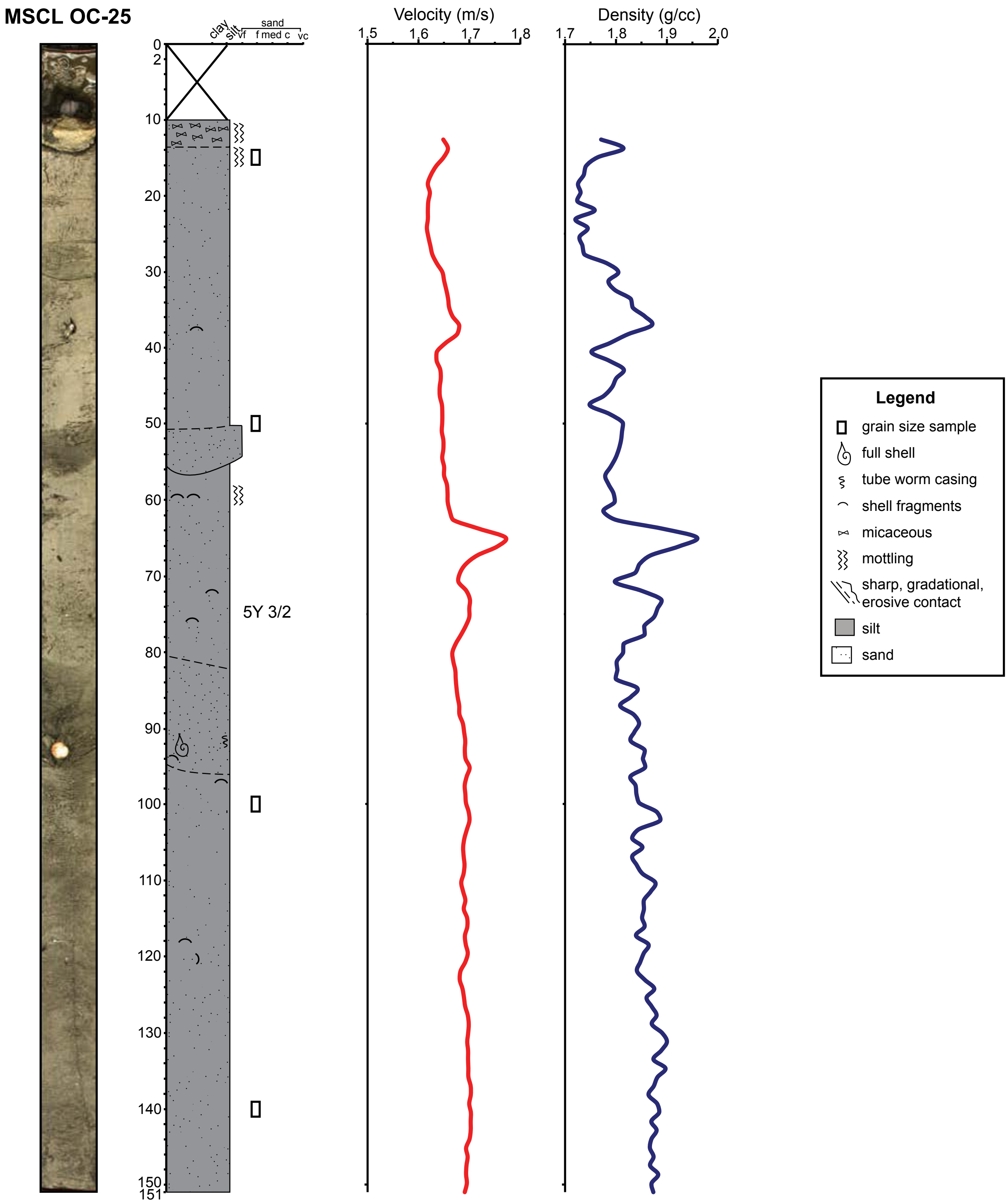


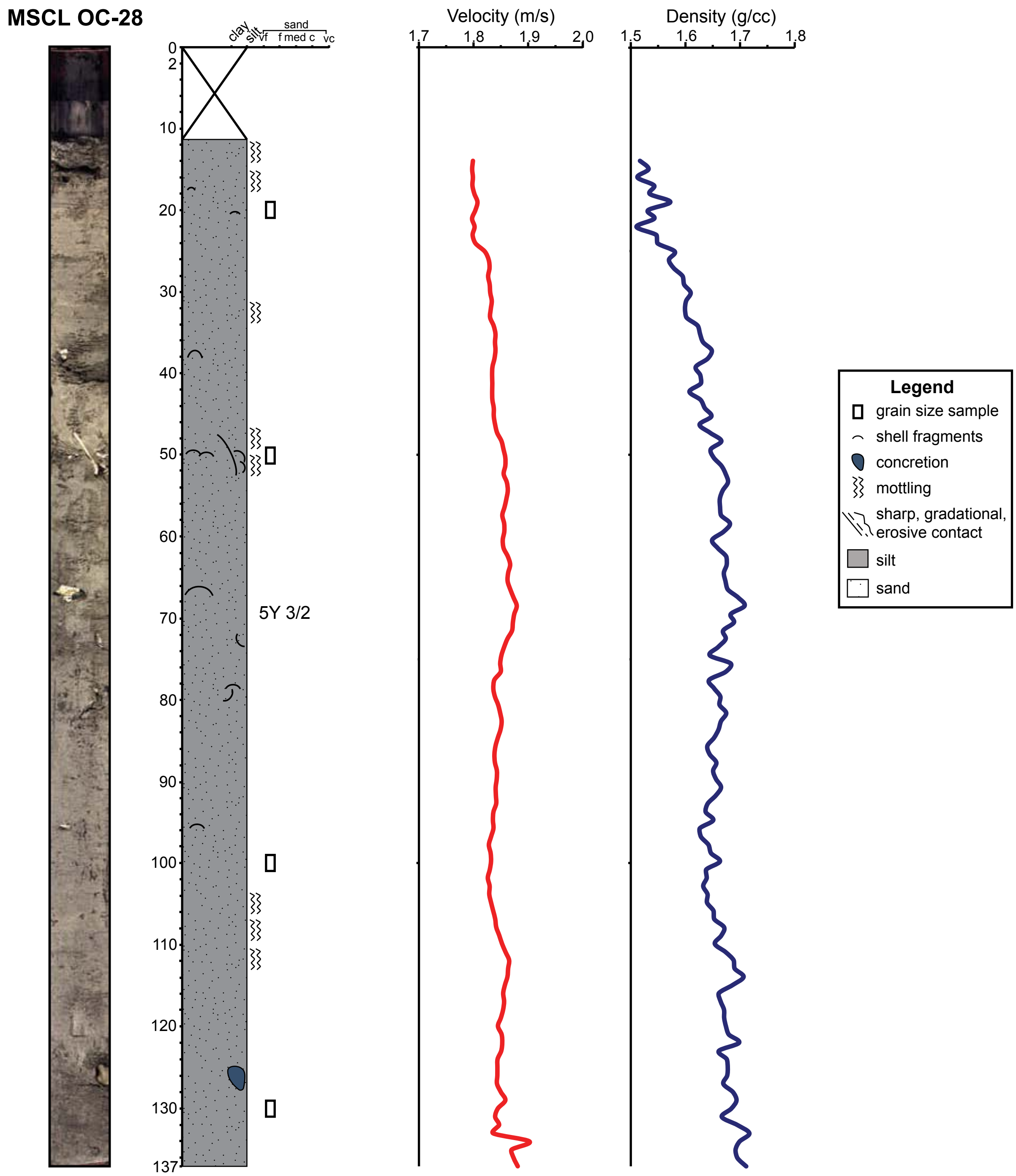
MSCL OC-22
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
5Y 3/2
Velocity (m/s)
1.6
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt with very fine sand



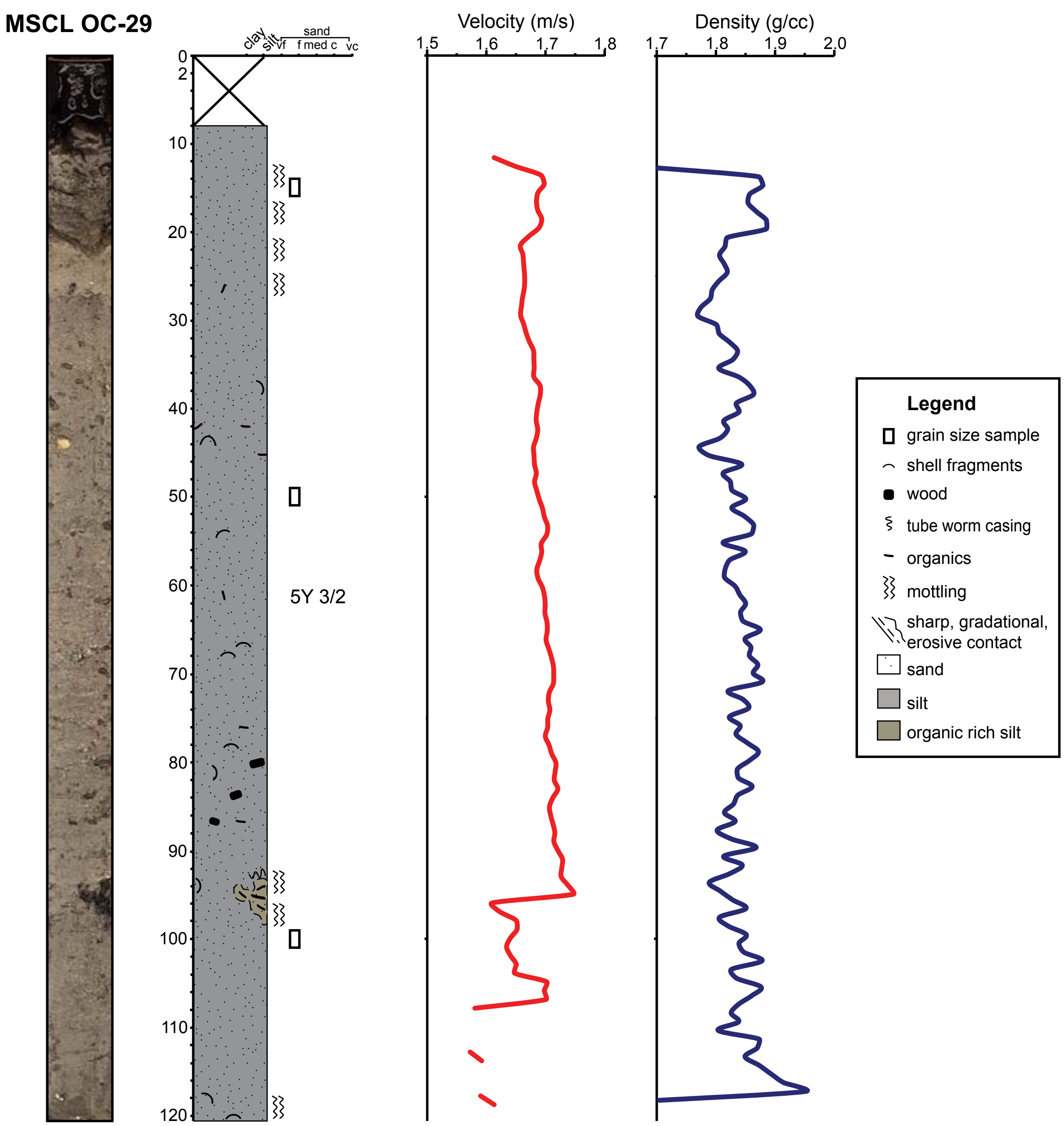
MSCL OC-23
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
139
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
tube worm casing
burrow
shell fragments
rip up clasts
mottling
sharp, gradational, erosive contact
silt
sand


MSCL OC-24
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
152
DY5 3/2
DY5 4/1
DY5 3/2
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.4
1.6
1.8
2.0
Legend
grain size sample
shell fragments
wood
tube worm casing
mottling
sharp, gradational, erosive contact
sand
silt
silt with some clay
clayey silt
silty clay

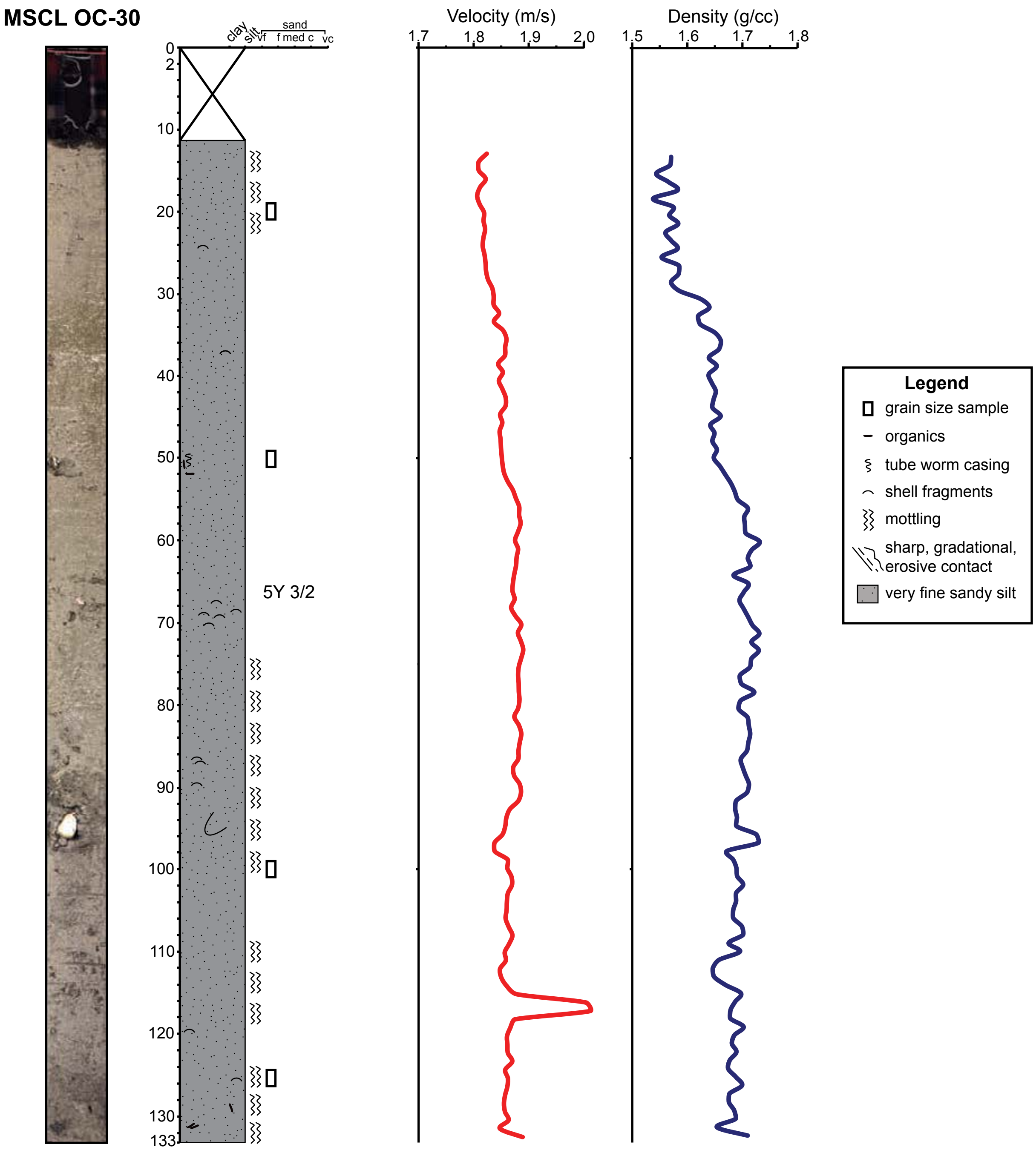

MSCL OC-25
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
151
5Y 3/2
Velocity (m/s)
1.5
1.6
1.7
1.8
Density (g/cc)
1.7
1.8
1.9
2.0
Legend
grain size sample
full shell
tube worm casing
shell fragments
micaceous
mottling
sharp, gradational, erosive contact
silt
sand

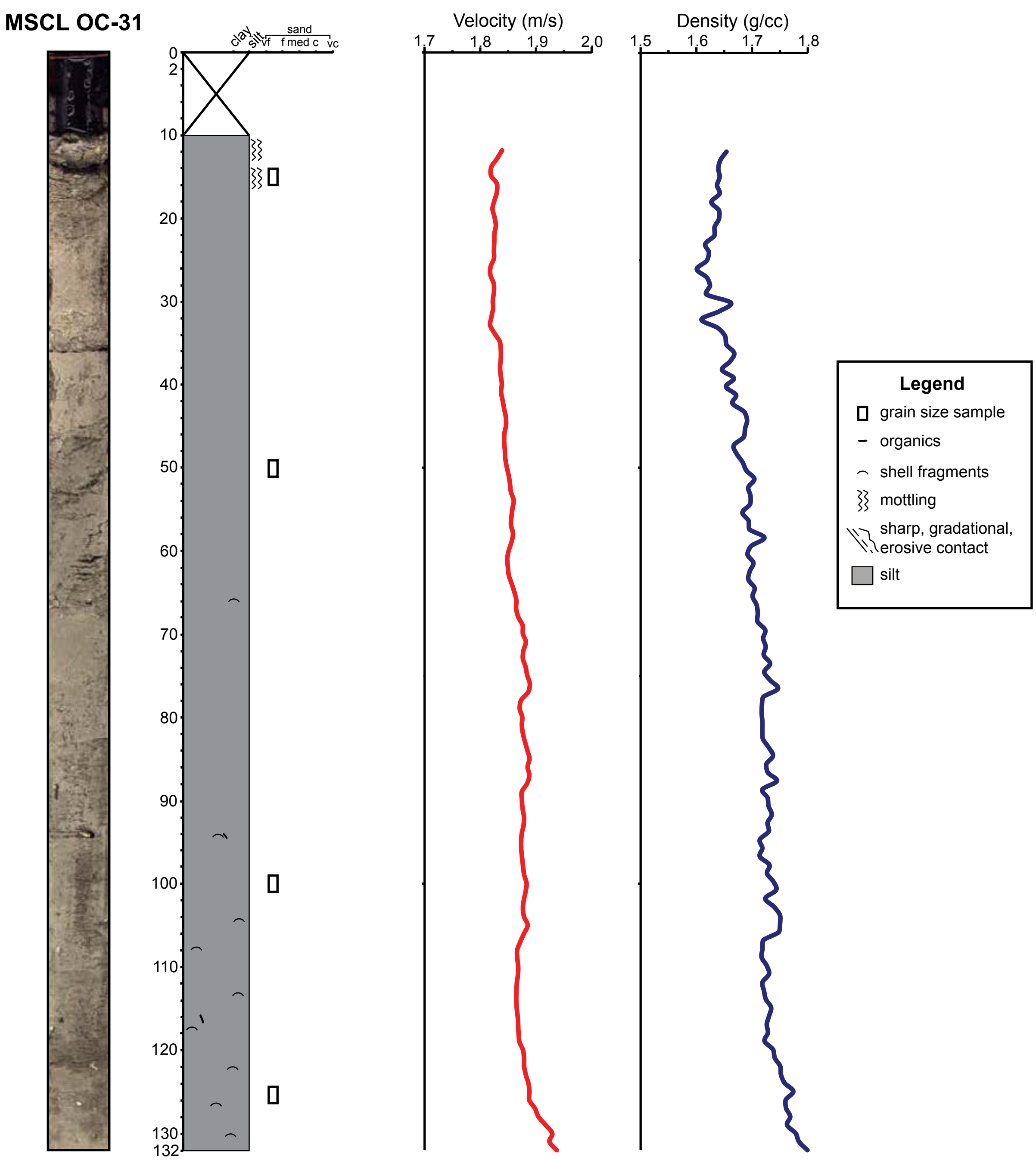


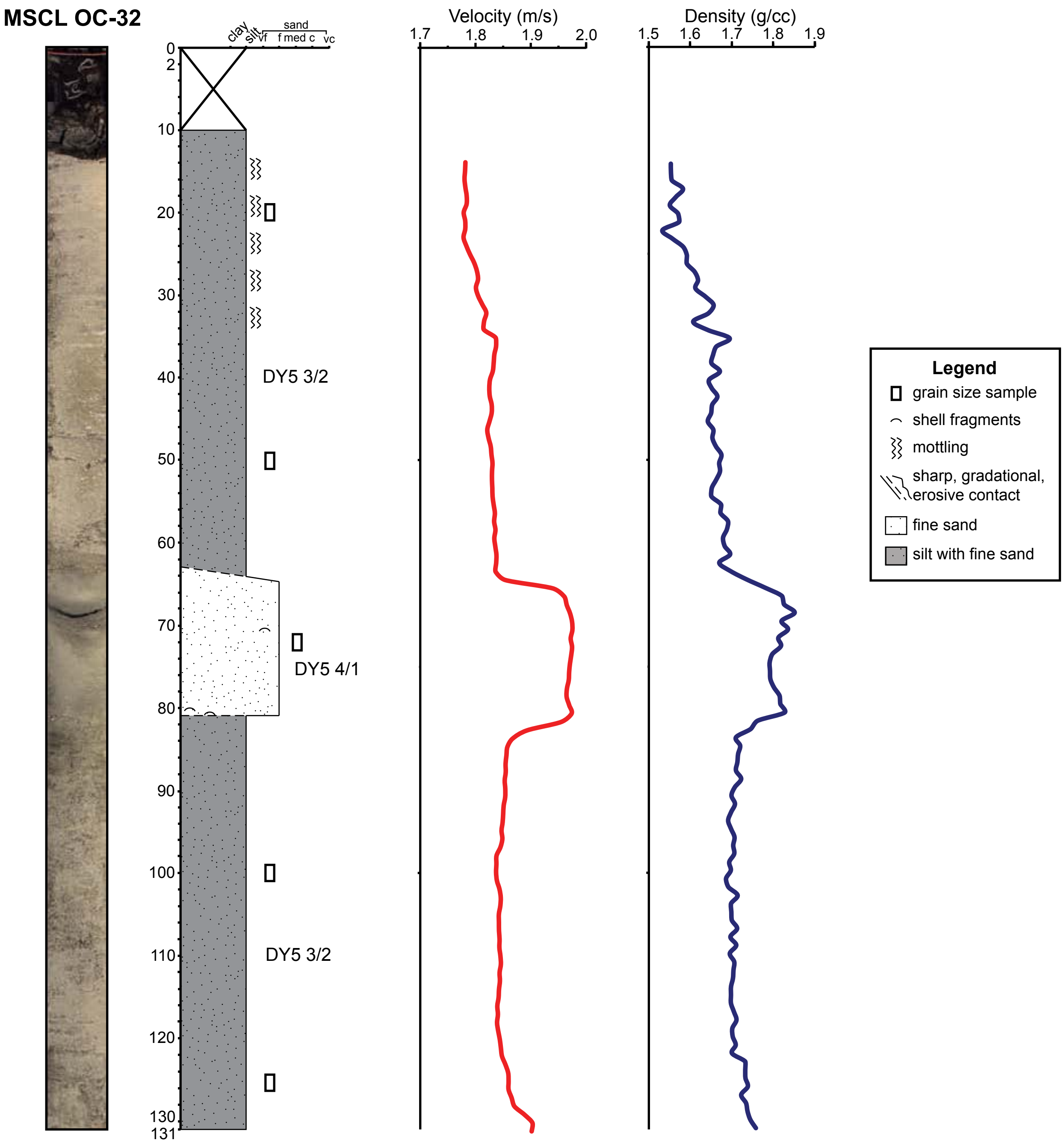
MSCL OC-28
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
137
5Y 3/2
Velocity (m/s)
1.7 1.8 1.9 2.0
Density (g/cc)
1.5 1.6 1.7 1.8
Legend
grain size sample
shell fragments
concretion
mottling
sharp, gradational, erosive contact
silt
sand

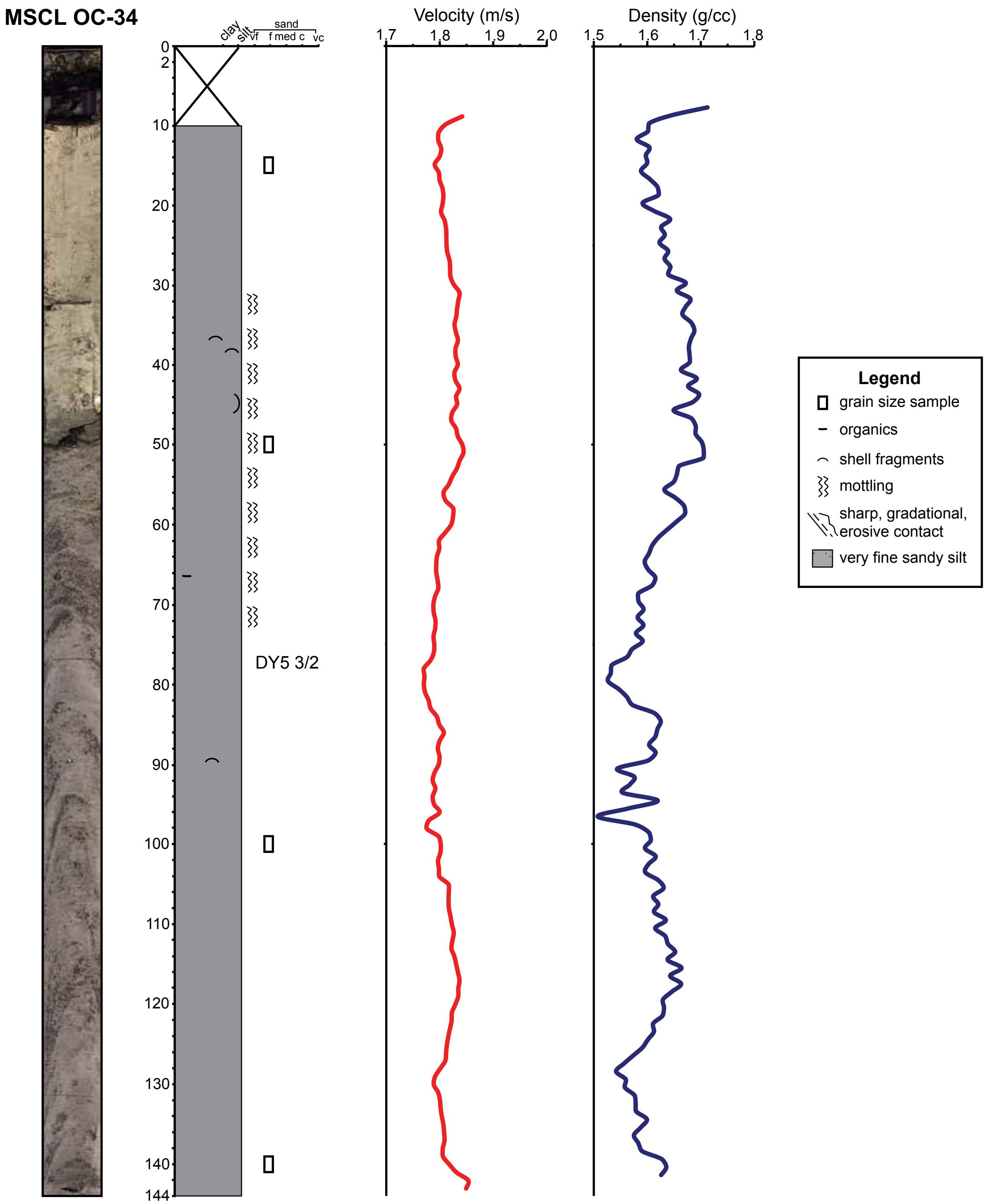


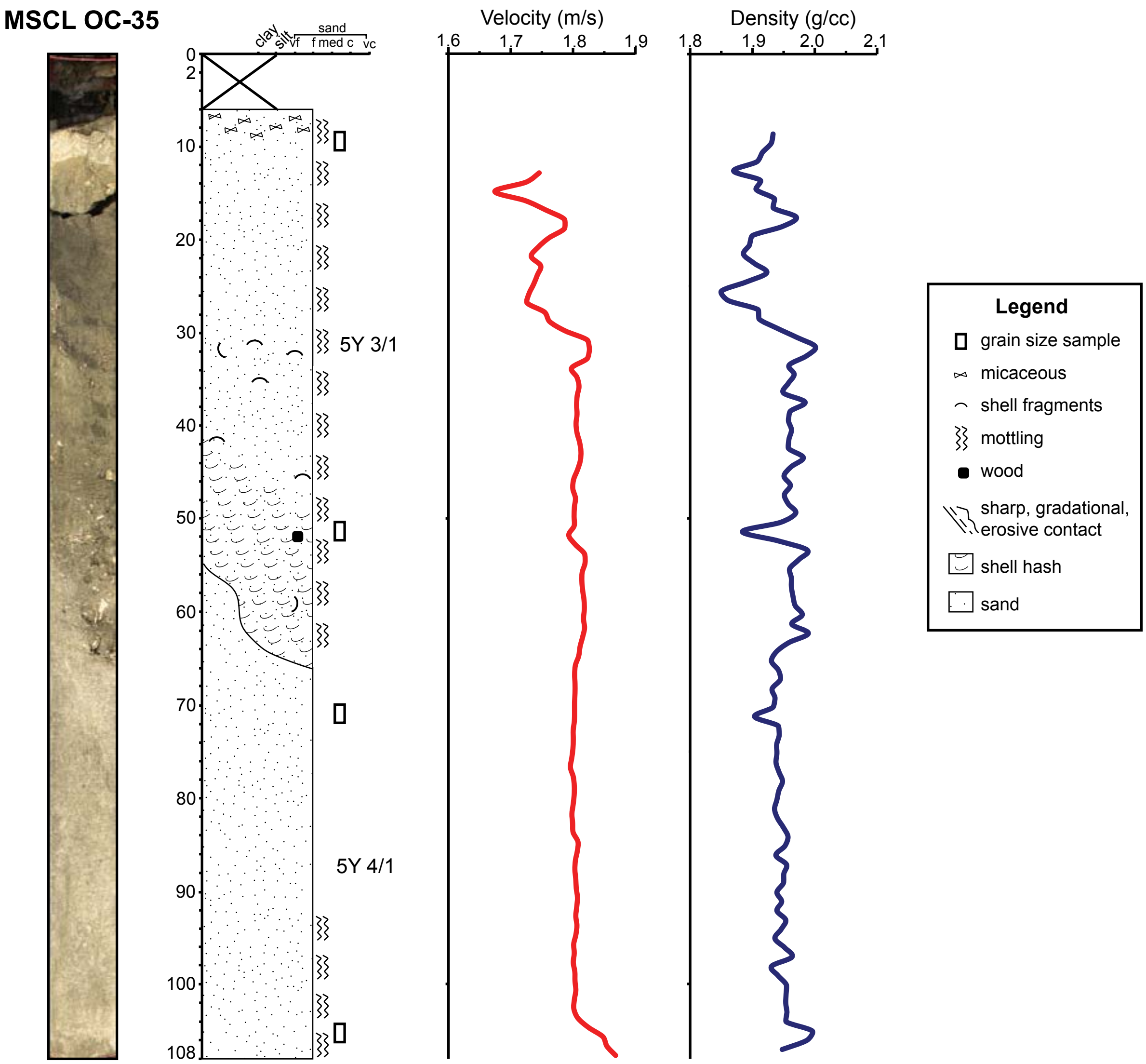
MSCL OC-29
clay
silt
sand
vf f med c vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
5Y 3/2
Velocity (m/s)
1.5 1.6 1.7 1.8
Density (g/cc)
1.7 1.8 1.9 2.0
Legend
grain size sample
shell fragments
wood
tube worm casing
organics
mottling
sharp, gradational, erosive contact
sand
silt
organic rich silt

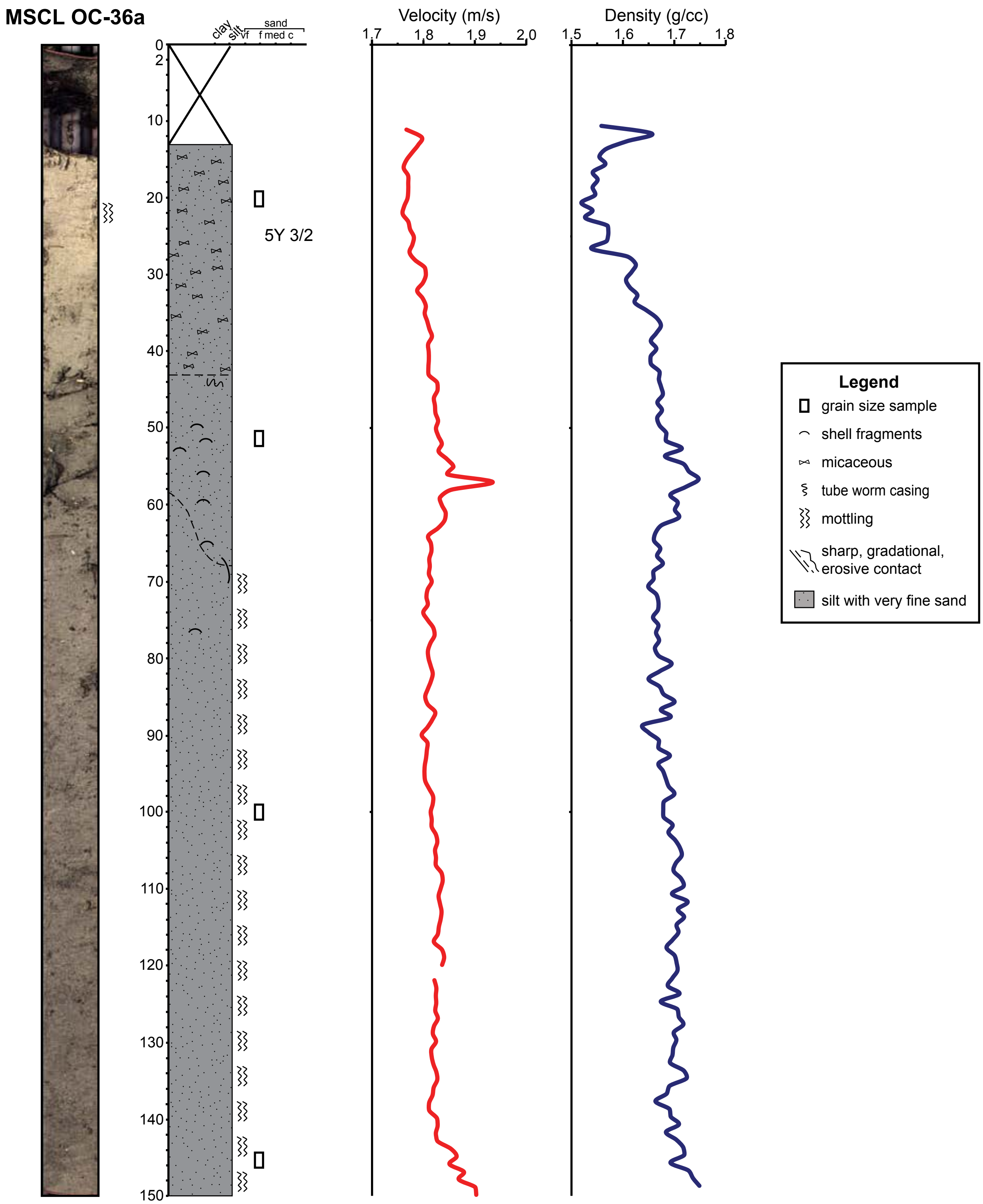

MSCL OC-30
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
133
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
organics
tube worm casing
shell fragments
mottling
sharp, gradational, erosive contact
very fine sandy silt


MSCL OC-31
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
132
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
organics
shell fragments
mottling
sharp, gradational, erosive contact
silt

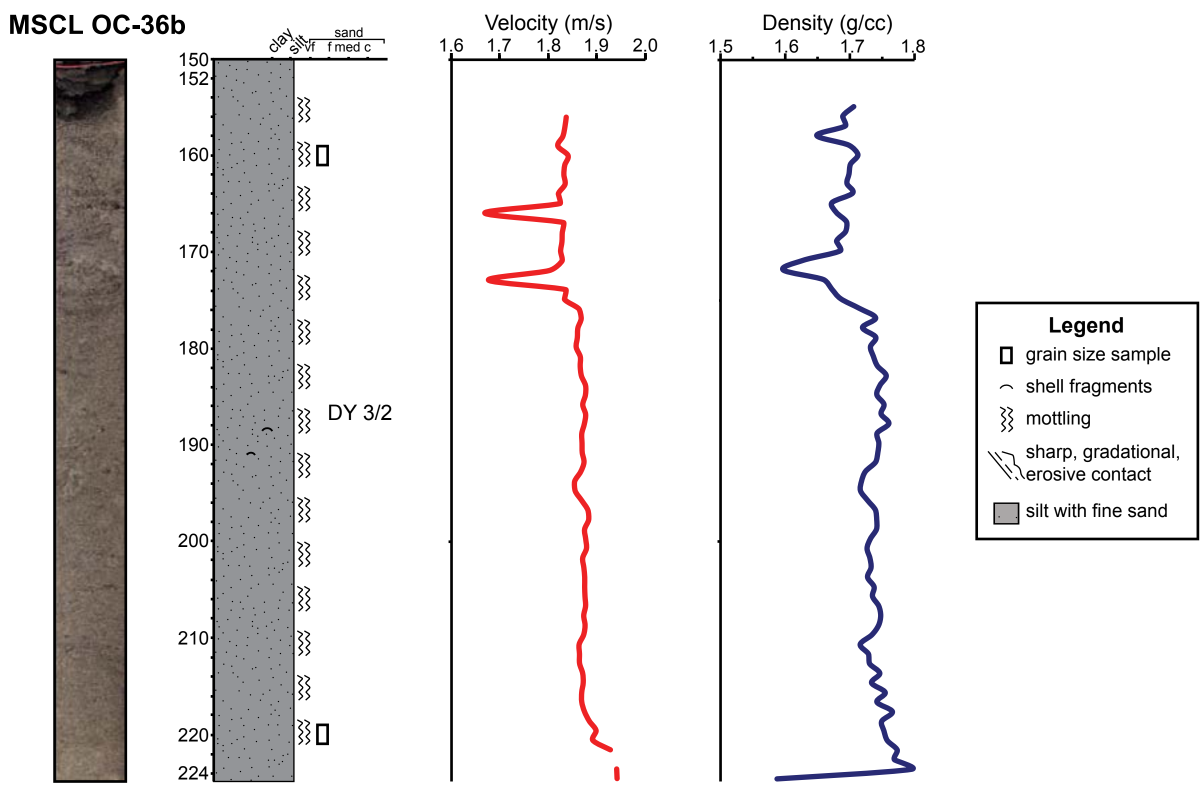

MSCL OC-32
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
131
DY5 3/2
DY5 4/1
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
fine sand
silt with fine sand

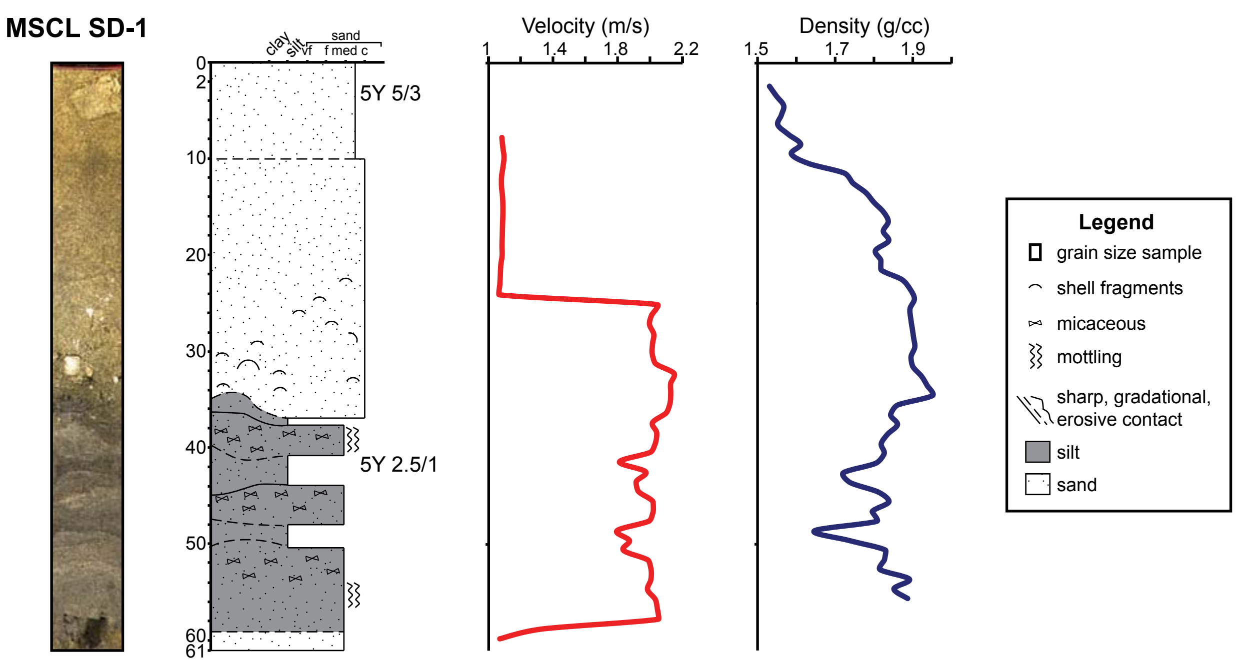

MSCL OC-34
clay
silt
sand
vf
f med c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
144
DY5 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
Legend
grain size sample
organics
shell fragments
mottling
sharp, gradational, erosive contact
very fine sandy silt

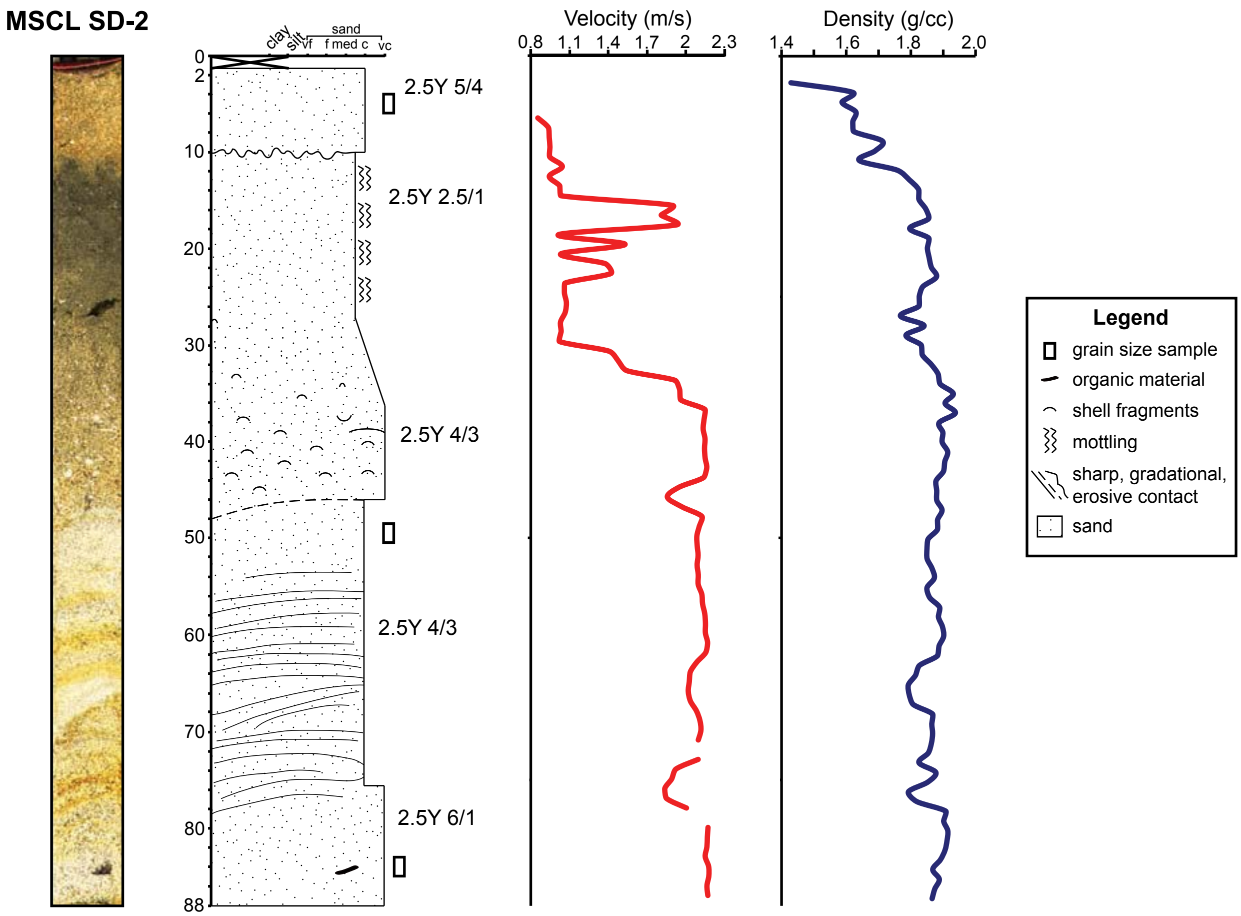

MSCL OC-35
clay
silt
sand
vf
f med c
vc
5Y 3/1
5Y 4/1
Velocity (m/s)
1.6
1.7
1.8
1.9
Density (g/cc)
1.8
1.9
2.0
2.1
Legend
grain size sample
micaceous
shell fragments
mottling
wood
sharp, gradational, erosive contact
shell hash
sand



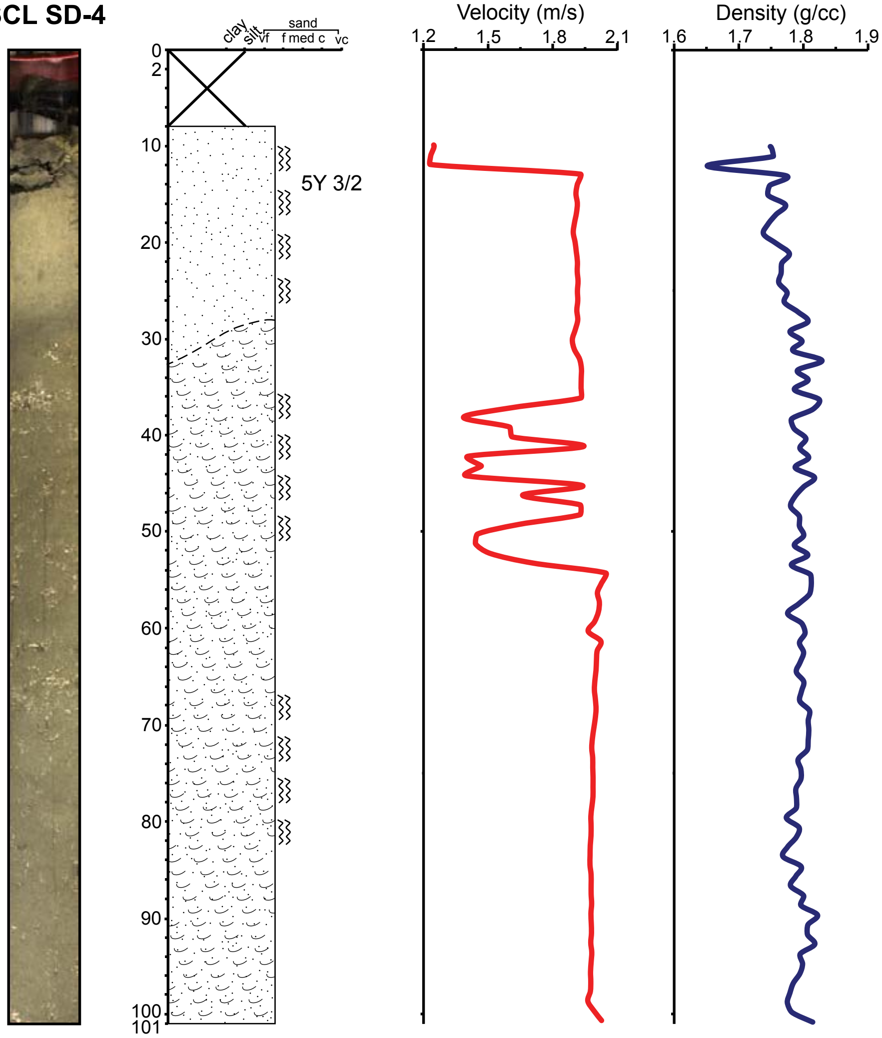
MSCL OC-36a
clay
silt
vf
sand
f med c
5Y 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Legend
grain size sample
shell fragments
micaceous
tube worm casing
mottling
sharp, gradational, erosive contact
silt with very fine sand


MSCL OC-36b
clay
silt
sand
vf
f med c
DY 3/2
Velocity (m/s)
1.6
1.7
1.8
1.9
2.0
Density (g/cc)
1.5
1.6
1.7
1.8
150
152
160
170
180
190
200
210
220
224
Legend
grain size sample
shell fragments
mottling
sharp, gradational, erosive contact
silt with fine sand

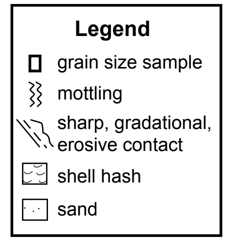

MSCL SD-1
clay
silt
sand
vf
f med c
5Y 5/3
5Y 2.5/1
Velocity (m/s)
1
1.4
1.8
2.2
Density (g/cc)
1.5
1.7
1.9
0
2
10
20
30
40
50
60
61
Legend
grain size sample
shell fragments
micaceous
mottling
sharp, gradational, erosive contact
silt
sand


MSCL SD-2
clay
silt
vf
sand
f med c
vc
2.5Y 5/4
2.5Y 2.5/1
2.5Y 4/3
2.5Y 4/3
2.5Y 6/1
0
2
10
20
30
40
50
60
70
80
88
Velocity (m/s)
0.8 1.1 1.4 1.7 2 2.3
Density (g/cc)
1.4 1.6 1.8 2.0
Legend
grain size sample
organic material
shell fragments
mottling
sharp, gradational, erosive contact
sand

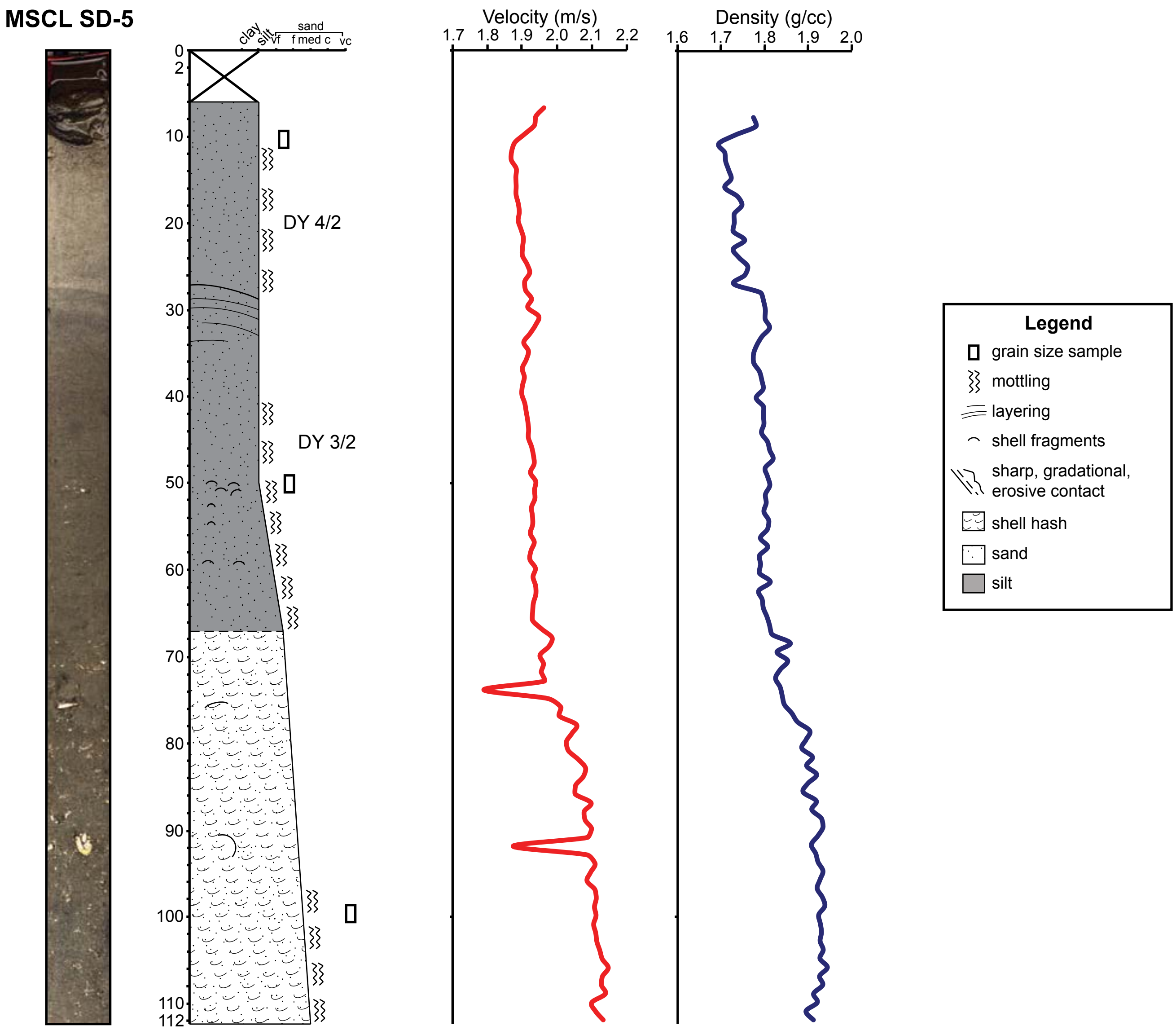
MSCL SD-4



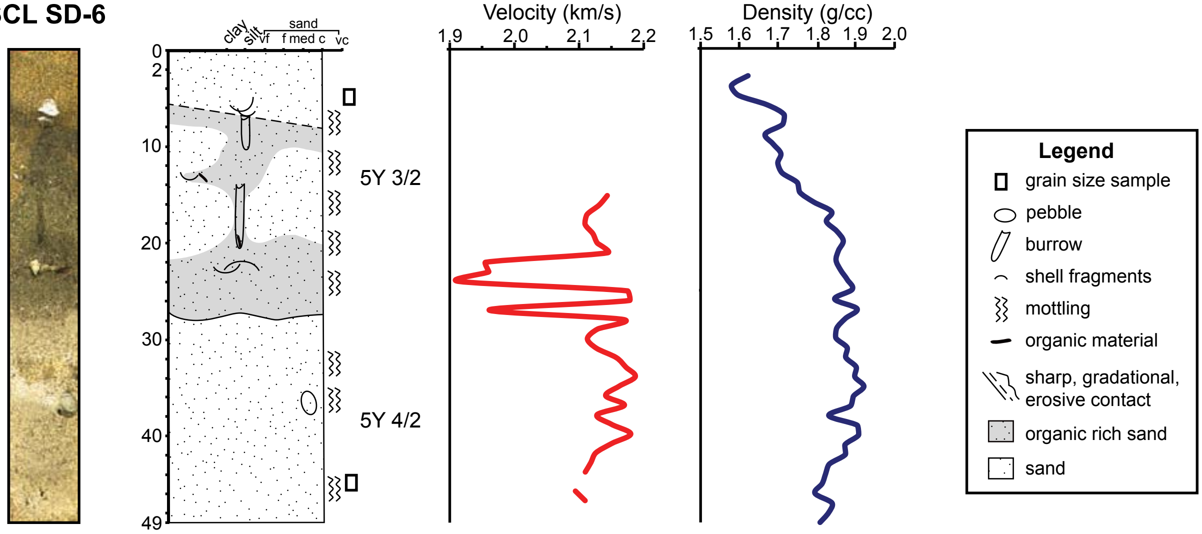
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
101
5Y 3/2
Velocity (m/s)
1.2
1.5
1.8
2.1
Density (g/cc)
1.6
1.7
1.8
1.9

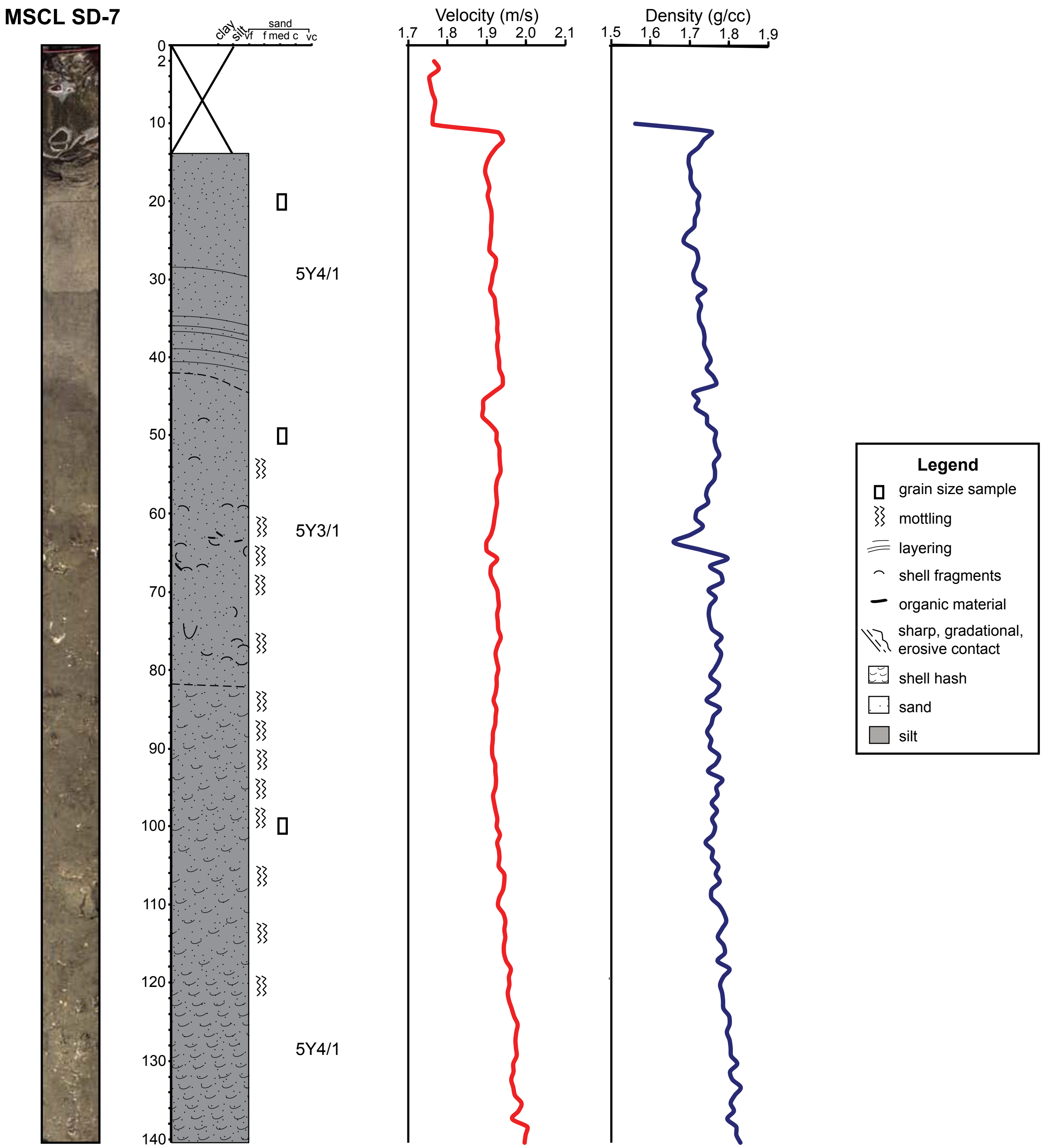


Legend
grain size sample
mottling
sharp, gradational, erosive contact
shell hash
sand


MSCL SD-5
clay
silt
sand
vf
f
med
c
vc
0
2
10
20
30
40
50
60
70
80
90
100
110
112
DY 4/2
DY 3/2
Velocity (m/s)
1.7
1.8
1.9
2.0
2.1
2.2
Density (g/cc)
1.6
1.7
1.8
1.9
2.0
Legend
grain size sample
mottling
layering
shell fragments
sharp, gradational, erosive contact
shell hash
sand
silt

MSCL SD-6


clay
silt
sand
vf f med c vc
0
2
10
20
30
40
49
5Y 3/2
5Y 4/2
Velocity (km/s)
1.9 2.0 2.1 2.2
Density (g/cc)
1.5 1.6 1.7 1.8 1.9 2.0
Legend
grain size sample
pebble
burrow
shell fragments
mottling
organic material
sharp, gradational, erosive contact
organic rich sand
sand



MSCL SD-7
clay
silt
sand
vf
f
med
c
vc
5Y4/1
5Y3/1
5Y4/1
Velocity (m/s)
1.7
1.8
1.9
2.0
2.1
Density (g/cc)
1.5
1.6
1.7
1.8
1.9
0
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Legend
grain size sample
mottling
layering
shell fragments
organic material
sharp, gradational, erosive contact
shell hash
sand
silt

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