Sediment of the Sea Floor

Herman A. Karl

Summary and Introduction

Many people perceive the sea floor to be a smooth blanket of sand similar to a sandy beach. For some areas of the sea floor this is true, but just as the sandy beach is flanked by rocky headland and muddy wetland, so are the smooth sandy plains of the sea floor flanked by various different substrates. This is the case for much of the sea floor in the Gulf of the Farallones.

The earliest general model of sediment distribution across the sea floor was that the size of sediment particles gradually decreased with increasing water depth. According to this model, the nearshore consisted of a blanket of sand—an extension of the sandy shore—that was gradually replaced by silt and then by clay in deeper water. This model was based on the concept that the energy of ocean currents and waves decreased from shallow water to deeper water and that, therefore, smaller particles could only settle to the bottom in less energetic, deeper water.

This early model was based on very limited data. These limited data led scientists to believe that the deep ocean floor, from which very few samples had been collected and of which no direct observations were possible, consisted of a uniform and monotonous layer of fine-grained sediment. As sampling techniques improved and more information was collected, scientists learned that the ocean bottom is as texturally varied and morphologically complex as the land surface. The physical characteristics (for example, size, shape, composition) and the distribution of sediment are the result of a complex interaction among geologic, oceanographic, and biologic processes. Moreover, scientists know that the distribution of sediment on the Continental Shelf is made more complex by deposits of relict sediment. Relict sediment is that material, generally coarse sand and gravel, left on the shelf when it was exposed during times of lower sea level.

Evidently, then, the distribution of different types and grain sizes of sediment and rocks provides clues about the geologic history of an area and the types of ocean currents that deposited or reworked the sediment. Moreover, the different substrates provide habitats for the various organisms that live on, in, and near the sea floor. Information about substrates in Gulf of the Farallones National Marine Sanctuary is used by scientists investigating biodiversity and ecologic systems to help understand and manage the variety of animals and plants that live in the sanctuary. Such information is also used by commercial fishermen as an aid for locating fishes and crabs that prefer a particular substrate.

The sea floor in the Gulf of the Farallones consists of many different types of substrate, including rock outcrops, gravel, sand, clay, and deposits of broken shells. Some of these different types of substrate are found very close to each other and have abrupt boundaries between them. On the Continental Shelf a wide corridor of sand extends westerly from the Golden Gate to the Farallon Islands. Silty sand and sandy silt bound the corridor to the northwest and southeast, and a band of silt extends around Point Reyes.

In general, the sediment on the surface of the Continental Slope is finer and more uniform than that on the Continental Shelf in the Gulf of the Farallones. Nonetheless, most of the surficial sediment on the Continental Slope in the area of the Gulf of the Farallones studied is very sandy, a condition that is unusual (continental slopes are generally characterized by silt and clay). The reason for this abundance of sand is not fully understood. In general, exceptionally strong currents are required to transport large amounts of sand from the shelf to the slope, but such situations are extremely uncommon.

It is not yet known whether the textural patterns and bedforms on the Continental Shelf in the Gulf of the Farallones reflect entirely present-day processes or whether some of these features are remnants of processes that operated during lower stands of sea level in the past. During the glacial cycles of the past several million years, sea levels were lowered to as much as 135 m (445 ft) below present-day sea level. Therefore, ancient relict features created during lower stands of sea level are common on Continental Shelves worldwide. Such lowstands of sea level would have exposed virtually all of the shelf in the Gulf of the Farallones.

Methods and Techniques

Various tools are used to sample the sea floor. Among the earliest and simplest devices was a lead weight smeared with grease attached to a long line. The weight was lowered to the sea floor, and grains of sand and bits of mud would adhere to the grease, providing an indication of the bottom sediment. This method was used by explorers and scientists as late as the 19th century. Obviously, such a device could not collect samples of pebbles and rocks. (This biased sampling is one reason why scientists thought the sea floor was composed mainly of sand, silt, and clay.) Sampling tools have been invented over the past 150 years that enable scientists to collect material ranging in size from clay to large boulders. Large, sturdy dredges are used to obtain rocks and boulders and to break off chunks of bedrock from rock ledges. Many specialized devices exist to sample sand and mud. Some of these devices simply scoop sediment from at and near the surface of the sea floor, and others force metal boxes and pipes into the substrate to collect cores of sediment; these cores vary in length from less than 1 m (approximately 3 ft) to many meters (feet). These surface samplers and subsurface corers are lowered on wire rope from ships. Samples also can be collected by divers in shallow water and by submersibles in water too deep for divers. Additionally, the sea floor can now be observed remotely by still and video cameras.

A great deal of information can be gleaned from the study of samples of material from the sea floor. Other chapters in this atlas describe the chemical composition of sediment and the mineralogical composition of sand grains collected from the Gulf of the Farallones study area. This chapter (1) describes the regional surficial-sediment distribution on the Continental Shelf and Slope in the study area and the physical characteristics of the sediment, principally the size or texture (sand, silt, clay, and so on); and (2) provides an example of the subsurface ("downcore stratigraphy") characteristics of sedimentary deposits on the Continental Slope in the study area.

Gulf of the Farallones Study Area

Sediment described in this chapter that characterizes the Gulf of the Farallones study area was sampled with two devices: (1) a Soutar/Van Veen sampler, used to scoop up sediment at and near the sea-floor surface; and (2) a gravity corer, used to take cores as long as 3 m (10 ft) from the sea floor. Cores provide additional information about the history of the deposits on the sea floor because they penetrate into older sedimentary deposits. The Soutar/Van Veen sampler was used on the Continental Shelf, and the gravity corer was used on the Continental Slope in the study area.

Samples and photographs show that the sea floor in the Gulf of the Farallones study area consists of many different types of substrate, including rock outcrops, gravel, sand, clay, and deposits of broken shells (fig. 1). The regional distribution of these different types substrate are shown in figure 1. Some of these different types of substrate are found very close to each other, and the boundaries between them are abrupt and nongradational. In general, surficial sediment on the Continental Slope is finer and less varied in composition and texture than that on the Continental Shelf in the study area.

Continental Shelf

Two maps (figs. 1, 2) illustrate how the number and density of samples influence the level of detail as to variety and distribution of sediment in the Gulf of the Farallones study area.

A sediment-distribution map based on a regional grid of 97 stations spaced 4 km (2.5 mi) apart over a 2,500 km^2 (960 mi^2) area suggests that much of the study area is covered by sand and silty mud (fig. 3). This map shows that a wide corridor of sand extends westerly from the Golden Gate to the Farallon Islands. Silty sand and sandy silt bound the corridor to the northwest and southeast, and a band of silt extends around Point Reyes. From this information, it might be concluded that the study area is floored by a fairly homogenous layer of sand and silt. Consider, however, the level of information provided by stations spaced 4 km (2.5 mi) apart. How much variation would be captured by such a random grid? To get some idea of how much textural variation may be missed by samples spaced so widely apart, focus on the area just east of the Farallon Islands. According to the sediment-distribution map, the sea floor here is covered by a uniform blanket of fine sand. Data from a grid of 171 stations collected 1 km (0.6 mi) apart in this area reveals an intricate distribution pattern of sediment ranging in size from fine to very coarse sand (fig. 4). This information demonstrates that the study area is much more complex than indicated by the sediment-distribution map based on the regional grid. This sample density provides data important to identification of biologic habitats and interpretation of the depositional processes operating in the Gulf of the Farallones. Even denser grids would likely provide more detailed information. However, the amount of time and the expense involved in the collection of many samples over a large area make it impractical to sample the entire Gulf of the Farallones at such high levels of density. Moreover, even with samples spaced as close as 1 km (0.6 mi), boundaries between textural fields must be estimated. Other instruments, such as sidescan sonar (see chapter on Landscape of the Sea Floor), can be used to view the sea floor and provide continuous information about its features (fig. 5). The most intricate textural patterns are clearly revealed when adjacent side-scan-sonar swaths are joined into a mosaic showing a large area of the sea floor. Grain size, however, cannot be deduced from side-scan-sonar images alone. To deduce the grain size, samples of sediment must be collected from specific sites. The scientist can then use these samples to infer the grain-size distribution over the area covered by the mosaic.

Continental Slope Surficial Grain-Size Distribution

Fewer samples were collected on the Continental Slope than on the adjacent Continental Shelf in the Gulf of the Farallones study area, and these samples are dispersed over a larger area. These samples indicate that the slope is covered mostly by silty and clayey sand (fig. 6). In contrast to the example given previously for the shelf, increasing the number and density of samples would probably not reveal much more variation in the distribution of sediment types on the floor of the Continental Slope in the study area. From many studies of continental margins around the world, scientists have learned that the sediment on slopes is typically finer and more homogenous than that on shelves. This generalization for the region is supported by side-scan-sonar mosaics (see chapter on Landscape of the Sea Floor) and photographs of the slope sea floor. In addition to a uniform distribution of sediment types, both the side-scan-sonar images and photographs show many rocky areas not covered by sediment or covered by only a thin dusting of sediment.

Downcore Stratigraphy

Cores collected on the slope were split in half so that vertical (stratigraphic) changes could be documented downcore. Geologists look for changes in color, layering, sediment texture, and many other physical properties. Many organisms live or have lived in the sediment. These organisms typically make characteristic structures as they burrow. Besides visual observations of the surface of the core, X-ray photographs (radiographs) of the core reveal structures and subtle changes that are not visually observed (fig. 7).

The core shown in figure 7 consists of three major vertical lithographic units. Unit 1, the uppermost unit, visually appears to be a homogeneous sandy silt. However, radiographs reveal some structures that represent the burrows of organisms, but show no strong regular laminations. An irregular contact bounds unit 1 and unit 2, which is a clayey silt mottled by burrows. The basal distribution, unit 3, is a bioturbated clayey silt. Unit 1 represents present-day depositional conditions. It is not known whether this unit represents sediment that accumulated gradually over an unknown period of time or a mass of sediment emplaced during a single rapid event. The mode of emplacement is fundamentally important to the interpretation of the depositional environment that characterizes the area of slope at which this core was collected.

Conclusions and Implications

It is not yet known whether the textural patterns and bedforms on the Continental Shelf in the Gulf of the Farallones study area reflect entirely present-day processes or whether some of these features are remnants of processes that operated during lower stands of sea level in the past. Ancient relict features created during lower stands of sea level are common on the Continental Shelf. In the past, eustatic (worldwide changes in the absolute volume of the ocean attributed to ice-age cycles) sea level was as much as 135 m (445 ft) below present-day sea level. Such lowstands of sea level would have exposed virtually all of the shelf in the study area. A regional unconformity detected on high-resolution seismic-reflection profiles proves that much of the shelf in the study area was subaerially exposed in the past. These facts need to be considered when using textural patterns and seabed morphology as an aid to interpret present-day ocean current systems operating on the shelf.

Most of the surficial sediment on the Continental Slope in the Gulf of the Farallones study area is very sandy, a condition that is unusual for sediment on the Continental Slope (slopes are generally characterized by silt and clay). The reason for this abundance of sand is not fully understood. Commonly, sandy sediment indicates strong currents or an abundant supply of coarse material. In general, exceptionally strong currents are required to transport large amounts of sand from the Continental Shelf to the Continental Slope; such situations are extremely uncommon. Coarse material is present on the Continental Slope, but generally it is masked or overwhelmed by fine sediment. Thus, coarse material composes a small percentage of the samples collected. Ordinarily, strong currents on the Continental Shelf winnow fine sediment from shallow-water deposits and transport this material in suspension to the lower-energy environment of the Continental Slope, where it settles and accumulates on the seabed. This fine silt and clay continues to accumulate and form thick water-saturated deposits, which commonly become unstable on the steep slopes.

Further Reading

Shepard, F.P., 1973, Submarine geology: New York, Harper and Row, 517 p.

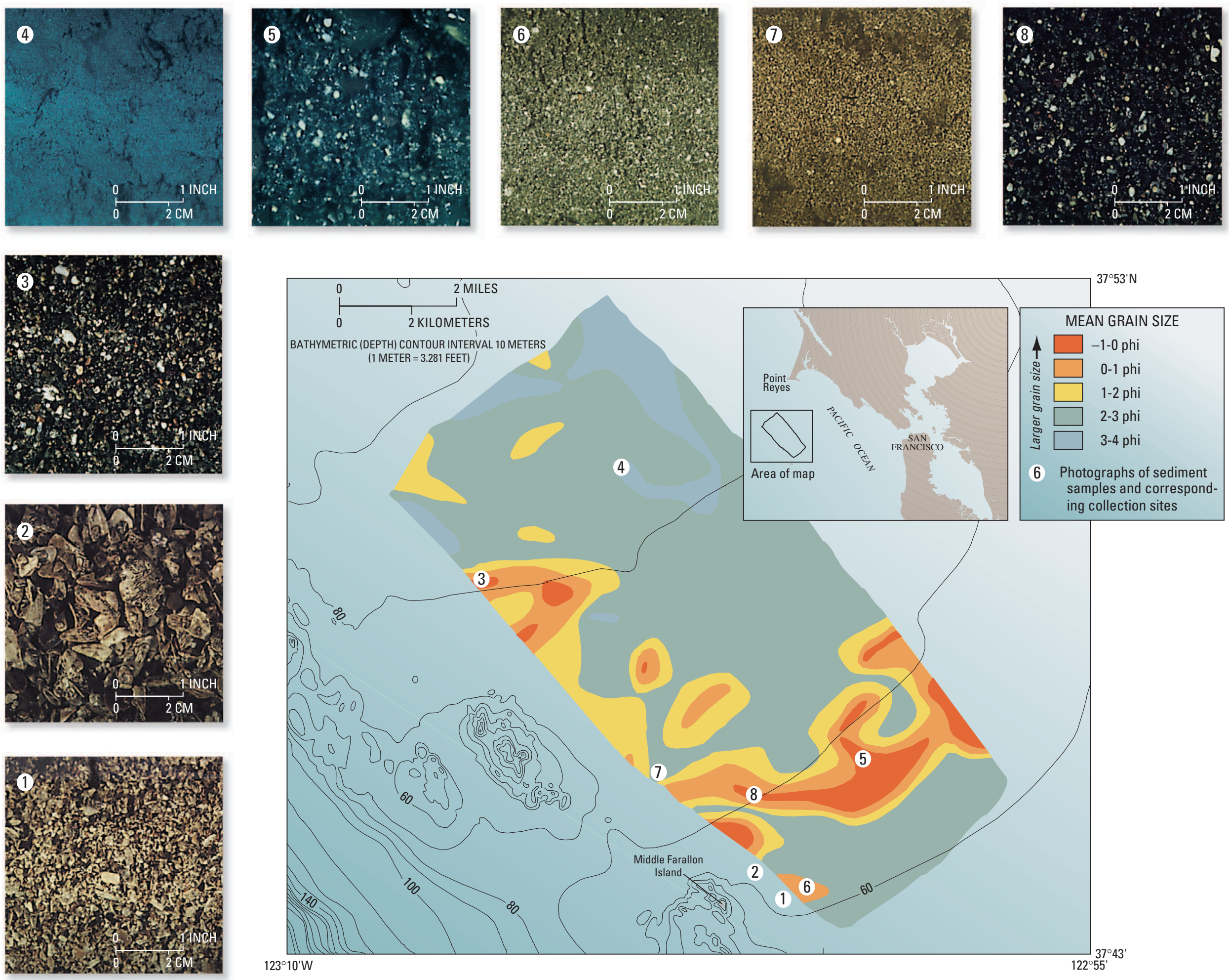

Figure 1. Distribution of sediment types near the Farallon Islands.

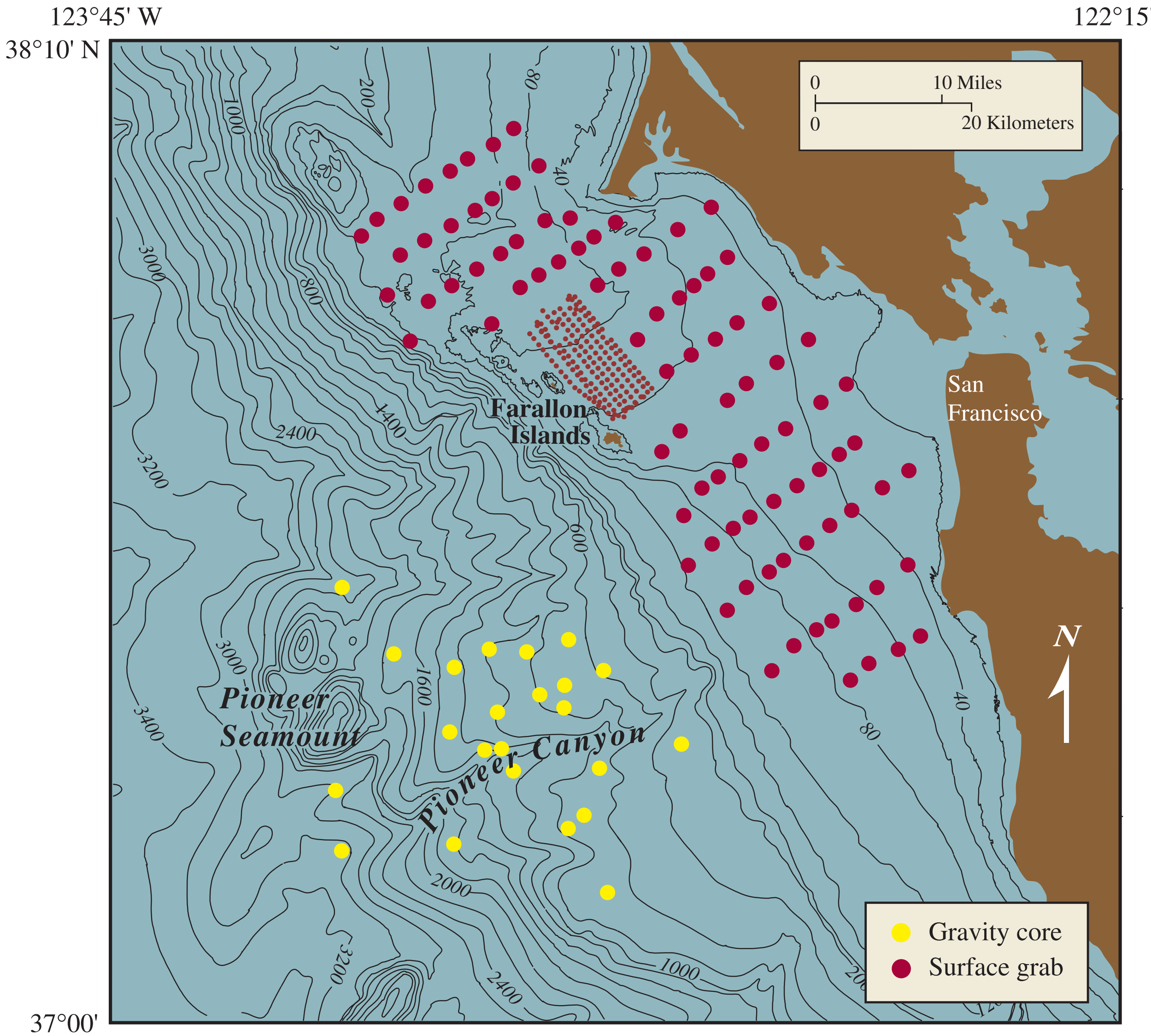

Figure 2. Gulf of the Farallones study area, showing sample locations on the Continental Shelf and Slope. Bathymetric contour interval 20 m (approx. 66 ft) to 200 m (approx. 660 ft); 200 m (approx. 660 ft) in deeper water.

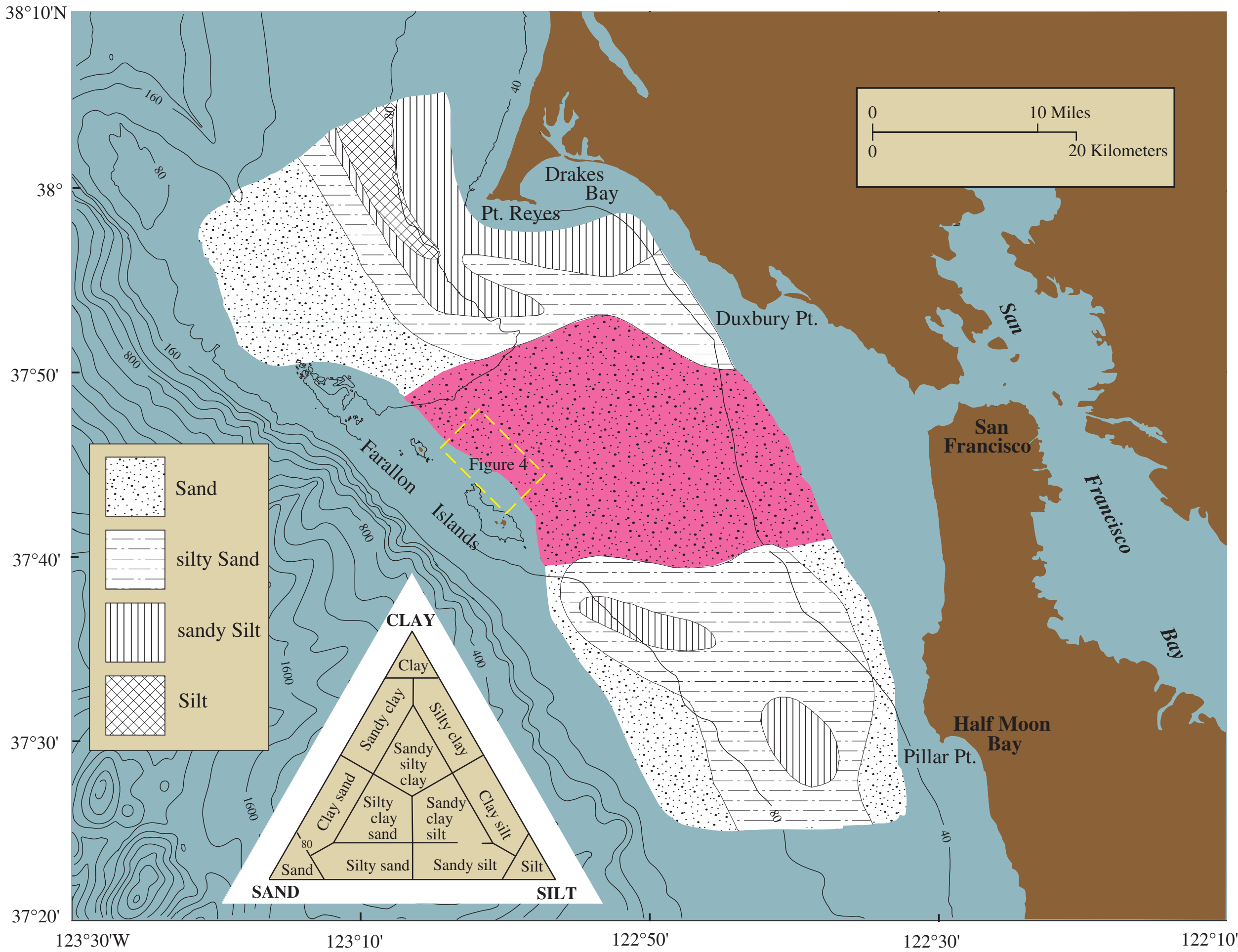

Figure 3. Gulf of the Farallones study area, showing sea-floor surficial-sediment texture. Important feature is a band of uniform sand (pink area) across the central part of the Continental Shelf. Figure 4 shows how detailed sampling reveals variety and type of sand in study area. Ternary diagram (triangle) illustrates how sediment is described in terms of its sand, silt, and clay content. Bathymetry in meters (1 m = 3.281 ft).

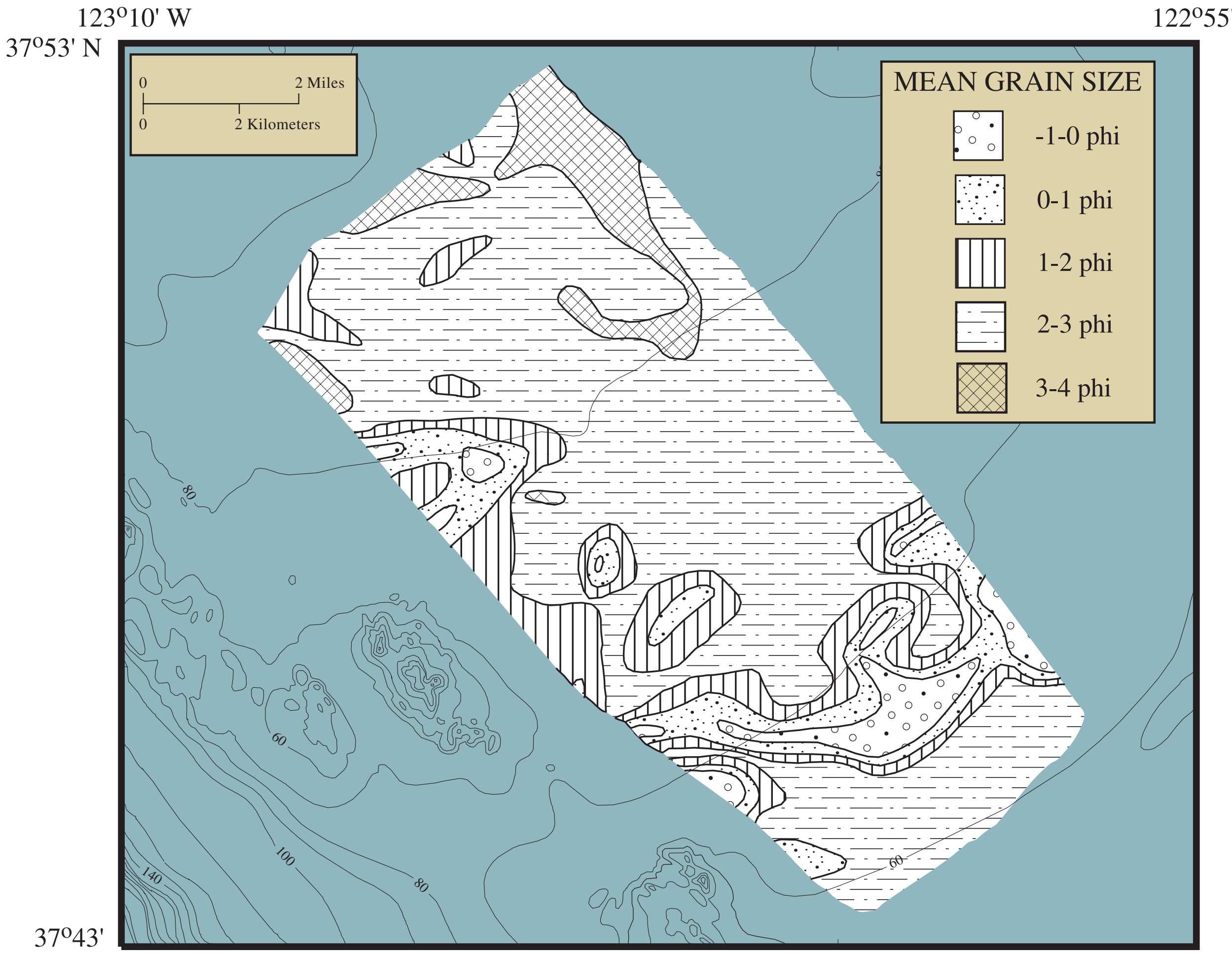

Figure 4. Detailed sediment-distribution map for area shown on figure 3. Bathymetry in meters (1 m = 3.281 ft).

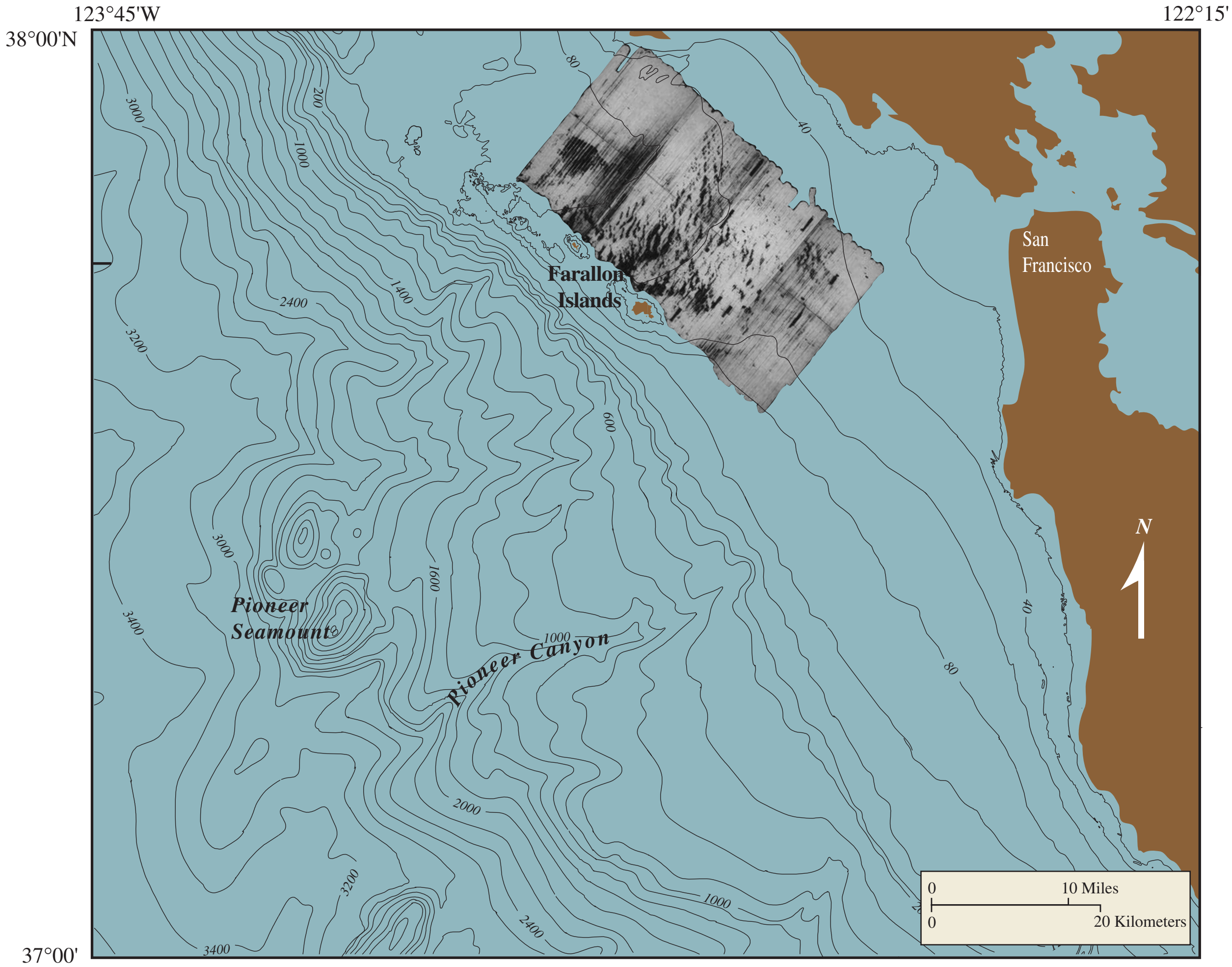

Figure 5. Sidescan-sonar mosaic of the Continental Shelf near the Farallon Islands, superimposed on a map of the Gulf of the Farallones. Bathymetric contour interval 20 m (approx. 66 ft) to 200 m (approx. 660 ft); 200 m (approx. 660 ft) in deeper water.

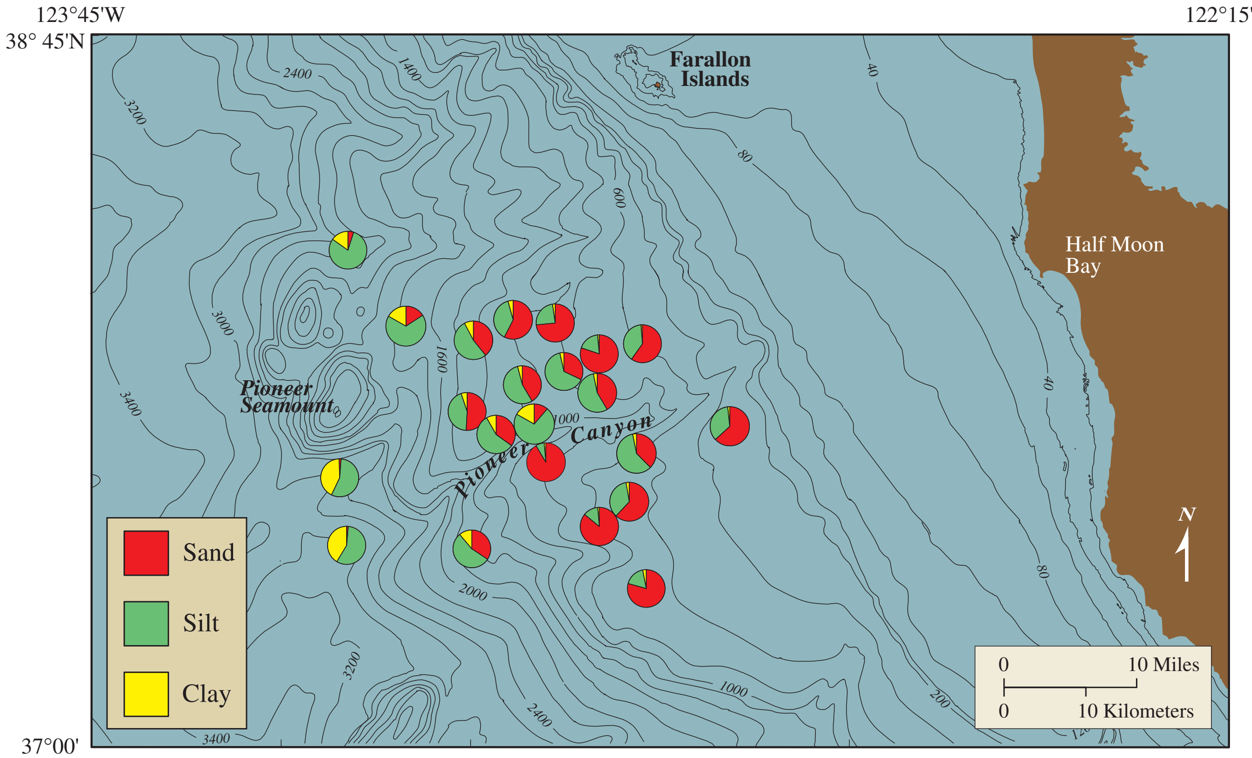

Figure 6. Continental Slope in Gulf of the Farallones study area, showing sediment distribution. Pie diagrams show relative proportions of sand, silt, and clay at specific sample locations. Bathymetric contour interval 20 m (approx. 66 ft) to 200 m (approx. 660 ft); 200 m (approx. 660 ft) in deeper water.

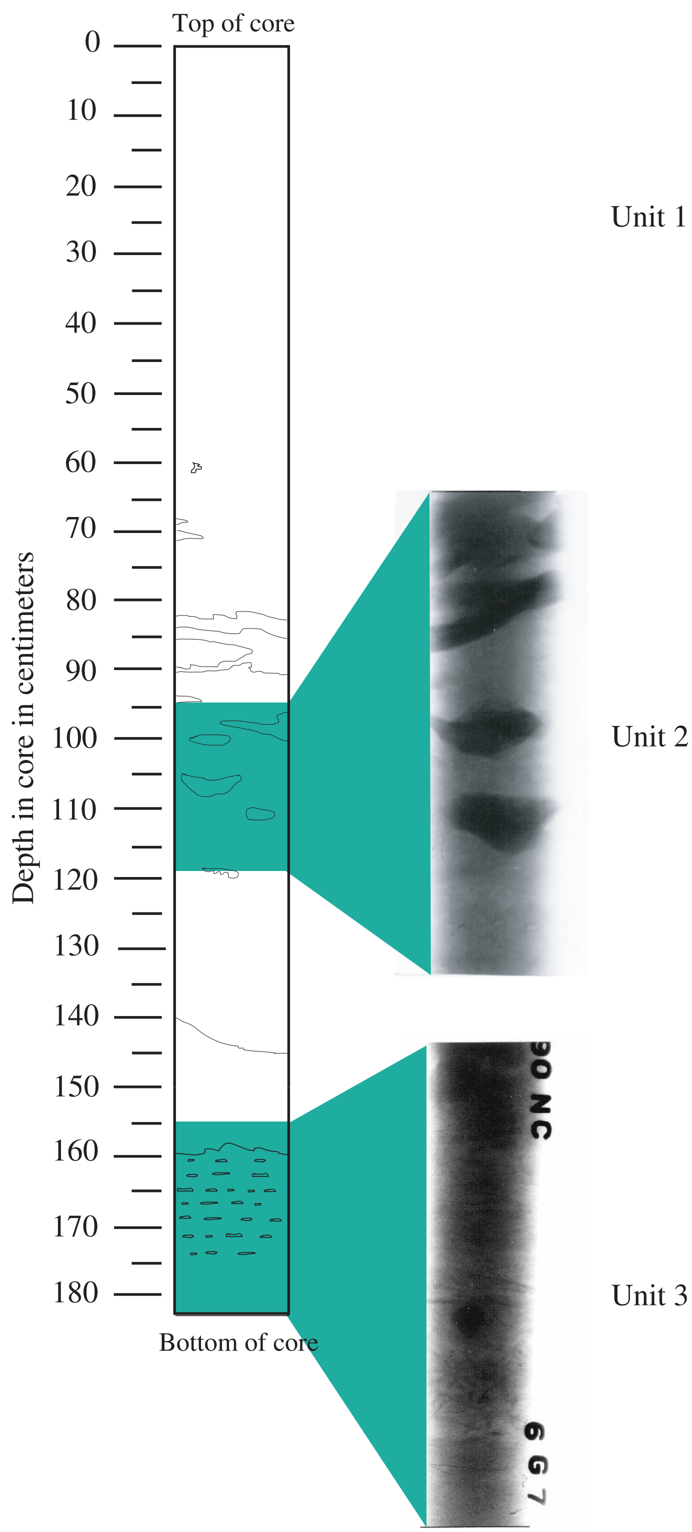

Figure 7. Sediment core collected on the Continental Slope in Gulf of the Farallones study area at a water depth of 795 m (2,620 ft), with radiographs for units 2 and 3. Dark blotches are burrows of organisms.