Heavy-Mineral Provinces on the Continental Shelf

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Summary and Introduction

Minerals are integral to every aspect of our lives—from esthetically pleasing gem stones to more mundane but essential components of concrete. In geology, minerals are useful in unraveling certain questions, such as where do large bodies of sediment come from (source), how do they move around (transport processes), and where do they settle (distribution). This chapter looks at these geologic issues in the Gulf of the Farallones by examining small (sand-size) mineral grains of high specific gravity ("heavy minerals"— in this study, minerals at least 2.96 times as dense as water). Small grains are apt to be transported great distances by natural processes. In contrast, large mineral grains are not transported far before coming to rest in a depositional basin and thus are not as diagnostic as smaller grains. Therefore, small particles of heavy minerals are good clues to sediment source, transport, and distribution.

The Gulf of the Farallones extends from Point Reyes on the north to Año Nuevo on the south and from the Golden Gate westward across the Continental Shelf to the Continental Slope beyond the Farallon Islands-Cordell Bank ridge. Water depths on the shelf are generally less than 100 m (330 ft). Most of the gulf lies west of the major tectonic feature known as the San Andreas Fault Zone, which separates two different types of basement rock: granitic rocks of the Salinian block on the west, and various sedimentary, volcanic, and metamorphic rocks of the Franciscan terranes to the east (see chapter on Earthquakes, Faults, and Tectonics).

The surficial sediment in the Gulf of the Farallones was initially eroded from rocks onshore and then transported and deposited in the present offshore basin. The agents of this process included faulting and folding of the Earth's crust and changes in global climate, including glaciation. The sediment of the sea floor in the gulf (see chapter on Sediment of the Sea Floor) is composed of sand, mud, some gravel, and biologic debris, such as shells and bone fragments (fig. 1).

Sediment on the Continental Shelf in the Gulf of the Farallones west of San Francisco Bay was systematically sampled by the U.S. Geological Survey in 1989 to study its characteristics, distribution, and origin. Various properties of the samples were analyzed, including grain size and mineralogic and chemical composition (see chapter on Chemical Composition of Surface Sediments on the Sea Floor). The minerals present in the samples reflect two major sources in the central California region: (1) the large variety of rock types of the Franciscan terranes and (2) granitic materials shed from the Sierra Nevada and similar rocks in the central California region. The two mineralogical assemblages are distributed in different areas of the shelf; how this distribution developed is less clear.

The mineral and chemical composition of sediments from the Gulf of the Farallones define four depositional provinces—two that are composed of granitic debris and two that reflect sources in the Franciscan terranes of northern California. The granitic sediment comes from two sources. The dominant source is the Sierra Nevada. The sediment from this source was transported down the Sacramento-San Joaquin drainage and through San Francisco Bay and the Golden Gate. The lesser source is the granitic basement rocks of the Salinian block west of the San Andreas Fault system. Sediment from a Sierran source is spread over the Gulf of the Farallones to a limited extent north of the Golden Gate and to at least the shelf edge south of the Gate. A small contribution of sediment from Salinian rocks of the Farallon Islands-Cordell Bank ridge, along the west edge of the shelf, is also found on the shelf near the ridge.

Minerals derived from the Franciscan terranes characterize surface sediment on the Continental Shelf in the northern Gulf of the Farallones. These minerals represent reworked shelf deposits, erosion of dune deposits accumulated during the last low stand of sea level, and coastal erosion of Franciscan bedrock exposures.

Methods

Sand is composed of an assortment of minerals, such as quartz, feldspar, and mica, as well as small rock fragments (fig. 1*B*). One of the most diagnostic mineral components for identifying possible sources of sediment is the heavy minerals, so called heavy because of their high specific gravity. Although heavy minerals commonly make up only a small part (generally less than or equal to 5 weight percent) of bottom sediment, they may give precise information about the types of rock from which the sediment was eroded. For example, if many grains of glaucophane (a blue amphibole) are present in a sediment, the sediment probably includes material eroded from glaucophane schist, a metamorphic rock that commonly occurs in the Franciscan terranes. The minerals need to be identified from grains that are somewhat representative of the grain size of the sampled sediment, which means that very small grains (finer than average beach sand) need to be examined by microscopic methods. Before examination, the heavy minerals are concentrated by separating them from minerals of lower specific gravity (light minerals).

For this study, sand with a grain size from 0.063 to 0.250 mm (0.0025–0.010 in.) was sieved from the bulk samples collected. The sand grains, in turn, were immersed in a high-density liquid to separate the heavy minerals (which sink in the liquid) from the light minerals (which float in the liquid). The heavy sand grains were mounted on glass slides, and at least 300 grains were identified and counted through a microscope to determine the abundance of each mineral type (figs. 1*C*, *D*). The results of the heavy-mineral observations are discussed in this report.

A statistical method called factor analysis was used to determine any patterns in the distribution of mineral groupings. All mineral counts are included in the calculation, and the resulting groupings of minerals are plotted on maps to understand better what geologic processes were responsible for their distribution (see fig. 3).

Results

Heavy minerals constitute less than 15 weight percent of the sandy-sediment samples from the Gulf of the Farallones, less than 7 weight percent in most samples (fig. 2). Samples with a moderately large heavy-mineral content occur off Point Reyes, west of the Golden Gate, and in the southern part of the study area.

Factor analysis of the heavy minerals defined two major depositional provinces, one dominated by minerals indicative of the Franciscan terranes (province 1) as a source, and one characteristic of granitic mineralogy (province 2). Province 1 covers the northwestern part of the Gulf of the Farallones. Sphene, garnet, glaucophane, and minor enstatite, lawsonite, and actinolite are characteristic of this province and are common mineral constituents of the different rock types in the Franciscan terranes (fig. 3*A*).

Province 2 covers a narrow strip along the coast north of the Golden Gate and broadens south of it. The minerals characteristic of this province are hornblende, hypersthene, and augite (fig. 3*B*). The abundance of hornblende is consistent with previous studies in the offshore area south of San Francisco and is partly attributed to granitic rocks of the Salinian terranes (for example, from Montara Mountain). Hypersthene and hornblende have been associated with sediment discharged by the

Sacramento-San Joaquin River system, which picks up hornblende from the granitic Sierra Nevada and hypersthene from interior volcanic terranes.

Discussion

For the Franciscan-derived sediment in the northern and western parts of the study area, possible transport paths depend on whether the sediment is modern or relict (ancient). If it is relict, then the sediment may have been shed from Franciscan exposures along the central California coast, with large contributions from the Russian River area to the north of the study area. The Russian River drains an area containing abundant Franciscan rocks. Younger sediment from the nearshore cliffs has similar Franciscan mineralogy, but cliff erosion cannot account for the amount and distribution of sediment in the gulf basin.

The distribution of granitic material west of the Golden Gate indicates that this material was transported by the Sacramento-San Joaquin Rivers to San Francisco Bay and then through the Golden Gate to the gulf. However, not much sediment of sand size or larger has reached the gulf in the past 5,000 years. The granitic material (province 2) may be supplanting the Franciscan sediment (province 1) in the western part of the gulf. We have no information about temporal changes that have affected the mapped boundary between the two heavy-mineral assemblages. Sediment containing minerals that are characteristic of granitic rocks currently may be shed from the Salinian-block exposures in the region: the Cordell-Farallon Islands block, part of the Point Reyes Peninsula and Bodega Head, and Montara Mountain. The presence of intermediate volcanic minerals (hypersthene) indicates that the Sierra Nevada was also a source. The modern discharge of sand-size sediment through the Golden Gate appears to be small because the sand-size and larger sediment carried by the rivers coming out of the Sacramento-San Joaquin Valleys is deposited upstream or in the upper reaches of San Francisco Bay.

This study of the mineralogy of selected samples on the shelf of the gulf gives a simple picture of the distribution of heavy-mineral assemblages on the sea floor, and supplies only part of the information needed to determine the transport pathways and the age (modern or relict) of the sediment. Other data related to the complex local tectonic history (faulting and crustal warping) and global climate variations need to be collected and integrated to complete our understanding of sediment movement in the study area.

Further Reading

Chin, J.L., Rubin, D.M., Karl, H.A., Schwab, W.C., and Twichell, D.C., 1989, Cruise report for the Gulf of the Farallones cruise F1–89–NC, F2–89–NC off the San Francisco Bay area: U.S. Geological Survey Open-File Report 89–417, 4 p.

Maher, N.M., Karl, H.A., Chin, J.C., and Schwab, W.C., 1991, Station locations and grain-size analysis of surficial sediment samples collected on the continental shelf, Gulf of Farallones during cruise F2–89–NC, January 1989: U.S. Geological Survey Open-File Report 91–375–A, 42 p.

Wilde, P., Lee, J., Yancey, T., and Glogoczowski, M., 1973, Recent sediments of the central California continental shelf. Part C. Interpretation and summary of results: Berkeley, University of California, Hydraulic Engineering Laboratory Technical Report HEL 2–38, 83 p.

Wong, F.L., and Klise, D.H., 1986, Heavy mineral, clay mineral, and geochemical data of surface sediments from coastal northern California rivers: U.S. Geological Survey Open-File Report 86–574, 13 p.

Yancey, T.E., and Lee, J.W., 1972, Major heavy mineral assemblages and heavy mineral provinces of the central California coast region: Geological Society of America Bulletin, v. 83, p. 2099–2104.

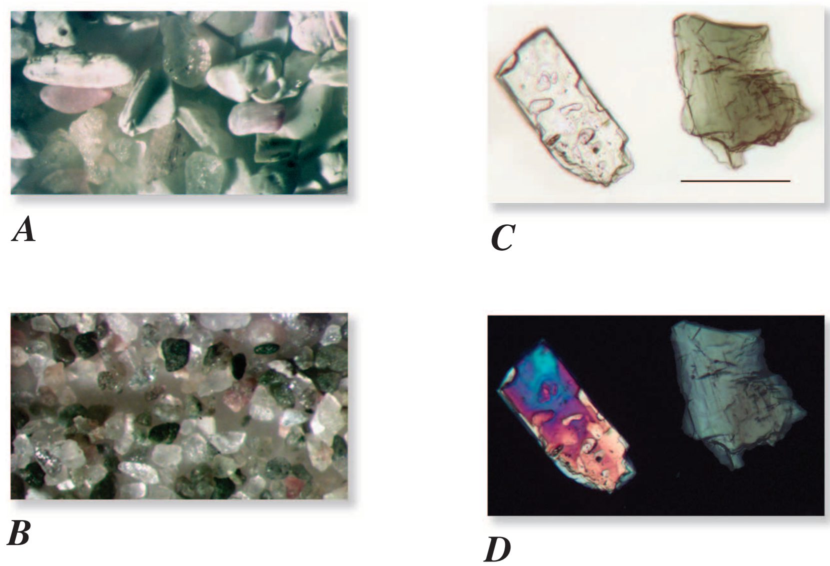

Figure 1. Photomicrographs of samples of surficial sediment collected from Gulf of the Farallones study area. *A*, Sample F2–89–NC M141, consisting mostly of shell material. Grains were sieved to include only those from 0.25 to 0.50 mm in diameter. Width of image is 4 mm. *B*, Light (lower specific gravity) mineral grains in sample F2–89–NC M43. Grains were sieved to include only those from 0.063 to 0.250 mm in diameter. Sample was then stirred into a jar of heavy liquid; these grains are representative of those that floated to top. Most light-colored grains are quartz or feldspar; dark grains are glauconite, a clay mineral. Width of image is 2.25 mm. *C*, *D*, Heavy-mineral grains in sample F2–89–NC G71, mounted on a glass slide for examination under a microscope. Grain on left is hypersthene; grain on right is hornblende. Heavy minerals are those that sink to bottom of jar of heavy liquid during separation process. In *C*, grains are photographed in plane-polarized light (single polarizing lens); in *D*, grains are photographed in crosspolarized light, with a second polarizer oriented 90° to the first. Characteristics of grains under each type of illumination help in identification. Count of number of grains of each type of mineral defines heavy-mineral assemblages in surficial sediment of the Gulf of the Farallones. Length of bar in *C* is 0.5 mm.

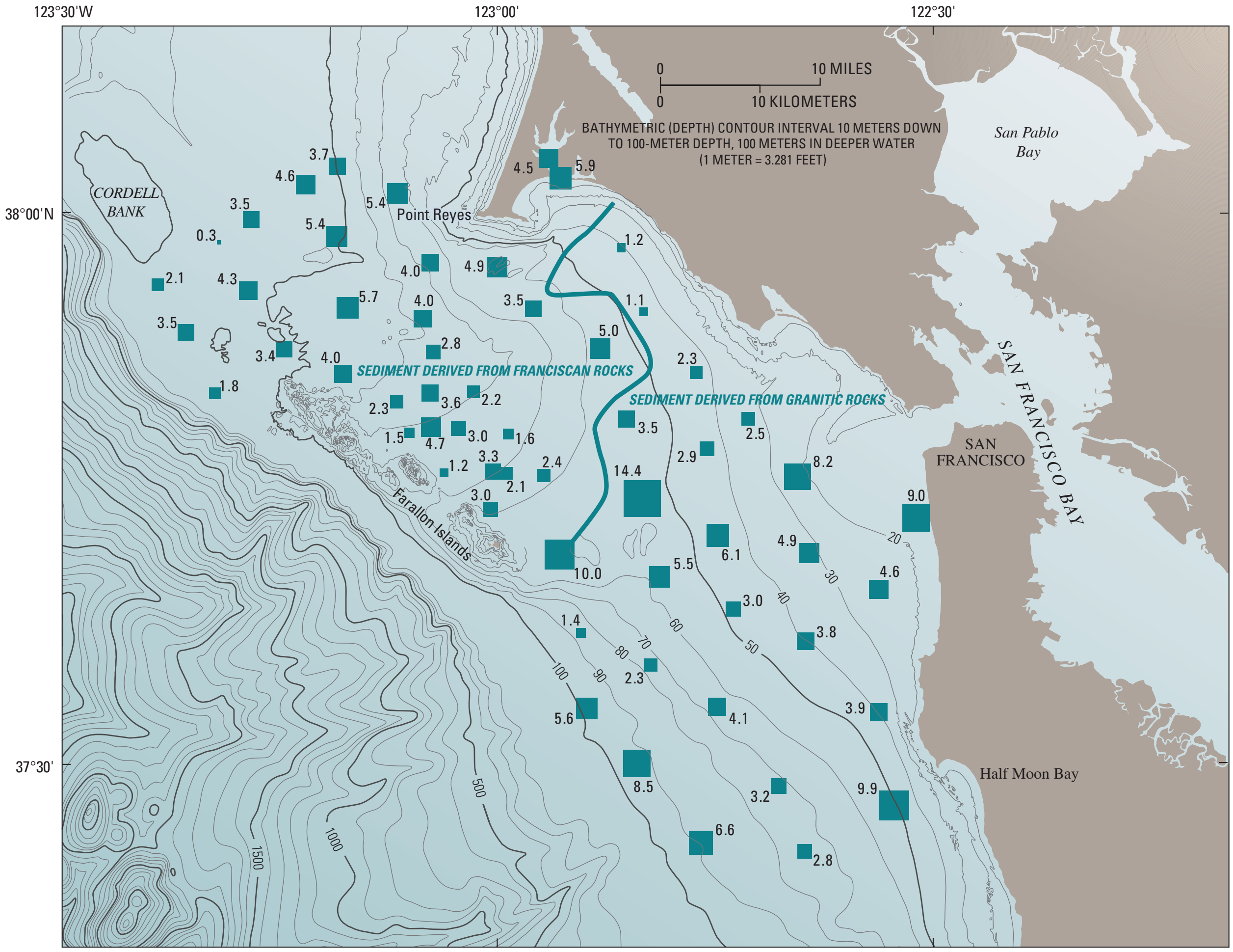

Figure 2. Gulf of the Farallones study area, showing abundance of heavy minerals (in weight percent) in sand-size fraction of surficial-sediment samples. Heavy line, approximate boundary between areas covered by different heavy-mineral assemblages. Size of shaded boxes is proportional to mineral abundance.

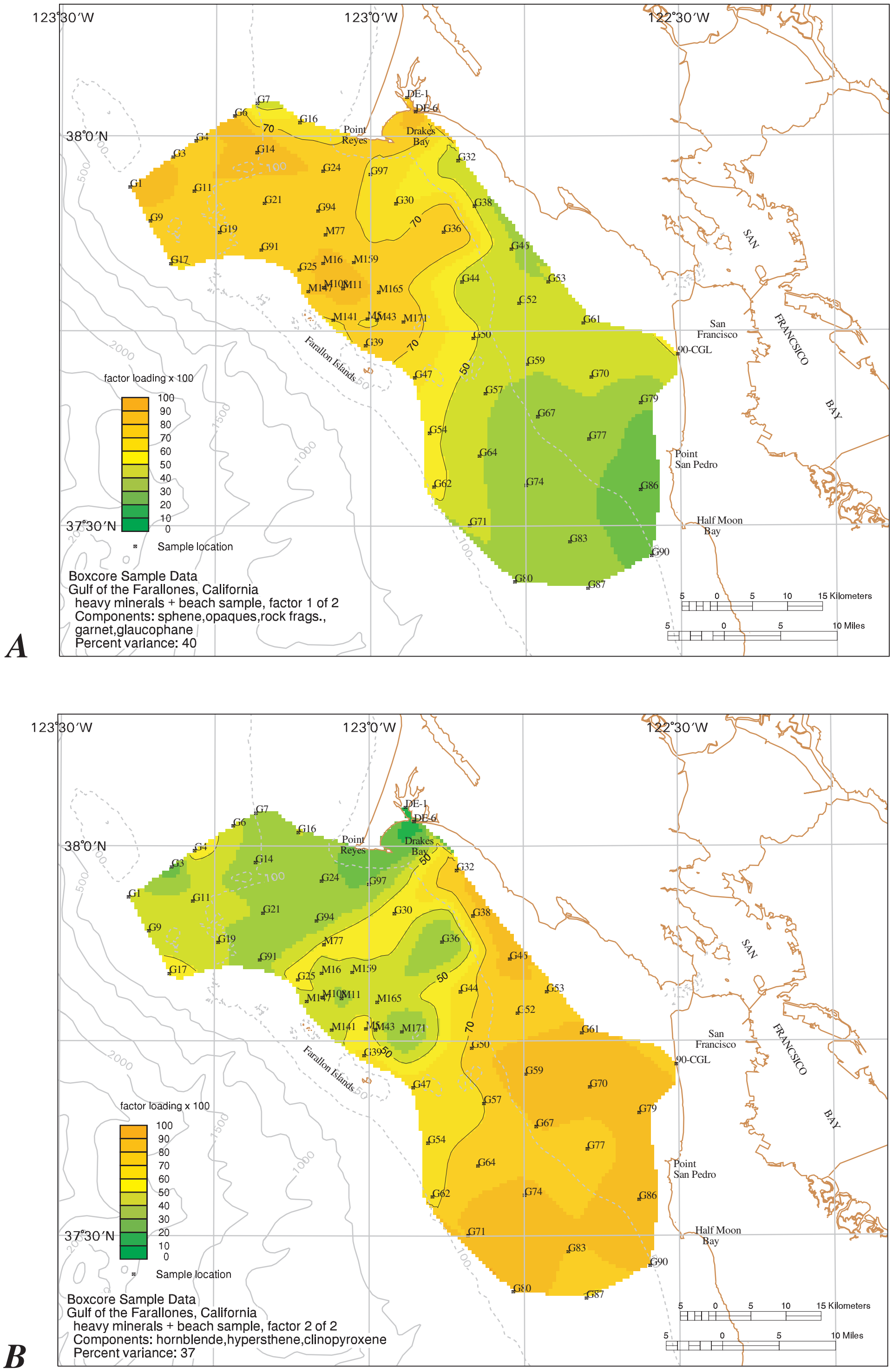

Figure 3. Gulf of the Farallones study area, showing two major groups (called factors) of heavy minerals identified by factor analysis in surficial sediment. One group (*A*) consists of heavy minerals in sediment eroded from Franciscan rocks throughout the California Coast Ranges; these minerals are more typical of the northwestern part of the study area. The other group (*B*) consists of heavy minerals more typical of sediment eroded from the Sierra Nevada and other similar granitic terranes; these minerals are concentrated in the southeastern part of the study area. Some overlap in the distribution of the two groups is apparent.