

# Regional Setting of the Gulf of the Farallones

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## Summary and Introduction

The Gulf of the Farallones lies in the offshore part of the San Francisco Bay region just beyond the Golden Gate (fig. 1). The bay region is home to more than 6 million people and has long been regarded as one of the most beautiful regions in the United States. It annually draws hundreds of thousands of tourists from all over the world to enjoy its hilly, often fog-shrouded terrain and its mild, Mediterranean climate, as well as to experience its cultural richness and diversity. The historical settlement of the bay region is intimately related to its geography, natural harbors, and mild climate.

The San Francisco Bay region (fig. 2) extends from the Point Reyes Peninsula southward to Monterey Bay and from the coast eastward to the Sacramento-San Joaquin Delta and also includes the offshore area out to a water depth of about 3,500 m (11,500 ft), which is the outer edge of the Continental Slope. This offshore area, where many residents of the region and tourists go to watch the annual migration of whales, as well as to boat and fish, includes the Gulf of the Farallones and the Farallon Islands. Although the sea floor in this area cannot be visually observed, scientists have learned much about it by using acoustic instruments (instruments that utilize sound sources and listening devices) and underwater cameras and video equipment.

The landscape features of the San Francisco Bay region are the cumulative result of millions of years of Earth history, involving the building and subsequent wearing down of mountains, volcanic eruptions and resulting outpourings of lava, large and small earthquakes, and the never-ending processes of wind and water erosion and deposition. Many of these processes are occurring today, although some of them occur at rates so slow that little change may be perceived over the course of a human lifetime. The sedimentary deposits and rocks of the region range in age from hundreds of millions of years to those still forming today. The entire spectrum of rocks present in the region records only a fraction of the Earth's history. The rock types range from the salt-and-pepper granitic rocks at Point Reyes and on the Farallon Islands, through various types of volcanic rocks (such as the pillow basalts in the Marin Headlands), to sedimentary rocks, such as the red to brown bricklike chert that forms the cliffs of the Marin Headlands and many of the hills of San Francisco, and the young sand-dune deposits that occur along the Pacific Coast.

The San Francisco Bay region straddles the boundary zone between two of the Earth's major tectonic plates. The Pacific Plate is slowly moving northward relative to the North American Plate, and this motion takes place along the San Andreas Fault and a network of associated subparallel faults, collectively called the San Andreas Fault Zone (see chapter on Earthquakes, Faults, and Tectonics). Rocks east of the San Andreas Fault Zone were mainly formed in approximately their present positions. However, many of the rocks found within the zone, like the Franciscan chert at the Marin Headlands, are ocean-floor rocks that have been scraped off onto the edge of North America over the past 150 million years.

The oldest of the rocks found west of the San Andreas Fault were formed hundreds of miles to the south, some near the present site of Los Angeles, and subsequently transported northward by movement along the San Andreas and its associated faults (fig. 3). Rocks west of the fault are, in fact, still being transported northward at about 5 cm (2 in) per year and after millions of years may reach the area where Alaska is today.

Mountain ranges in the San Francisco Bay region trend mostly northwest and are separated by broad basins and narrow valleys. Many of the ridgecrests in the Coast Range, the major mountain range in the region, rise above 300 m (1,000 ft), and a few above 1,200 m (4,000 ft). The highest peaks include Mount Hamilton at 1,333 m (4,373 ft), Mount Diablo at 1,174 m (3,849 ft), and Mount Tamalpais at 795 m (2,606 ft).

As recently as about 10,000 years ago, at the end of the last ice age, great sheets of ice (glaciers) covered much of Earth's northern hemisphere. Because so much water was stored in these glaciers, sea level was about 100 m (300 ft) lower than at present, and the coastline of the San Francisco Bay region was situated as much as 56 km (35 mi) seaward of its present position, near coastal hills whose tops are now the Farallon Islands. The melting of the ice sheets caused worldwide sea level to rise, forming the Gulf of the Farallones and San Francisco Bay.

If the vast volume of ocean water that now covers the floor of the gulf could be removed, people would see a varied landscape. That landscape is as rich in diversity and rugged splendor as that on the nearby shore (see chapter on Landscape of the Sea Floor).

## **San Francisco Bay**

San Francisco Bay is a system of interconnected water bodies that extend from the Sacramento-San Joaquin Delta in the east to the Pacific Ocean in the west (fig. 2).

The bay is the largest estuary on the west coast of the United States; from east to west, it spans a distance of about 68 km (42 mi), and from north to south about 82 km (51 mi). The adjacent drainage basins of the Sacramento and San Joaquin Rivers, the main sources of freshwater for the bay, encompass approximately 40 percent of the land area of California and are the largest riverine systems in the State. The Sacramento-San Joaquin Delta is a system of interconnected sloughs and islands, many of which are at or below sea level. As much as 30 percent of the freshwater that normally would flow into San Francisco Bay is diverted southward for agricultural usage. The bay has an average water depth of only 6 m (20 ft) and is dissected by tidal channels that are 10 to 20 m (33–66 ft) deep. Depths range from 110 m (360 ft) at the Golden Gate to near sea level for many of the wetlands that surround the bay. The tidal prism, which is the mass of water that enters and exits the bay through the Golden Gate four times daily, is about 1.54 km<sup>3</sup>, or 1,250,000 acre-feet (an acre-foot is the amount of water necessary to fill an area the size of an acre to a depth of 1 ft, approximately 43,560 ft<sup>3</sup>).

San Francisco Bay has changed significantly since the late 1800's, a period that coincides with a rapid increase in population in the region and central California. In the 1880's, the bay had a surface area (covered by water) of about 1,970 km<sup>2</sup> (760 mi<sup>2</sup>). This period, however, also coincides with the advent of gold mining in the Sierra Nevada. Gold mining at that time was chiefly conducted by removing huge amounts of soil by injecting water under pressure, a process known as "hydraulic mining." Both the soil removed and the soil that remained were much more susceptible to erosion by water each winter and spring, forcing vast amounts of sediment into streams and then the rivers that drain the Sierra Nevada. A large volume of this debris and sediment ultimately was transported to San Francisco Bay. The added sediment greatly accelerated the natural rate of sedimentation and caused a reduction in the bay's surface area by at least 40 percent by adding sediment to the bay's margins and flats. This infilling has seriously altered the bay by reducing its total water volume and greatly altering the tidal circulation.

Since the era of hydraulic mining, human activity has continued to alter San Francisco Bay, both intentionally and unintentionally. As many as 100 species of invertebrates, including mus-

sels, clams, and crabs, have been introduced into the bay since about the 1850's, mostly by the release of ships' ballast water. Practically all common large invertebrates present in the tidal flats of the bay, and some of the planktonic (swimming or floating) invertebrates and algae found in the bay's waters, are introduced species. In 1850, the bay had about 2,200 km<sup>2</sup> (545,000 acres) of tidal wetlands. By 1987, this area had been reduced to 180 km<sup>2</sup> (44,400 acres), as a result of diking, filling, and reclamation activities. The cumulative effect of more than 100 years of change is that San Francisco Bay is now considered to be the major estuary in the United States most modified by human activity.

San Francisco Bay has been in its present configuration for only about the past 7,000 to 5,000 years. Scientific examination (laboratory analyses of sediments, mineralogy, microfossils, plant and organic remains) of core material derived from boreholes drilled into the bay (for the purpose of siting bridge foundations) reveals that on the present site of the bay there have been at least four estuaries and four stream valleys during the past 1 million years. This period coincides with the occurrence of the great ice ages, when large continental glaciers thousands of meters thick covered the northern parts of North America and Europe. These continental glaciers were comparable to the ice sheet, at least 3 km (2 mi) thick, that presently covers Antarctica. Much of the bay formed about 10,000 to 5,000 years ago, a period when most of the great glaciers melted, causing worldwide sea level to rise. Before this rise in sea level, when sea level was about 100 m (330 ft) lower than at present, the coastline of the San Francisco Bay region was situated somewhere near the Farallon Islands, about 56 km (35 mi) seaward of its present position. The site of San Francisco Bay, before the rise in sea level, was mostly a broad stream valley and terrestrial lowland, somewhat similar to parts of the present Great Valley of California. Many of the hills we know today probably existed, and many of the lowland areas not occupied by the stream valley were covered by the sand dunes that still can be seen today covering parts of the San Francisco peninsula. When the great continental glaciers melted, a huge volume of water was added to the world's oceans, and from about 10,000 to 5,000 years ago, sea level rose rapidly. The rapid rise in sea level caused the coastline to retreat across the area now known as the Gulf of the Farallones, until it reached its present position about 5,000 years ago. At about the same time that the coastline was rapidly retreating, the stream valley that crossed the present site of San Francisco Bay and continued through the Golden Gate across ancient lowlands to what are now the Farallon Islands was being flooded by the rising sea. West of the Golden Gate, the entrenched stream valley was flooded until the water overtopped its banks and began flooding the surrounding lowlands. The rapid rate in sea-level rise slowed about 5,000 years ago, by which time much of the bay as it is recognized today was in existence. Topographic features that remained above water included the Marin Headlands, Alcatraz Island, Angel Island, Yerba Buena Island, the Tiburon Peninsula, and the hills of San Francisco. Other geomorphic features in the region that owe their existence the latest great rise in sea level include Lake Merced, Richardson Bay, Bolinas Lagoon, Tomales Bay, and Drakes Bay and Drakes Estero (named after Sir Francis Drake, the English explorer who supposedly landed there to repair his ship in the 1500's).

## **Regional Geology**

The oldest rocks known in the San Francisco Bay region are about 100 to 150 million years old (Late Jurassic to Cretaceous). The geologic time represented by all of the rocks in the region is only about 3 percent of Earth's 4.5-billion-year history. Some of the most widespread rocks in the region belong to an assemblage called the Franciscan Complex, a name attributable to the

excellent exposures of these rocks on the San Francisco peninsula. These rocks also occur on the Marin Headlands, Angel Island, Alcatraz Island, Yerba Buena Island, the Brothers Islands, and elsewhere. The oldest rocks of the Franciscan Complex were deposited in an ancient proto-Pacific Ocean basin. This ancient ocean basin probably stretched from about Santa Barbara to the State of Oregon. As much as 6,100 m (20,000 ft) of this assemblage accumulated during the existence of the ocean basin. Although Franciscan rocks are known to underlie as much as 20 percent of California, a large volume of this assemblage was probably removed from the “rock record” by erosion and other processes and lost forever.

Some of the more common rocks in the Franciscan complex originated as sea-floor sediment (sand and mud), others from the settling out of microscopic animals known as radiolarians (to form the red to brown brick-like chert seen all around the San Francisco Peninsula and in the Marin Headlands), and still others from the outpouring of lava forming volcanic rocks, such as pillow basalt (fig. 4). The radiolarian chert is commonly associated with volcanic pillow basalt, and some of the red color in the chert may come from iron in the volcanic rocks. Almost everywhere these rocks are found, they are deformed and commonly broken, both in outcrop (within a cliff face) and as individual pieces or “knockers,” some larger than houses.

Detailed studies of the rocks of the Franciscan Complex show that after they were deposited on the ancient ocean floor, they were pushed underneath the continental plate of North America by sea-floor spreading. During this process, sections and pieces of the sea floor were scraped off the oceanic plate that was being subducted beneath the North American Plate and became attached to the continent. The rocks that were attached to the continent are the Franciscan rocks that we see today in the San Francisco Bay region. The San Francisco Peninsula itself is composed of four or more different terranes of Franciscan rocks. In fact, there is ample evidence that much of what is now the State of California was added onto the North American Continent by sea-floor-spreading processes during the past several hundred million years. As pieces were added to the continental edge, California grew westward. The radiolarian chert is probably the most distinctive of the Franciscan rocks, owing to its red color and brick-like appearance. The cherts commonly are highly contorted, much like toothpaste that has been squeezed out of a tube and then compressed. Their brick-like appearance results from closely fractured individual layers that are stacked on top of one another to form beds that vary in thickness.

Many of the salt-and-pepper or pink granitic rocks in the San Francisco Bay region, such as those on the Farallon Islands, Point Reyes Peninsula, and Montara Mountain, are part of the huge rock slab known as the Salinian terranes that occur exclusively to the west of the San Andreas Fault (fig. 3). These terranes are thought to have been transported along the San Andreas Fault from far to the south, possibly from the present area of Los Angeles. Transport occurred extremely slowly over tens of millions of years. This movement is still occurring, but the rate of transport is so slow that , the amount of change (lateral or horizontal transport) is nearly imperceptible in a human lifetime. At some time in the future, the rocks adjacent to San Francisco on the west side of the San Andreas Fault may end up near the State of Alaska.

The granitic rocks in the San Francisco Bay region, which are about 100 million years old, represent once-molten magma that rose slowly from deep below the Earth’s surface and intruded overlying rocks. Some of these overlying rocks, including parts of the Franciscan Complex were “baked” by the magma. Similar granitic rocks can be found elsewhere in California on the Monterey Peninsula, at Point Lobos near Carmel, at Ben Lomond Mountain, and at Bodega Head. These granitic rocks are also considered to be similar to those in many parts of the Sierra Nevada.

Overlying the basement rocks on both sides of the San Andreas Fault are younger sedimentary formations. These rocks include deep-sea deposits (fig. 5A), shallow marine fossiliferous sands (fig. 5B), and volcanic ash layers (fig. 6).

## **Offshore Area**

The Gulf of the Farallones lies west of the Golden Gate and is part of the eastern Pacific Ocean. The sea floor below the waters of the gulf is subdivided into distinct zones on the basis of topography. The innermost zone is known as the Continental Shelf; it extends from the shoreline west to the shelf break. The shelf break is a natural feature that marks where the relatively flat Continental Shelf ends and the relatively steep Continental Slope begins. In the Gulf of the Farallones, the shelf break occurs at about 100 to 150 m (330–490 ft) water depth. The Continental Slope continues to a water depth of 3,500 to 4,000 m (11,500–13,100 ft), where the deep ocean basin begins. Together, the Continental Shelf, shelf break, and Continental Slope constitute the continental margin of North America in this area of California.

## **Continental Shelf**

Just off the Golden Gate, on the innermost part of the Continental Shelf in the Gulf of the Farallones, is a submerged feature, called the Golden Gate Bar, that few people except mariners and fisherman know about. This feature is a large crescentic mound of sand that extends seaward from the Golden Gate across the inner part of the Gulf of the Farallones (fig. 7). Golden Gate Bar extends about 10 km (6 mi) from east to west and 14 km (9 mi) from north to south. At its shallowest point, the surface of the bar is only 7 m (23 ft) below the ocean's surface, whereas the sea floor immediately adjacent to the bar is 12 to 18 m (40–60 ft) deep. Deeper draft vessels that use San Francisco Bay, such as oil tankers, easily draw 15 m (50 ft) when fully loaded. If such a fully loaded vessel were to wander outside of the navigation lane that transects the bar, it could easily run aground on this shallow part of the bar, known as Potatopatch Shoal. This shoal presumably owes its name to historical events. In the 1800's, schooners sailing from Bodega Bay with deckloads of potatoes often lost their loads in the rough-waters that commonly prevail over this part of the bar. During such conditions, mariners have reported steep waves of 6 to 8 m (20–26 ft) over the bar.

The existence of the Golden Gate Bar is mainly known from the immense number of soundings that have been taken off the Golden Gate as a means of ensuring safe passage for the many vessels that enter and exit San Francisco Bay. The Golden Gate effectively serves as the "harbor mouth" for the entire bay and the ports that line its interior. The origin of Golden Gate Bar is still unclear, but it appears to be formed of sand transported by currents along the California coast that has piled up off the Golden Gate, owing to the swift ebb-tidal current that exits the bay. The sand is presumably kept offshore (rather than being transported into the bay) by the speed and strength of the ebb-tidal currents. At least some of the sand that composes the bar may have been derived from hydraulic mining for gold deposits in the Sierra Nevada during the 1800's. Recent evidence suggests that the Golden Gate Bar may be retreating shoreward.

The Continental Shelf stretches another 20 to 30 km (12–19 mi) beyond Golden Gate Bar, terminating at the shelf break. The morphology and general nature of the Continental Shelf in the Gulf of the Farallones are known from past geologic work, as well as from the studies described in this report. Remote means had to be used from aboard ship to study the sea floor in this area. None of the remote methods used provided complete, 100-percent coverage of the area studied in

the Gulf of the Farallones. Therefore, observations on remotely acquired data are considered to be “representative” of what is happening in nature.

The Point Reyes Peninsula to the north and the granitic Farallon Island chain to the west form the topographic elements that partly enclose an area of the eastern Pacific Ocean to form the Gulf of the Farallones. The gulf extends about 90 km (56 mi) from northwest to southeast and 45 km (28 mi) from east to west. From the cliffs adjacent to the Golden Gate on a clear day, almost the entire breadth of the gulf is visible. Also, the location of the Potatopatch Shoal on Golden Gate Bar is revealed when heavy winds are blowing and a good ocean swell is running by the waves that break over the shoal. The Point Reyes headlands are visible to the northwest, and the small islands and pinnacles of the Farallon Islands can be seen to the west. Much of the gulf’s western boundary is characterized by discontinuous pinnacles and islands of granitic rock belonging to the Farallon Island chain and Cordell Bank. Only a few of the rocks in the Farallon Island chain, such as Southeast Farallon, Middle Farallon, and Noonday Rock, actually rise above the ocean’s surface, whereas all of Cordell Bank is submerged. The entire gulf, the Point Reyes Peninsula, the Farallon Islands, and Cordell Bank are part of the Salinian terranes.

The Gulf of the Farallones and some nearby shoreline areas are part of Gulf of the Farallones National Marine Sanctuary (fig. 2), a prime area for both recreational and commercial fishing. Recent statistics show that it may be the largest charterboat salmon-fishing area in California. Fishing grounds and marine habitats are at least partly related to the physical setting and geology of the area. The gulf is situated along the annual migration path of the gray whale, and thousands of people yearly take charterboats to the gulf to watch these majestic mammals as they migrate through the area. The gulf is also a heavily trafficked area, with about 3,000 to 4,000 large vessels transiting it annually, using three separate navigation/traffic lanes maintained by the U.S. Coast Guard.

A typical profile of the floor of the Continental Shelf off California would show a gentle slope seaward, with little topographic relief from the shoreline to the shelf break. On a two-dimensional map, this topography would be represented by fairly regularly spaced bathymetric contour lines (lines that connect points of equal water depth) that more or less parallel the California coastline. At the shelf break, the two-dimensional map would show the contours becoming closely spaced and typically more crenulated or sawtoothed in pattern. This pattern at the shelf break indicates that sea floor steepens considerably and is commonly cut by gullies running down the Continental Slope.

This general pattern is consistent for Continental Shelf areas from Monterey Bay to the Half Moon Bay and for the shelf along the coast north of Point Reyes. South of Southeast Farallon Island, the southernmost of the island chain, the sea floor slopes continuously seaward from the mainland to the shelf break. Similarly, the sea floor off the north coastline of the Point Reyes Peninsula north to at least Point Arena, a distance of 120 km (75 mi), and from Half Moon Bay to Santa Cruz, a distance of 80 km (50 mi) is characterized by bathymetric contours that parallel the mainland shoreline and slope continuously seaward from the coast to the shelf break. However, the shelf in the Gulf of the Farallones shows a contrasting pattern of sea-floor topography. Bathymetric contours in the gulf more or less parallel the mainland coastline from the shoreline out to a water depth of about 50 m (160 ft). Beyond this depth, over much of the gulf, bathymetric contours change their trend and no longer parallel the mainland shore.

East of the Farallon Islands and for most of the floor of the gulf, bathymetric contours take the shape of a “horseshoe” that opens to the northwest (fig. 7). Furthermore, the spacing of the

contours widens out in a northwestward direction. This horseshoe pattern in bathymetry characterizes the gulf from a line south and east of the Farallon Islands northwest to the unnamed submarine canyon east of Cordell Bank. The sea floor over this part of the gulf slopes northwestward, rather than westward or southwestward, as is typical for Continental Shelf areas off central California. The wide spacing of contours indicates that the slope of the sea floor over this area of the gulf is gentle and relatively flat, more so than in the shelf areas just to the north and south.

Investigations conducted by U.S. Geological Survey (USGS) scientists on the uppermost 25 to 50 m (80–160 ft) of sediments and rocks beneath the sea floor in the Gulf of the Farallones reveal the reason for the contrasting pattern in bathymetry and the northwestward slope of the sea floor. Much of the gulf is underlain by a bedrock trough that consists of a varying thickness of rocks thousands to tens of millions of years old that, in turn, appear to overlie crystalline bedrock which is about 100 million years old. Other studies have shown that on the west flank of this trough the bedrock rises to the sea floor and is similar to the granitic rock that form the Farallon Islands. The sea floor in much of the Gulf of the Farallones slopes to the northwest, following the surface of the older rocks that compose the bedrock trough under the gulf. The east boundary of the trough coincides with the San Andreas Fault. Most of the older, harder rocks that compose this trough under the gulf are covered by only a thin veneer of young soft sediment. However, two areas, one south of Point Reyes and the other southeast of the Farallon Islands, are depositional areas where as much as 15 to 20 m (49–66 ft) of soft sediment has accumulated.

A sonar image of the sea floor (see chapter on Sediment of the Sea Floor) just northeast of the northern part of the Farallon Islands chain reveals an area of bedrock that is exposed on the sea-floor. Sometime after its formation, the bedrock was compressed and folded to form a structure known as a structural fold. This fold can be seen on the sonar image because little to no soft sediment covers it. Similar structural features can be seen in roadcuts along highways and at Fitzgerald Marine Reserve near Half Moon Bay (fig. 2), where a bedrock fold forms tide pools adjacent to the beach.

The physiographic feature that separates the relatively flat Continental Shelf from the steeper Continental Slope is the shelf break. This feature, also referred to as the shelf edge or shelf-slope break, is the point at which the first major change in gradient occurs at the outer edge of the Continental Shelf. In the San Francisco Bay region, the shelf break has been designated the “Farallon Escarpment”; it occurs at a water depth of about 100 to 150 m (330–490 ft).

## **Continental Slope**

The Continental Slope is the relatively steep part of the continental margin that runs from the shelf break to the deep ocean basin. The Continental Slope in the Gulf of the Farallones, as studied by the USGS using side-scan sonar, was divided into two provinces. The slope in the northern province differs markedly from that in the southern province in several aspects. In the northern province, west of Cordell Bank and the Farallon Islands, the slope is about 35 km (22 mi) wide. In contrast, the slope in the southern province, adjacent to Pioneer Canyon, is 75 km (47 mi) wide. The regional slope from the shelf break to the basin floor has a gradient of about 5° in the northern province and 2.5° in the southern province. Locally, gradients are as steep as 33°. The northern province is narrower, steeper, and extensively dissected by submarine canyons and gullies that appear to stretch from the shelf break down to the deep basin (fig. 7). The sawtooth or crenulated appearance of the bathymetric contours over the northern province suggests that the Continental Slope here is highly irregular. The southern province has several small submarine

canyons/gullies on the outer part of its margin; however, only Pioneer Canyon appears to cross the entire width of the slope in this area. At the base of the Continental Slope in this area are Pioneer and Gumdrop Seamounts (fig. 7), a pair of undersea volcanoes that are tens of millions of years old.

Onshore, the topography in the San Francisco Bay region trends northwest-southeast (fig. 7), the result of millions of years of movement along the San Andreas Fault and its associated faults. Offshore, however, no such trend is apparent, and the topography of the Continental Slope appears to be dominated by the submarine canyons, gullies, and their intervening ridges that run across the slope from the shelf break to deep water. Onshore, Mount Diablo at 1,174 m (3,849 ft) and Mount Hamilton at 1,333 m (4,373 ft), both in the east bay, are the features with the most relief in the San Francisco Bay area. In contrast, the summit of Pioneer Seamount is about 1,950 m (6,400 ft) above the adjacent sea floor, and the Continental Slope has a topographic relief of about 2,000 m (6,560 ft), greater than onshore in this area of central California. Relief within Pioneer Canyon itself varies by at least 400 m (1,300 ft). As a matter of interest, Monterey Canyon, a submarine canyon at the south of the San Francisco Bay region, exhibits a relief comparable to that of the majestic Grand Canyon of Colorado.

Adjacent to Pioneer Canyon, at the base of the Continental Slope, are three undersea mountains, which from south to north are Guide, Pioneer, and Gumdrop Seamounts. The summits of these seamounts are, respectively, at the depths of 1,750 m (5,740 ft), 850 m (2,790 ft), and 1,350 m (4,430 ft). Guide Seamount rises about 1,000 m (3,300 ft) above the adjacent sea floor, Pioneer Seamount rises about 1,950 m (6,400 ft) above the adjacent sea floor, and Gumdrop Seamount rises 800 m (2,600 ft) above the adjacent sea floor.

The Continental Slope south of the Farallones is relatively wide and is a broad plain running from the shelf break to the base of the slope adjacent to Pioneer Canyon, a major feature that interrupts this broad plain and cuts the plain from the shelf break to the base of slope. In its headward area, at the shelf break, Pioneer Canyon consists of two smaller canyons that merge downslope to form the main valley of the canyon, which then meanders in a sinuous pattern down the slope. The shallow troughs immediately adjacent to the main submarine valley are abandoned valleys (former courses of the main valley). Identical features are associated with stream valleys on land. Pioneer Canyon is the largest submarine canyon on this part of the continental margin. It does not appear to link up with any present river system on land, and so its origin is unclear. Several smaller submarine canyons cut the middle to lower Continental Slope north of Pioneer Canyon but do not extend upslope to the shelf break. South of Pioneer Canyon, the Continental Slope is relatively broad and undissected for at least 25 km (15 mi).

## **Conclusion**

Few residents and visitors know that beneath the waters of the Gulf of the Farallones is a complex topography that is comparable to that of nearby onshore areas of the San Francisco Bay region. If the vast volume of ocean water covering the floor of the gulf could be removed, people would see a landscape that is rich in diversity and rugged splendor.

## Further Reading

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*A*



*B*

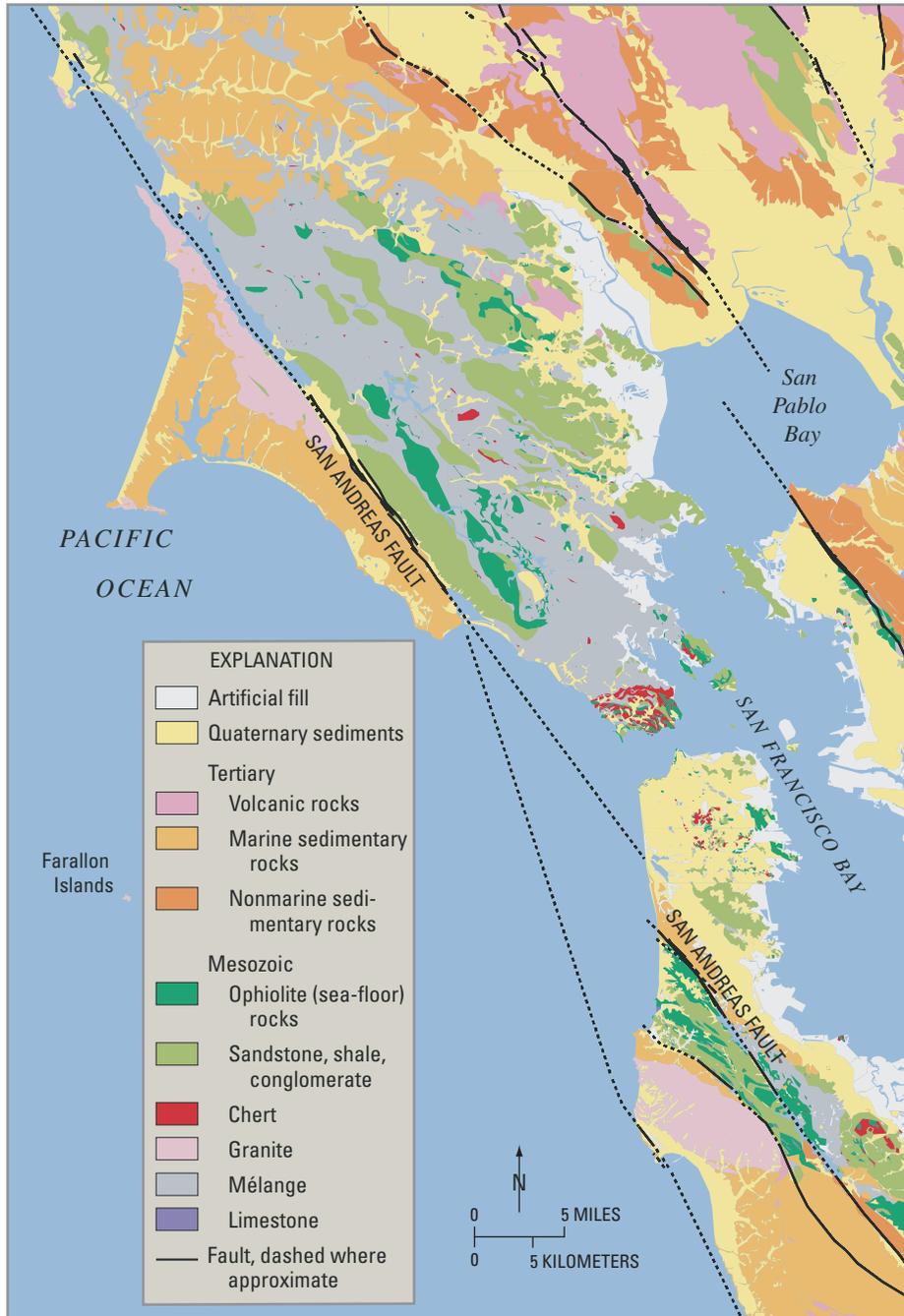


*C*

**Figure 1.** Views of the Golden Gate, the entrance to San Francisco Bay. *A*, View eastward from the Marin Headlands toward the Golden Gate Bridge and downtown San Francisco; Alcatraz Island can be seen at the upper left, Treasure and Yerba Buena Islands and the San Francisco Bay Bridge are seen in the middle distance, and the hills of the heavily populated east bay, which includes the city of Oakland, can be seen beyond the Bay Bridge. *B*, View westward through the Golden Gate looking out into the Gulf of the Farallones. *C*, Closeup westward view of the Marin Headlands taken from a similar vantage point as photograph *A*; the headlands are mostly composed of Franciscan chert and pillow basalts (see fig. 4). (U.S. Geological Survey photographs by Phil Stoffer.)



Figure 2. Map of the San Francisco Bay region.



**Figure 3.** Geologic map of San Francisco Bay region, showing the San Andreas Fault, related faults, and regional rock types.



*A*



*B*

**Figure 4.** Some rocks of the San Francisco Bay region dating from the Mesozoic Era (250 to 65 million years ago): Franciscan cherts (*A*) and pillow basalts (*B*) of the Marin Headlands, which were originally formed on the ocean floor 150 to 100 million years ago. (U.S. Geological Survey photographs by Bruce Rogers.)



*A*



*B*

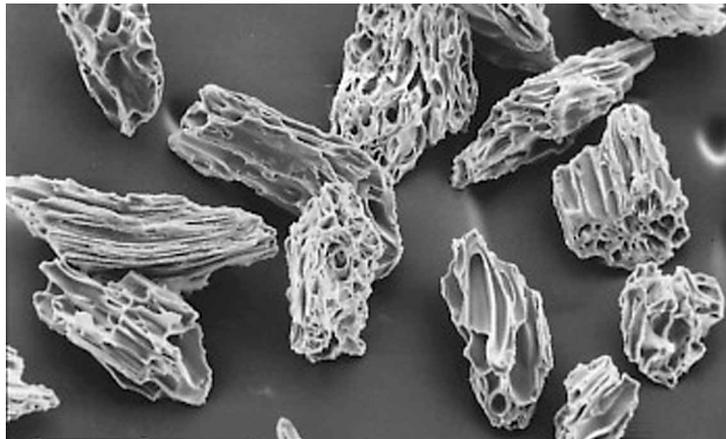
**Figure 5.** Some sedimentary rocks of the San Francisco Bay region dating from the Tertiary Period (65 to 1.6 million years ago): *A*, deposits of an approximately 50-million-year-old submarine landslide exposed near Año Nuevo on the coast south of San Francisco; *B*, a beach cobble of the Purisima Formation on the coast south of San Francisco containing abundant fossils, mostly clams, that lived in shallow marine waters a few million years ago and are similar to those living in the region's coastal waters today. (U.S. Geological Survey photographs by Phil Stoffer.)



**A**

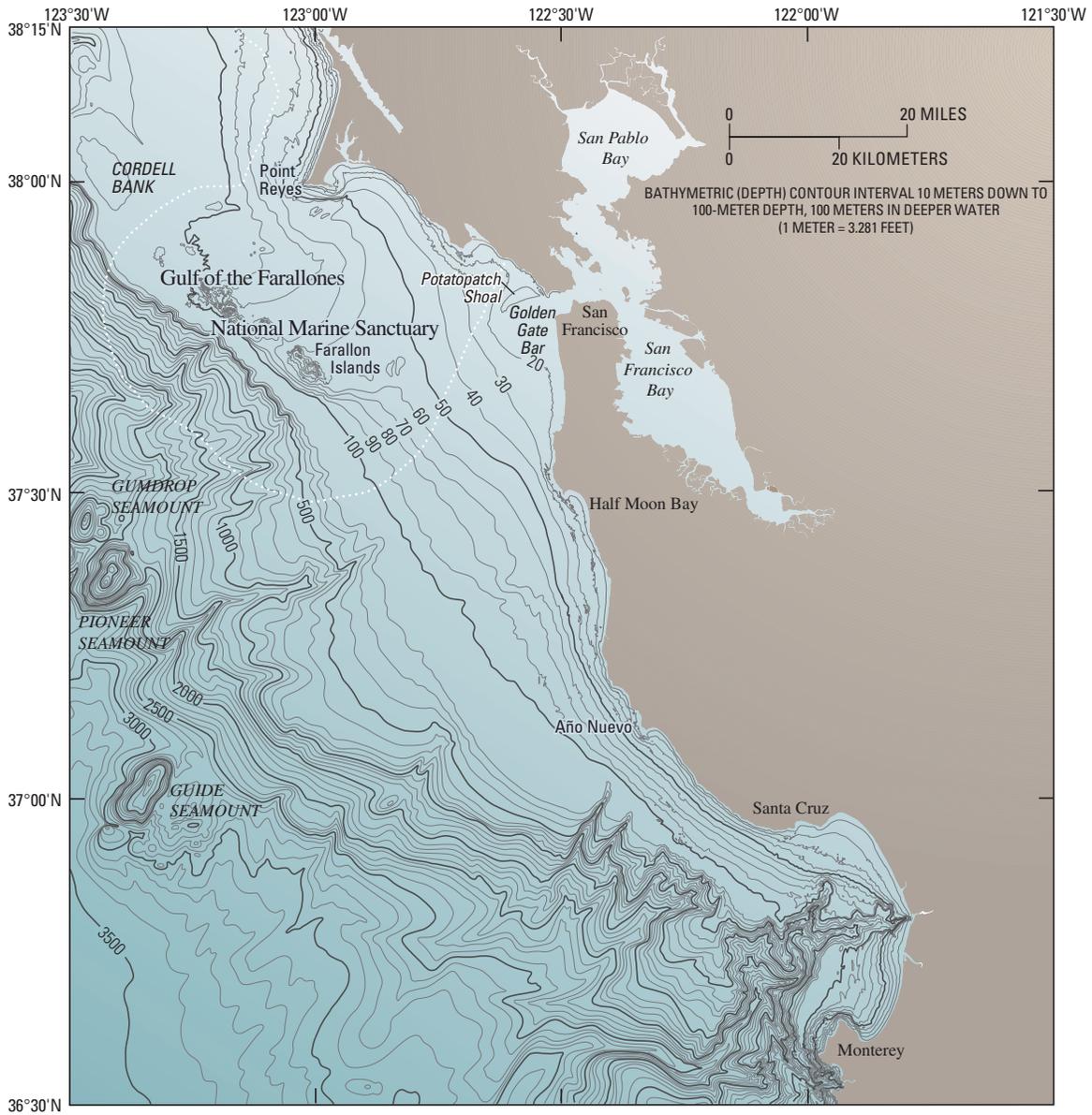


**B**



**C**

**Figure 6.** *A*, Quaternary (less than 1.6 million years old) deposits of the marine and coastal Merced Formation in an eroded seacliff at Fort Funston Beach in San Francisco (U.S. Geological Survey photograph by Phil Stoffer). The white band in the middle of this approximately 50-m (150-ft) cliff is the Rockland Ash, a layer of volcanic ash from a powerful eruption that occurred in the Lassen area of northern California about 600,000 years ago. That eruption was 50 times larger than the 1980 eruption of Mount St. Helens, Washington, and because the winds at the time of the eruption were blowing southward, ash several inches thick was deposited as far south as the San Francisco Bay area. *B*, Map shows known distribution of the Rockland Ash. *C*, Particles from Rockland Ash magnified about 70 times.



**Figure 7.** Bathymetry offshore of the San Francisco Bay region, depicted in a traditional two-dimensional map, using contours to represent lines of equal elevation below sea level. From the shoreline to 150-m water depth (490 ft) the contour interval is 10 m (33 ft); beyond 150-m water depth the contour interval is 50 m (165 ft). Bathymetric data from U.S. National Ocean Survey. The shelf break occurs at 100- to 150-m water depth (330–490 ft) and the deep ocean basin is water deeper than 3,500 to 4,000 m (11,500–13,200 ft).