San Francisco Coastal Geology Field Class
BACKGROUND/REVIEW

Produced by Katryn Wiese
(send edits/comments to katryn.wiese@mail.ccsf.edu)

This class is about

- MAKING OBSERVATIONS in the field – really seeing – textures, shapes, relationships, etc.
- RECORDING OBSERVATIONS in the field – including keeping field notes and noting weather and location details
- EVALUATING YOUR OBSERVATIONS – thinking about the processes going on in the area and the science behind the features you're seeing (formations, evolution, connections, etc.)
- MAKING HYPOTHESES, based on your observations and evaluations.
- EVALUATING YOUR HYPOTHESES AND MODIFYING THEM – based on new data picked up as more data collected and observations made

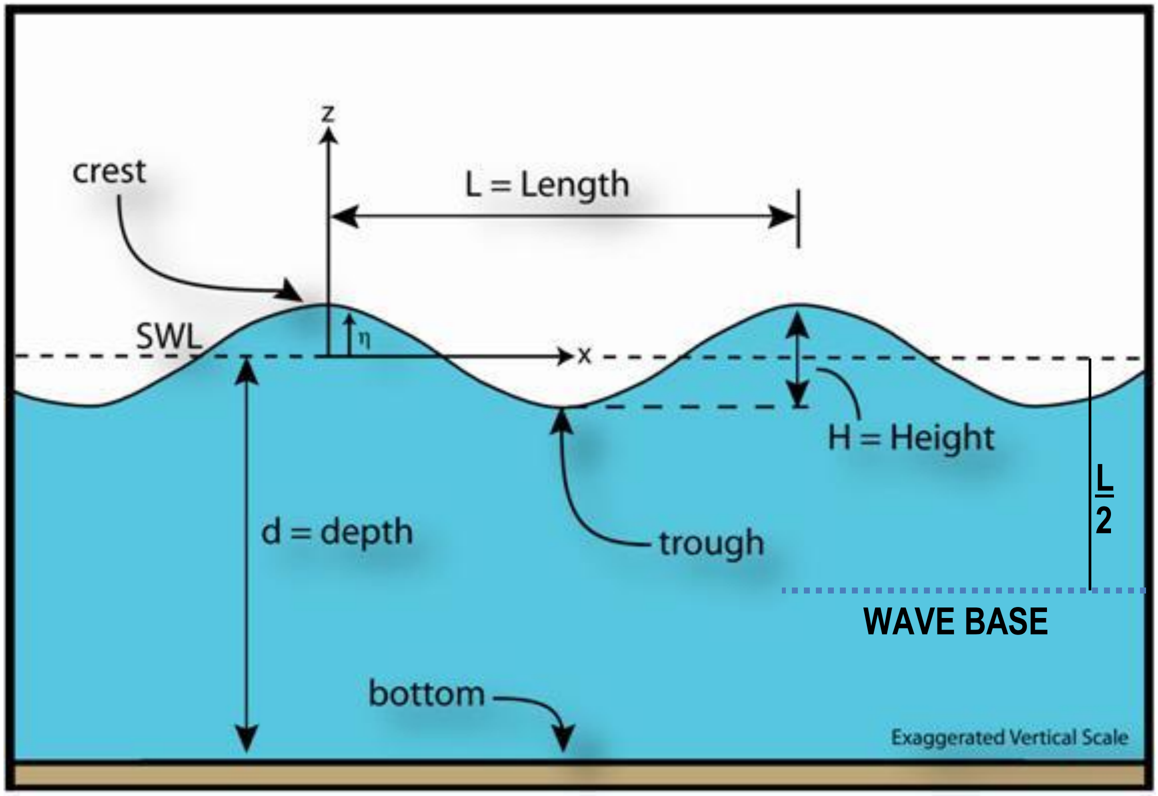
Waves and Tidal Processes

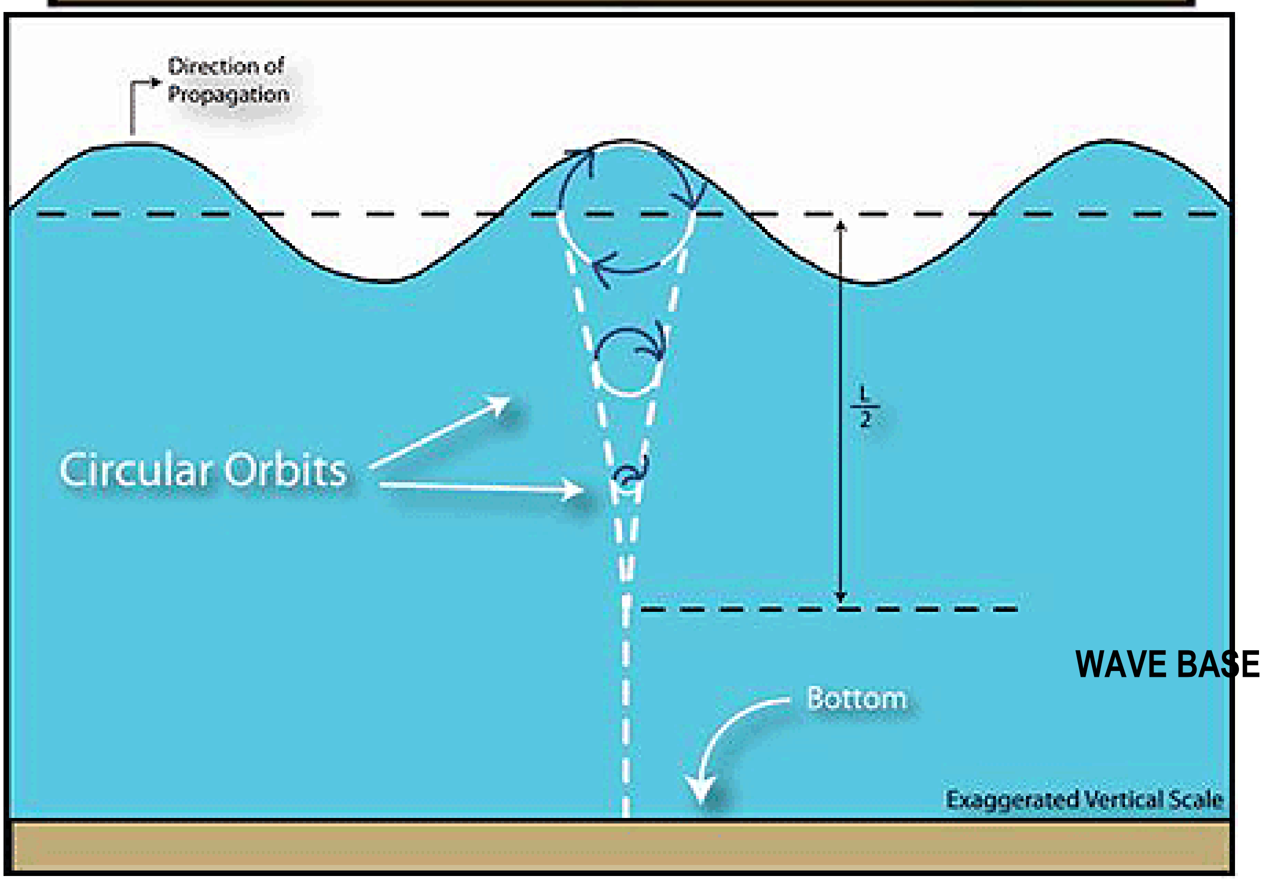
Most waves that approach the beach (and that come of us ride) are called **swell** and come from far-distant storms. Energy from winds is transferred to the water in the form of *oscillating wave energy*. The energy propagates, but the water simply oscillates or in a small circular orbit, returning to it original position. When the wave energy finally hits the beaches, possibly thousands of miles away, the energy dissipates in the surf zone as the waves touch bottom and eventually break.

One important type of wave that has huge impact on the coastline is the **tidal wave**. Tides are produced from the difference in Moon-Earth gravitational forces that are experienced on two opposing sides of the planet – the side facing the moon (which is closer and thus pulled more strongly) and the opposite side (which is further away and thus lags behind). The result is two bulges of water that are in line with the moon. The Earth rotates once every 24 hrs and 50 minutes beneath those bulges (the moon moves 50 minutes in its orbit by the time the Earth finishes one 24-hr rotation, and thus it must rotate 50 more minutes before catching up again to the bulge at which it started).

Wave **height** is the vertical distance between the highest point (**crest**) and lowest point (**trough**). **Wavelength** is defined as the distance between two **crests**. **Period** is the amount of time it takes for one entire wavelength to pass a given point. As waves approach the shore, they interact with the seafloor, and wave height grows, wavelength shrinks, but period stays the same. The crest of the tidal bulges are high tides – the areas in between are the troughs or low tides. The Earth rotates through 2 complete tidal waves in one 24 hr & 50 min period, so the period of a single tidal wave is 12 hr and 25 mins.

Because tidal bulges are trapped in ocean basins, they behave like water sloshing in a bucket. They slosh around center points once every 12 hr and 25 mins in a counter clockwise fashion in the Northern Hemisphere. As high tide approaches, the water moves up onto the shore, called a **flood current**. At high tide, water moves neither in nor out. This time is called **slack water**. As water retreats from the beach, the moving water is called **ebb current**. Tidal height varies on the planet from a few centimeters (close to the center point of the sloshing bucket) to a maximum of 55 feet (far away from the center of the sloshing bucket). For sea level to rise and fall that distance twice every day, a lot of energy is transferred, and a lot of coastline is alternately exposed and covered by water, creating the coastal intertidal zone, an important part of coastal topography.





Above two images from US Department of Transportation, Federal Highway Administration (Note: z and x in top image represent two dimensions (like x and y) on a graph. η is wave amplitude. SWL = Stillwater level. In the bottom image, wave base is shown at a depth of ½ the wavelength as measured from SWL. Note that in this case, as the bottom depth (d) is deeper than wave base, this image represents a deep-water wave. What about the top wave? Is it deep or shallow water?)

Marine Rocks & Sediments

Sedimentary Rocks

Sedimentary rocks form through the **precipitation** (solids coming out of a liquid) of minerals directly from water (example: salt flats that form when seawater evaporates) or through the **lithification** (solidification) of **sediment** – small particles of rocks, minerals, and organic material deposited in piles on Earth's surface. Two lithification processes are:

- **Cementation** of sediments usually by watery solutions that percolate through buried sediments and deposit mineral glues that then cement the sediments together). Example: solid sandstone that used to be moving sand dunes.
- **Compaction** of sediments (usually by burying sediment under layers of other rocks and sediments). Example: Mudstone that used to be soft mud-sized grains accumulating on the bottom of the ocean or lake.

In sediment, we use grain size (if grains are present) to help determine the formation environment and rock type. What types of waters would allow gravels to deposit? Sands? Muds?

- Gravel (>2 mm) – Associated with high-energy waters, like headlands or the base of cliffs.
- Sand (< 2 mm, > 1/16 mm) – Associated with moderate-energy waters, like beaches or rivers.
- Mud (<1/16 mm) – Associated with low-energy waters, like lagoons and the deep sea.

Rock name	Description	Possible formation environment
Sandstone	Sand-sized particles. Well to fairly well sorted. Dominantly the mineral *quartz* (*SiO_2*); may also contain rock fragments if sands are immature.	Along beaches, in sand dune regions, along inner continental shelves, submarine canyons, and in trenches where there are subduction zones – all places where sand-sized grains accumulate, carried by wind, water, or turbidity currents.
Mudstone	Mud-sized particles only. Usually clay minerals.	Areas of still water where mud-sized grains can settle out: tidal flats, lagoons, and the deep sea. Collections of clay occur in the deep sea where airborne clay (off deserts) or suspended clay from river runoff (off major rivers) settles to the abyssal plains. Chemical weathering of many common minerals on Earth's surface produces the clay.
Conglomerate or breccia 2 samples	Mud to gravel-sized grains. Very poorly sorted. Usually composed of rock fragments.	Areas where grains of all sizes drop out of glaciers, water, or gravity (landslides): headlands or the base of cliffs. When grains are angular, we call the rock *breccia*; when rounded, *conglomerate*
Chert	Green, yellow, red, white, opaque, smooth, dense, microcrystalline *SiO_2* (can't see crystals). Hard (can't scratch with steel).	On the deep ocean floor, through the lithification of siliceous oozes (muds comprised primarily of SiO_2 plankton shells that settle out of the water). More rarely: in hydrothermal areas where quartz (SiO_2) precipitates from water.

Igneous rocks

Igneous rocks form from the solidification of **magmas** (molten rock). Magmas form at depth when the Earth's mantle melts. Hot, fluid magmas are lower density than the rocks within which they form. Magmas rise toward Earth's surface, where they cool to become igneous rocks. If magmas erupt on the Earth's surface, they cool very quickly and form crystals that are too small to see with the eye or no crystals at all (glass). We call such igneous rocks **extrusive or volcanic**. If magmas cool slowly under the surface, they can form large crystals. We call such igneous rocks **intrusive or plutonic**.. (Like the formation of rock candy, larger crystals required slower cooling.)

Igneous rocks that you can find in oceanic settings are primarily **basalt** and **gabbro:** high-density, dark-colored rocks. Basalt is the extrusive form; gabbro the intrusive form. These rocks form when magma supply is large and consistent and doesn't have to travel through thick crust (oceanic crust is very thin ~ 5 km). Such settings include spreading centers, ocean-ocean subduction zones, and oceanic hotspots. Wherever basalt erupts, underneath the surface some of that same magma is trapped and cools slowly to form the intrusive equivalent of basalt, called gabbro**.** Continental igneous rocks, on the other hand, are primarily **granites** – lower density than basalt, and light colored. Granites form when magmas have a long transit time through the crust and cool slowly under volcanoes. That's why they're associated with continents, whose crust is up to 100 km in some places. Remember: basalts are denser than granites. This difference leads to oceanic crust being denser than continental crust, which is why oceanic crust (thin and dense) subducts, while continental crust (thick and buoyant) doesn't.

Rock name	Description	Possible formation environment
Basalt	Black, microcrystalline, dense. Can show chemical weathering of iron (rust) on exposed surfaces.	Oceanic volcanoes – spreading centers, island arcs associated with subduction zone volcanism, and hotspots. The *pillow basalt* variety forms when oceanic volcanism occurs under water, chilling the lava quickly as it erupts from cracks or vents on the seafloor.
Granite	Macrocrystalline. Minerals visible with eye – *quartz* (clear to grey), *feldspar* (white or pink), and *biotite* or *hornblende* (black).	Underneath continental volcanoes where long-travelled magmas cool slowly under the surface.

Metamorphic rocks

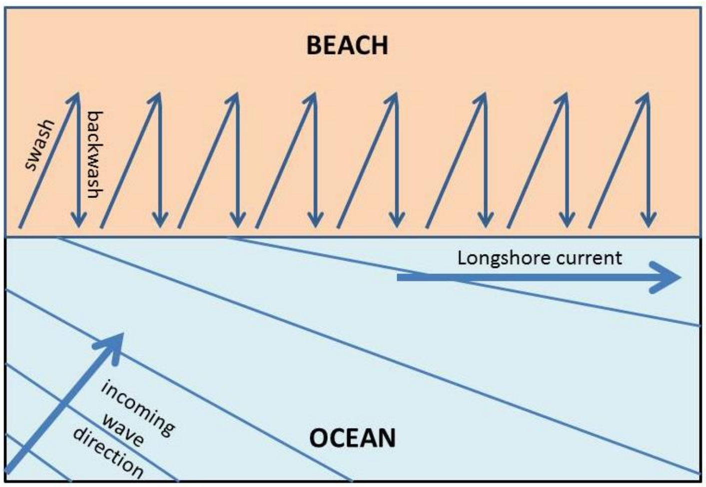
Metamorphic rocks form from the alteration of other rocks. Such alteration occurs from increases in pressure, increases in temperature, and/or addition of chemically active fluids.

Rock name	Description	Possible formation environment
Serpentinite	Green (any shade), mottled, massive. Smooth, rounded slippery surfaces. Usually displays slickened grooves on outside surfaces.	Mantle rocks that are exposed to hydrothermal solutions under seafloor spreading centers. Minerals in rocks hydrate to form low density serpentine, eventually pockets of which squeeze upward along subduction zones towards the surface (like watermelon seeds squeezed between your fingers).

You can go to the website to review different rock types (flashcards and helpful handouts).

Beach Sand – General

Beach sand consists of small particles of rocks, minerals, and organic material, broken up, transported, and deposited along beaches. Sand is moved along beaches by **longshore transport**, a process whereby incoming waves hit the shore with a component of push in one direction. This push picks up sand and water and moves it that direction. For North America this push is usually to the south (since most storms happen to the north, generating waves that move to the south). Sand is also moved onshore and offshore during seasons (onshore during summer when wave activity is low and offshore during winter when wave activity is higher and more erosive).

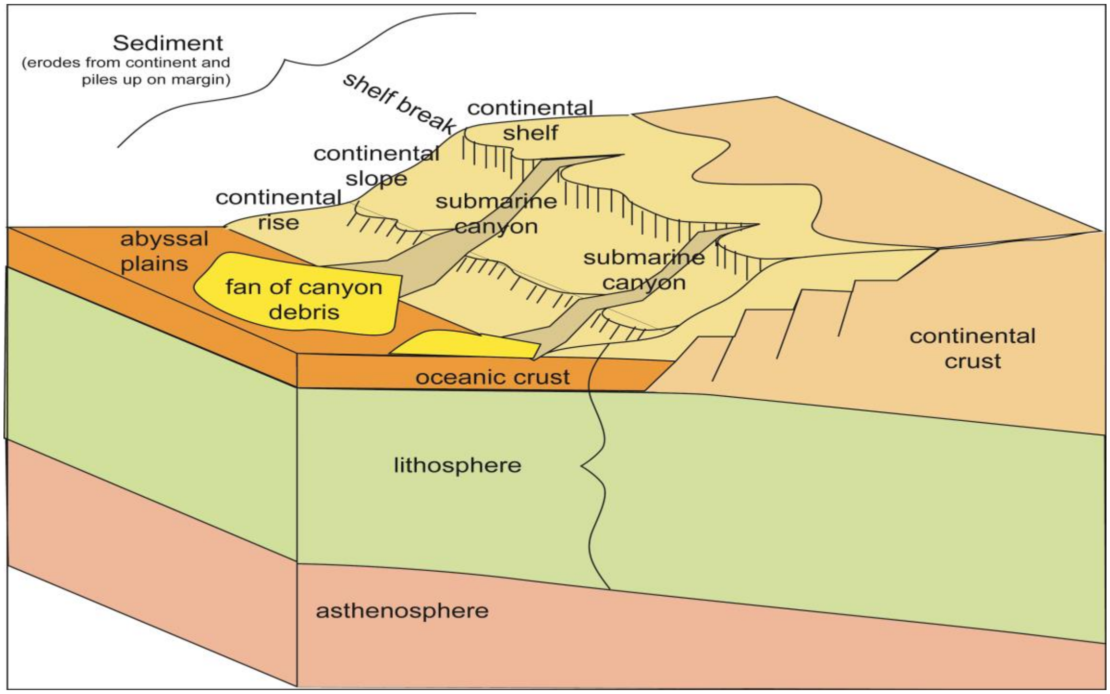


Generalized schematic of how waves approaching the shore at an angle produce a zig-zag migration of sand and water along the beach. The incoming waves push the sand up at an angle. Gravity returns it straight down.
The result = beach and longshore drift (sand migration) and longshore current (water migration).

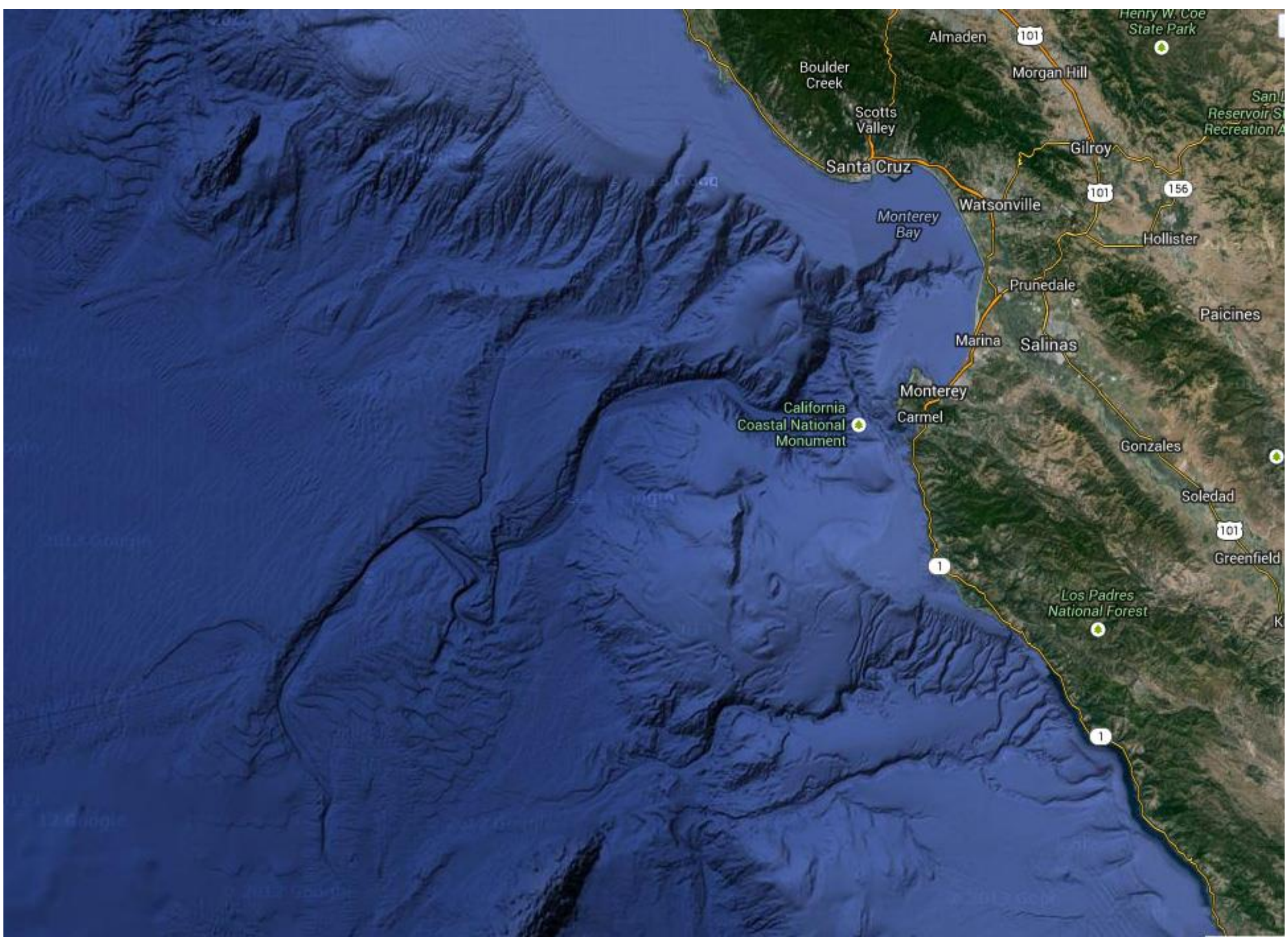
Sand is produced when rocks break down. Not all rocks break down with the same ease. Some resist **weathering** (break down) and **erosion** (removal by agents such as wind, water, and gravity). The rocks that resist erosion are left behind, often with beautiful sculpted landforms and features representing their erosion. The opposite of erosion is to drop sediment in a pile: **deposition**. Many beach features are developed by deposition, and these include any piles of sand, like sand dunes, spits, and barrier islands. The west coast of North America is generally characterized by erosional features, because our coastline is constantly uplifting, bringing new resistant rock to the surface to erode. Only in areas where the land is sinking or subsiding will deposition dominate. Since the east coast of North America is a sinking or subsiding coastline, it is dominated by depositional features, such as long barrier island provinces.

Ultimate sources of beach sediment	**Ultimate sinks for sand (where it ends up)**
• Eroded material brought from the backcountry via rivers and distributed along beaches by longshore transport • Local rocks eroding (headlands and cliffs) • Local biological debris (like coral reefs)	Sand is ultimately removed from the longshore transport system: • Wind blows it onshore where it is buried and turned to sandstone. • *Submarine canyons* pull beach sand offshore, ultimately dumping it at the base of the canyon in a fan on the continental rise.

Submarine canyons are carved by avalanches of sediment (called ***turbidity currents)*** that fall down the edge of the continental shelf, where sediment accumulates from the dumping by rivers. On the western margin of North America, we have a very narrow shelf. It extends only 27 miles offshore here in San Francisco (and is recognized by the location of the Farallon Islands, which sit at the edge of the shelf). The water is only about 300 to 350 feet deep at the edge of the shelf, and then only a mile or two further west, it drops steeply down the “slope” to about 15,000 feet!



Continental Shelf Details – not to scale.

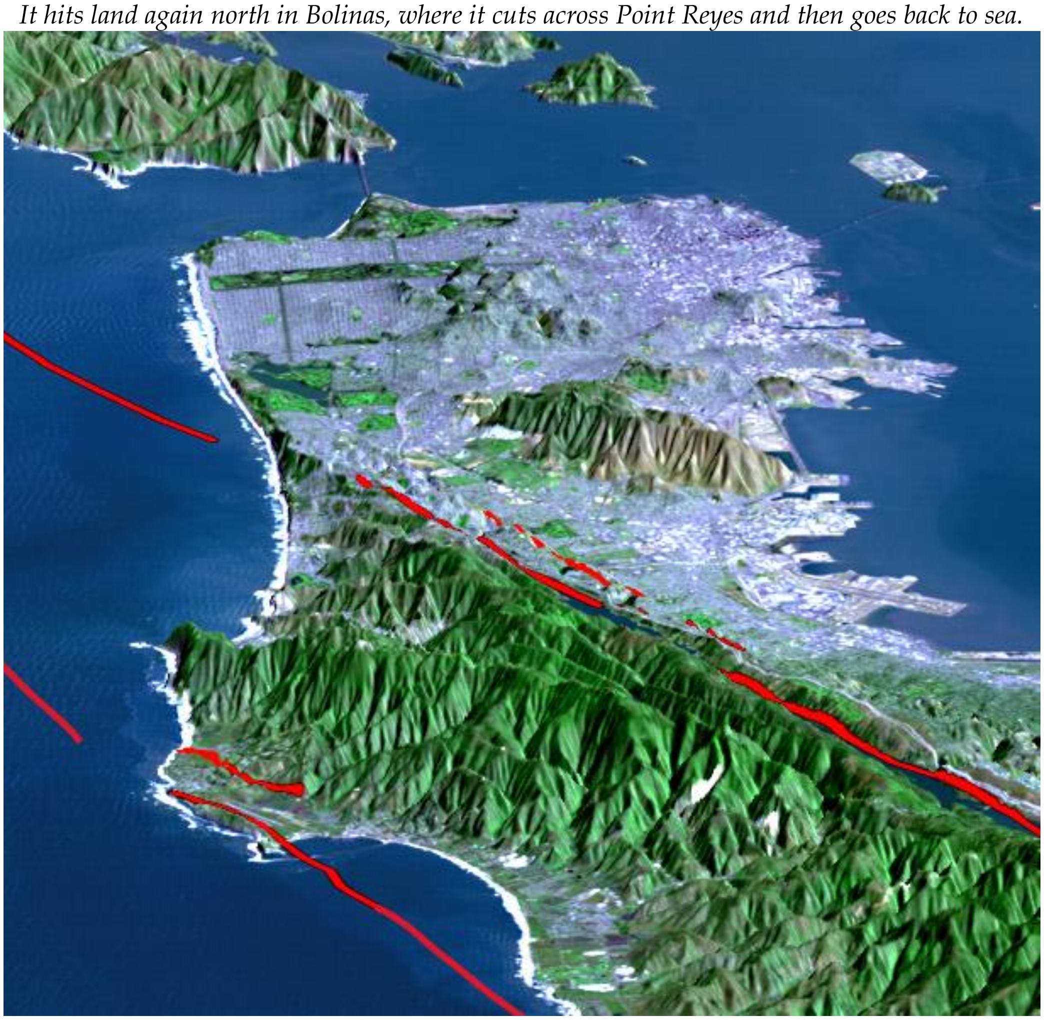


Sidescan sonar image of the Monterey Bay Canyon area. (Image Google: NASA, TerraMetrics)

Coastal uplift

For the past 5 m.y., while uplift has occurred along the California coast ranges, the area around San Francisco Bay has been an anomaly – subsiding and letting the Pacific Ocean flood into the Sacramento River to form San Francisco Bay. The tops of some of the older hills became islands, such as Alcatraz and Angel Island. Most of the high points you see are what we call "erosional remnants" – resistant rock left behind while that around it has eroded away.

(Image: USGS): The San Andreas fault trace leaves the coast at Mussel Rock south of Fort Funston. It hits land again north in Bolinas, where it cuts across Point Reyes and then goes back to sea.



Notice that the region around San Francisco Bay is uplifting (mountainous), while the Bay itself is subsiding.

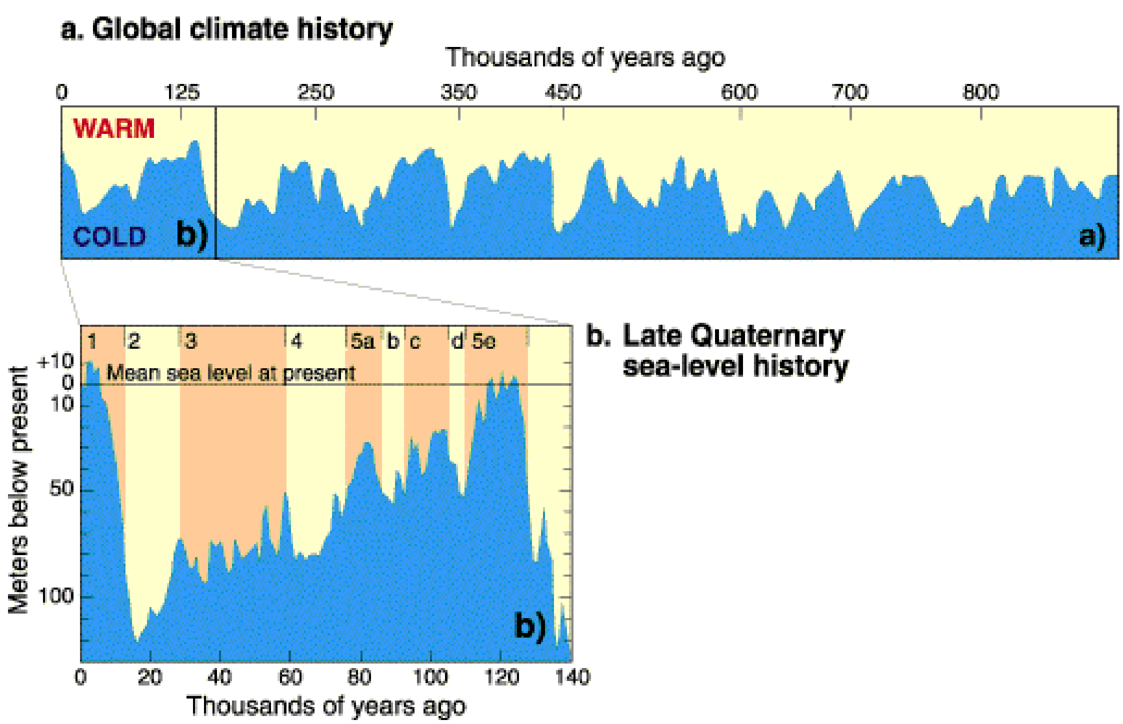
Ice ages and coastlines

For the last 2 my, San Francisco Bay has alternately emptied and filled as sea level fell and rose with growing and waning ice ages. Such migrations of the coastline occur regularly, which is why it's so common to find fossils of marine animals far to the west (under today's ocean water) and far to the east. During interglacial times when sea level was high (as it is today), the bay was full of water, and the Sacramento River sediments never reached the Pacific, dropping instead into the Bay. During glacial periods, when sea level was low, the Sacramento River flowed through the Golden Gate and deposited sand along the Pacific shoreline tens of miles west of the present shore.

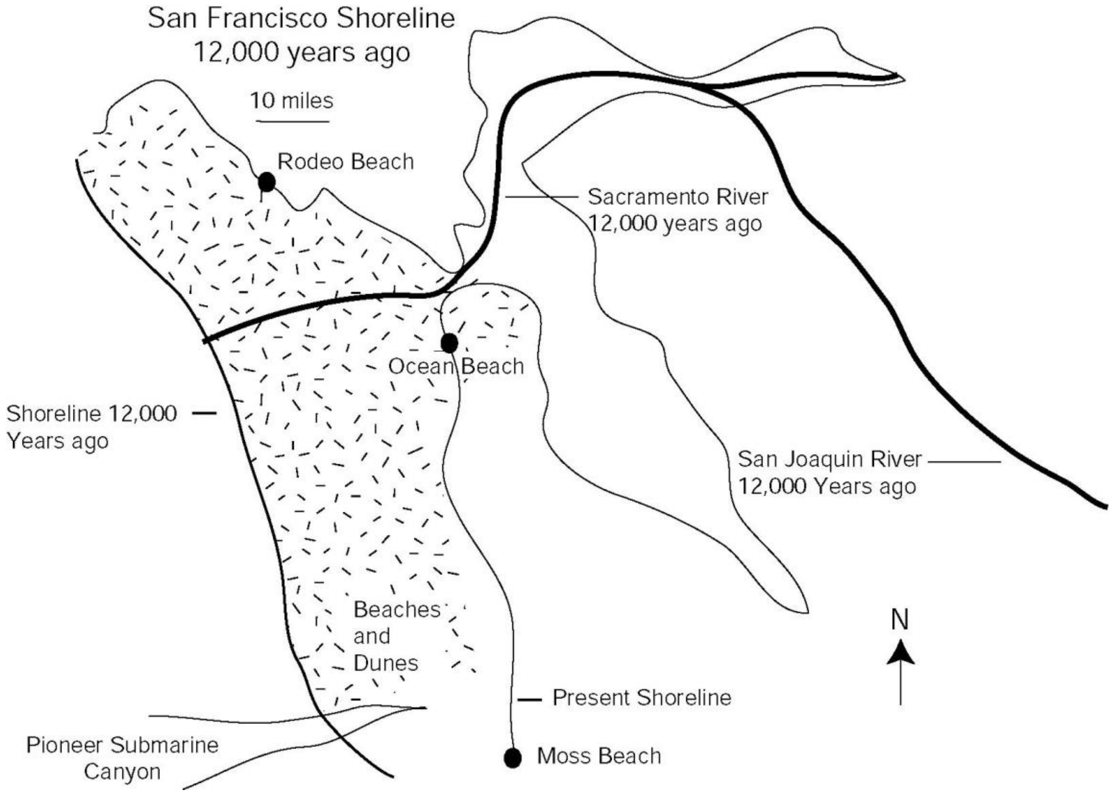
During the last ice age, 10-15,000 years ago, sea level was 300 to 400 ft lower than today; there was no water in the bay; and the shoreline was about 30 miles west of Ocean Beach. Wind blew much of this sand inland to form sand dunes that covered most of San Francisco and the continental shelf. Most of these old beach sands and dunes are now covered by the sea (as the Sacramento River was flooded and pushed inland to Sacramento) and exist as patches of sand several miles offshore (Potato Patch Shoal off the Golden Gate, for example). The dunes still on land are now underlying the majority of San Francisco's urban development, hence the severe shaking experienced in these areas during earthquakes.

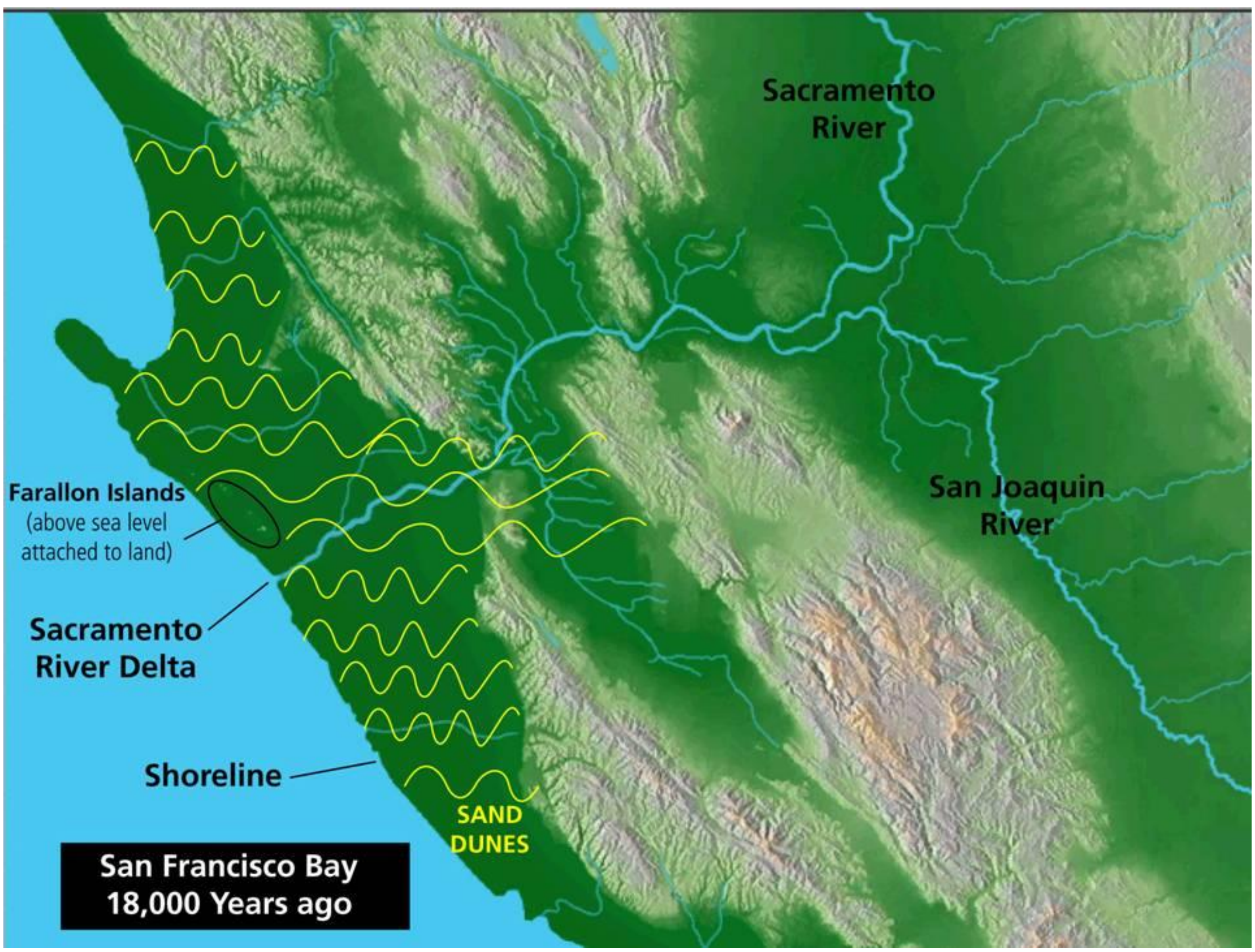
Today's source of Ocean Beach sand are these old dune deposits, now covered by water. The sand in the old dunes is ultimately derived from Sierra Nevada granite that, after weathering in the Sierras, was picked up and carried by rivers (ultimately the Sacramento River) to the Pacific Ocean. Waves push these now-covered pockets of sand ashore during the summer months, and waves distribute it southward. (Note: there is no current river source or local erosion source for Ocean Beach sand. Few rocks exist in the area to erode, and the Sacramento River deposits its sediment up in Sacramento. If it weren't for these old, covered deposits of sand, there would be no Ocean Beach.)

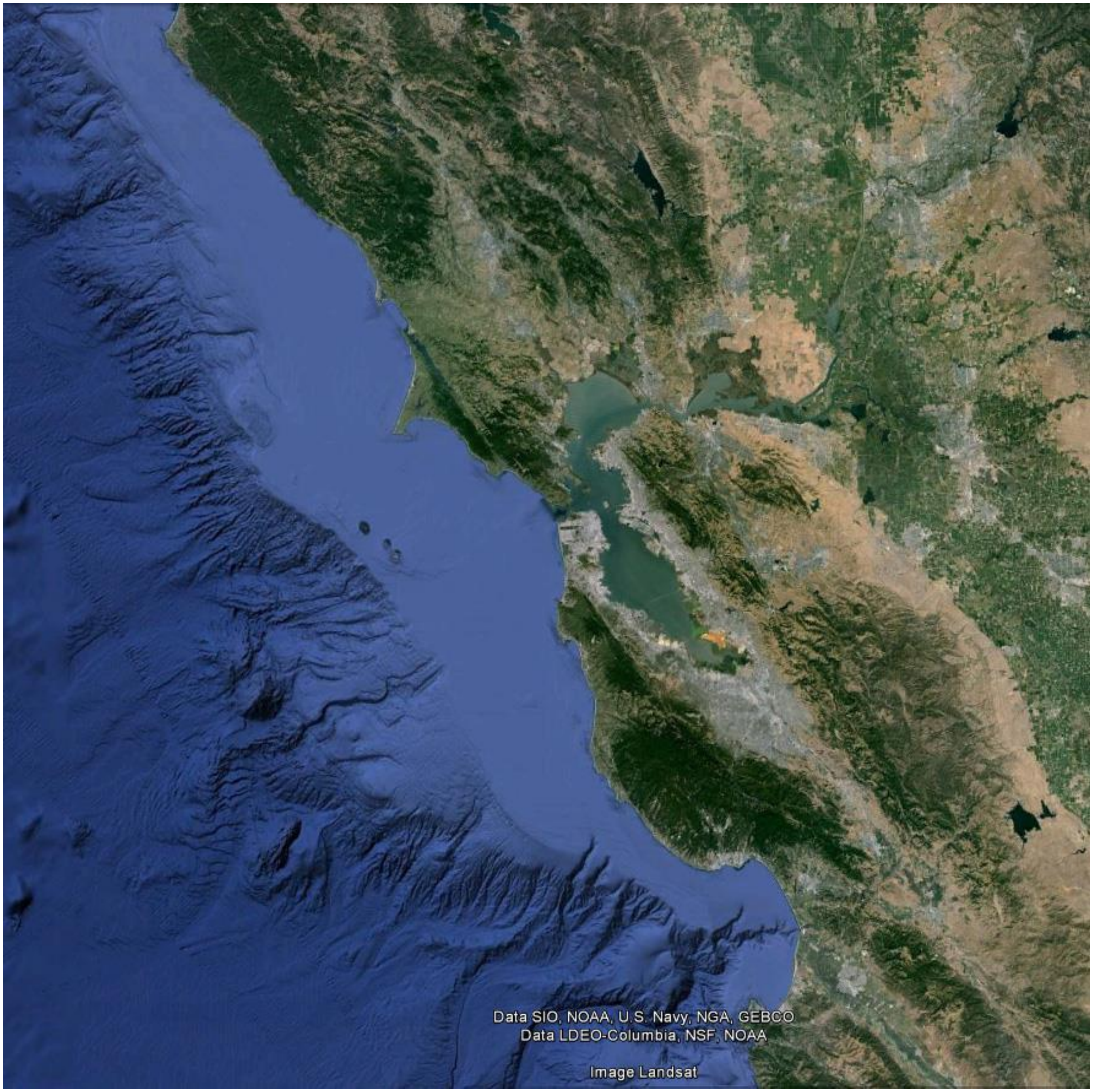
Based on these figures, note also that the Pioneer Submarine Canyon sits offshore just south of San Francisco. Most of the Ocean Beach sand that is part of longshore transport is sucked offshore just north of Moss Beach and ends up at the bottom of the Pioneer Submarine Canyon. Note also the inlet to San Francisco Bay to the north of Ocean Beach. Can sand move across this inlet to let Marin Headlands beaches feed Ocean Beach? Why or why not?



Sea level changes over the past 1 million years. Image from NOAA


San Francisco Shoreline
12,000 years ago
10 miles
Rodeo Beach
Sacramento River
12,000 years ago
Ocean Beach
Shoreline 12,000
Years ago
San Joaquin River
12,000 Years ago
Beaches
and
Dunes
N
Present Shoreline
Pioneer Submarine
Canyon
Moss Beach


Sacramento
River
San Joaquin
River
Farallon Islands
(above sea level
attached to land)
Sacramento
River Delta
Shoreline
SAND
DUNES
San Francisco Bay
18,000 Years ago


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
Image Landsat

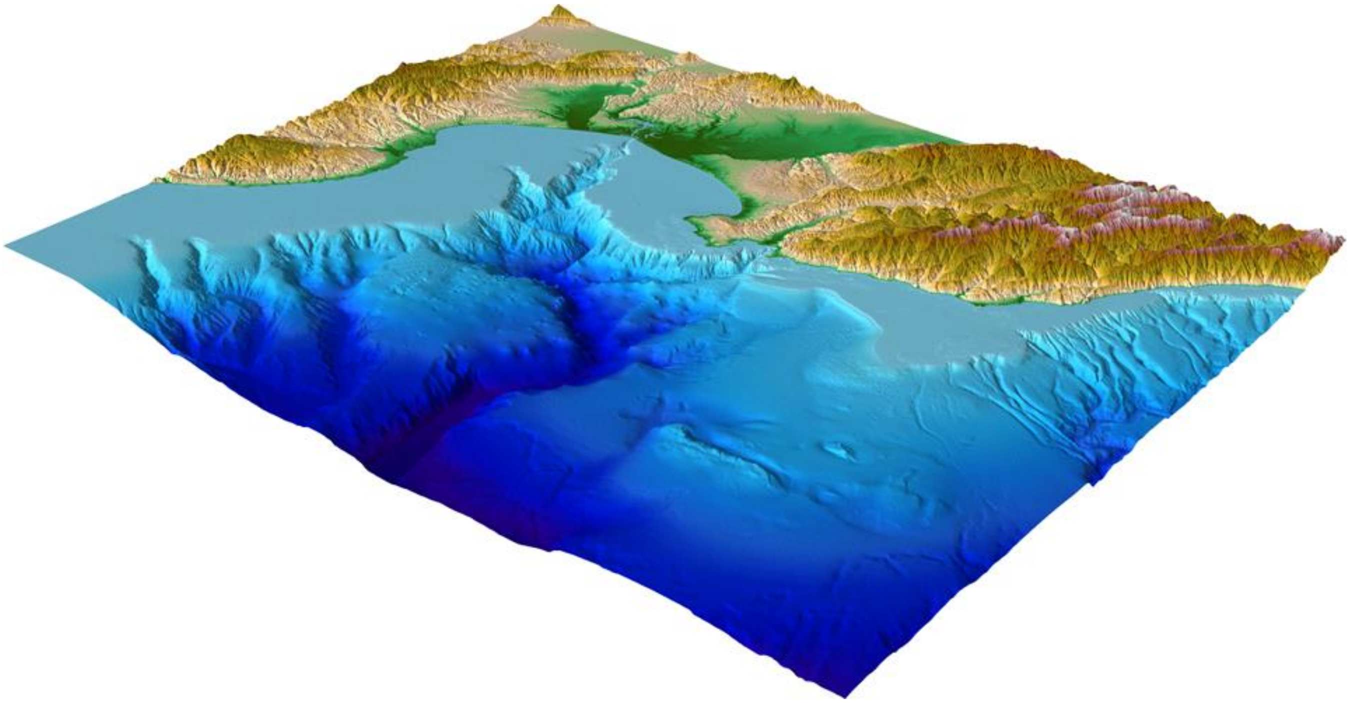
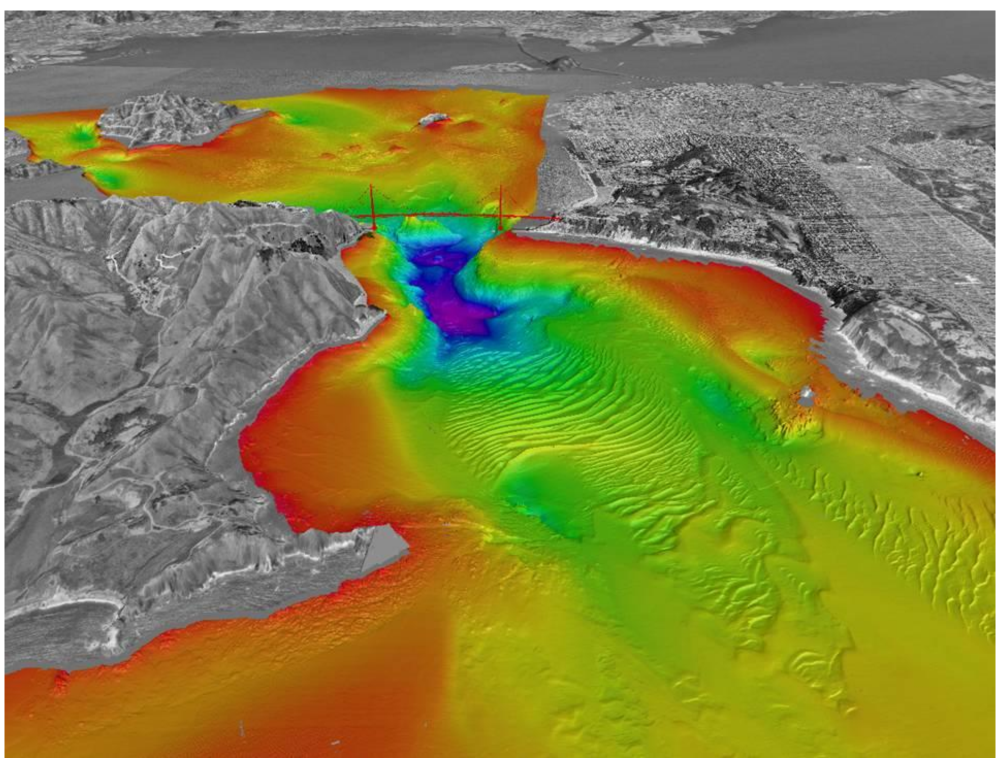


Image of submarine canyon showing edge of continental shelf (~300 to 400 feet deep).
The darker blue that represents the deeper abyssal plains are on average 15-16,000 feet deep. NOAA



Side scan sonar view east under Golden Gate Bridge. Depth at center (under bridge) is 351 feet. Rest of image is on average 25 feet deep. Dunes represent underwater sand sculpted by incoming and outgoing tidal currents.

Sand excavated from below a home in the Mission District.
These were the sand dunes that covered San Francisco before we built a city here.

Sand Analysis

Grain composition – As grains physically weather from their parent rock, they are also undergoing chemical weathering. (*Physical breakdown/weathering* is simply making a grain smaller. *Chemical breakdown/weathering* is transforming the grain's composition, from feldspar to clay, for example, or simply by dissolving the mineral.) The longer a grain has been separated from its source, the more exposure it has had to the elements, and the more potential it has to have been chemically weathered. Resistant minerals can exist at Earth's surface for a long time without chemically weathering. Easily weathered grains cannot. The range of grain composition found in sediment is a good indicator of distance from source. Near source, all compositions can exist. However, after long transit, most of the easily weathered grains should be gone, and the composition of sediment should consist mostly of resistant minerals.

Most resistant components:	Quartz (comes usually from granite weathering), Chert
	Magnetite (comes usually from granite or basalt weathering)
Moderately resistant components:	Feldspar (comes usually from granite weathering)
Easily weathered components:	Black nonmagnetic minerals (comes usually from granite weathering)
	Rock fragments: Granite, Basalt, Mudstone, Serpentinite
	Shells (comes from offshore reefs)

IDENTIFICATION -- Samples are available for reference. These hints will help with composition ID:

BLACK

- **Magnetite –** Place a bit of sample onto white paper and hold over a magnet. (Black and magnetic)
- **Black nomagnetic** – includes rock fragments like mudstone, basalt, serpentinite, etc.

LIGHT COLORED (clear or white)

- **Quartz –** Clear and glassy. Typically jagged because it is such a hard mineral.

- **Feldspar –** Typically white or pink and tablet shaped. Opaque. Distinguishing from shells can be difficult. Look to see if other shells are present for comparison.
- **Shells –** Typically white or pink or blue or multicolored. Can come in any shape or size, though usually has pits, ridges, ornamentation, or is thin and curved.
- **Granite –** Note that the rock granite is composed of the minerals feldspar, quartz, and a nonmagnetic, dark mineral. The rock will look salt-and-pepper colored (multicolored)

RED OR GREEN

- **Chert** – Typically smooth, rounded red or light or bright green (various shades).

Grain size – Grains are largest near their source (when first weathered off parent rock, grains can really be any size; large grains will dominate, however). As grains are moved away from their source by wind, water, or gravity, they continue to break down, becoming smaller. While small grains are easily transported, only high-energy water can transport large grains.

Gravel (>2 mm)
  Coarse sand (1.3-2 mm)
  Medium sand (0.7 to 1.3 mm)
  Fine sand (1/16 to 0.7 mm)
Mud (<1/16 mm)

GRAIN SIZE IDENTIFICATION GUIDELINES

Most of the sand you will be looking at is sand sized. Expect it to range from large muds to fine gravels. Use sample sizes to compare against your new samples, but also be sure to check your answers by comparing samples against each other. Line them up from finest to coarsest and make sure your answers match!

PERCENTAGE IDENTIFICATION GUIDELINES

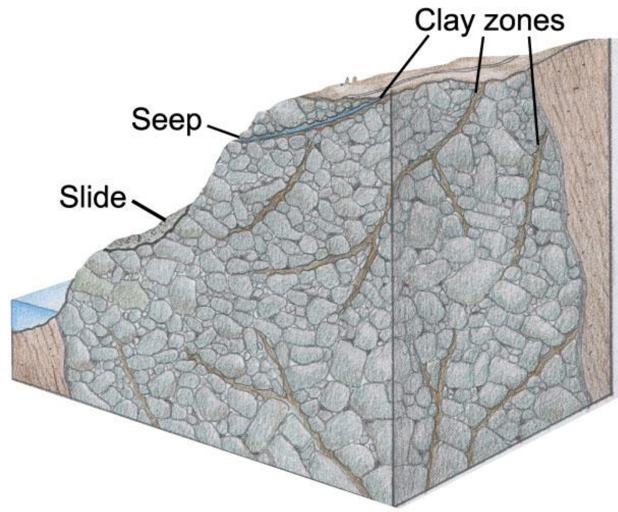
Percentages are estimates. Expect there to be differences from one person to another. What shouldn't be different, however, is relative abundance. First thing you should do is ask which size or composition is the most abundant, then next, etc. Make sure your numeric percentages match that relative analysis and add to 100%.

SOURCE DETERMINATION GUIDELINES

Go back to the composition data to answer this question. Ensure your numbers there match your numbers here. First off, your shell percentage should match your reef percentage (reefs are where shelled organisms live). Reefs are right offshore of the beach and represent little transit. Secondly, all low-resistance components must be locally derived; any transport would have broken them down. Usually, the medium-resistance components are also locally derived, though it is possible for some of them to have been transported a distance. Use other information to make this determination. The resistant components can either have traveled a long distance OR have been locally derived. Use grain size and local rock types to make this decision. For example, a beach of mostly fine-grained quartz has had all the low-to-medium resistance components removed. Grain size and composition indicate long-distance travel. However, a beach with high amounts of quartz, but also feldspar and black nonmagnetics components could originate from the breakdown of a local granite, if one exists. Grain size in such a case should be larger than the former case.

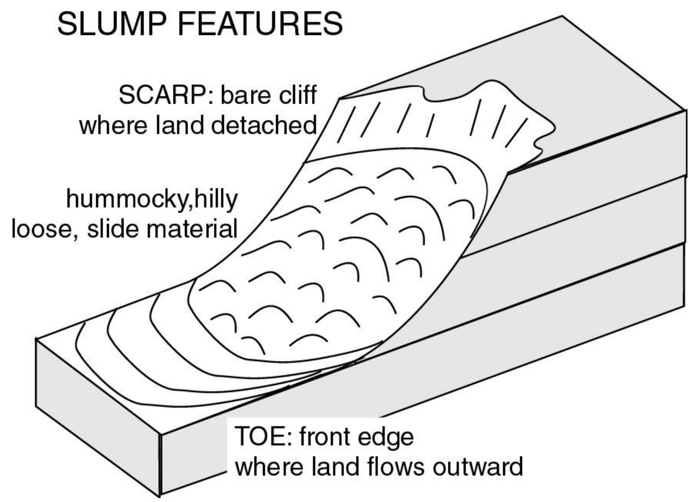
Serpentinite and Landslides

Serpentinite is a rock composed entirely of the mineral **serpentine**. Soils formed from serpentine are characterized by anomalous plant life, due to the composition of serpentine, which is an iron and magnesium silicate. There is almost no aluminum, so no clay soils are formed, and the soil is thin and gravelly. The serpentine also has toxic amounts of Mg, Ni, Cr, and Co, and is low in plant nutrients such as K, Na, Ca, and P.
Most common plants avoid serpentinite, but a few hardy and specialized plants thrive under these conditions: including Tiburon Indian Paintbrush, Oakland Star Tulip, and the very rare Tiburon Mariposa Lily (~2 ft high and blooms in May and June with cinnamon and yellow flowers).



SERPENTINITE:
Image: Will Elder, National Park Service

On fresh exposures, the rock is pale green, sometimes with dark specks about the size of small peas. Many homeowners think that if they build their homes on solid rocks, they'll have little chance of a landslide. But the solid rocks are really just boulders surrounded by a clay matrix. And if the boulder is serpentinite, it will dissolve quickly and get weak when in contact with surface water. Rainwater accumulates in fractures in the serpentinite and quickly dissolves the rock, turning it into a soft, slippery material. In places, some large blocks of this serpentinite have broken off and are slowly sliding down hillsides, lubricated by the soft and slippery weathered material within. Nearby clay will also move up the fractures. Putting water along these weathered zones is like putting wax on the bottoms of skis. The fine matrix holds water near the surface and is quite slippery when wet. The flows downhill, taking roads, buildings, and whatever else has been built on it.



Fort Funston

The sea cliff of Fort Funston consists of layers of sandstone, mudstones, and conglomerates. These rocks were beaches, lagoons, sand dunes, and headlands several hundreds of thousands of years ago. These ancient deposits formed by the same depositional processes that you see in action on the beaches today. The sequence of rocks within the sea cliff are called the **Merced Formation**, and they formed in a small sedimentary basin along the San Andreas fault. After deposition, the formation was cut by the fault, and rocks on the west side were carried 20 miles north.

The viewing platform at Fort Funston is the remainder of a **marine terrace**, an ancient wave-cut platform, now uplifted 150 ft above sea level. This particular wave-cut platform is about 100,000 years old and used to extend many miles out into the Pacific. Marine terraces are common along the California coast north and south of San Francisco where uplift has been continual, but not in San Francisco, which has been an area of subsidence.

During the Wisconsin ice age (10,000 to 15,000 years ago), sea level fell, the land uplifted, a new wave-cut platform eroded into the old one, and the shoreline moved westward several miles. Though sea level rose again after the ice age, the land continued to uplift. The old wave-cut platform remained above sea level, and the new one continued to erode back (as it is continuing to do today). The bluff or cliff that is below the viewing platform is evidence of this erosion, and as long as nature remains unimpeded, erosion will continue, and Fort Funston itself will someday disappear.

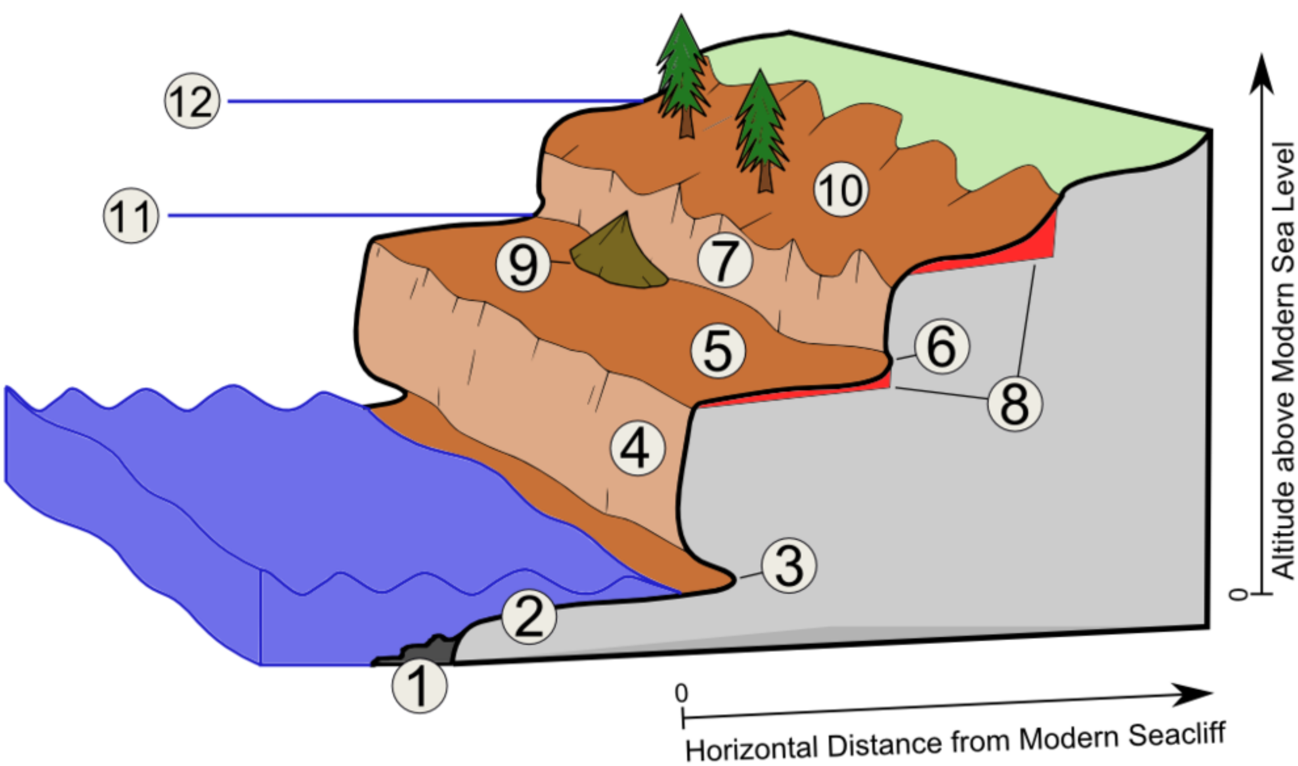
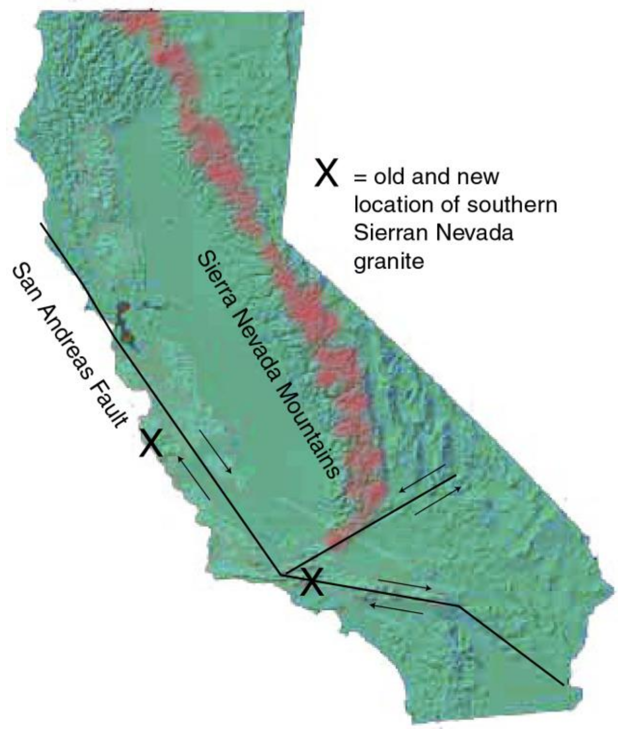


Image: Shekk12 Creative Commons: CC BY-SA 3.0.
Typical sequence of erosional marine terraces. 1) low tide cliff/ramp with deposition, 2) modern shore (wave-cut/abrasion-) platform, 3) notch/inner edge, modern shoreline angle, 4) modern sea cliff, 5) old shore (wave-cut/abrasion-) platform, 6) paleo-shoreline angle, 7) paleo-sea cliff, 8) terrace cover deposits/marine deposits, colluvium, 9) alluvial fan, 10) decayed and covered sea cliff and shore platform, 11) paleo-sea level I, 12) paleo-sea level II.

Montara Mountain Rocks

The granite exposed on Montara beach (and on Montara Mountain behind the beach) formed 85 Ma under volcanoes of the southernmost Sierra Nevada, when it was a volcanic arc for the Franciscan subduction zone (65 – 175 Ma). By 25 Ma (when the San Andreas Fault (SAF) formed, and the Franciscan subduction period was long over), the Sierra volcanoes had eroded and uplifted, exposing the underlying granites. The SAF cut the southern Sierra Nevada, slicing off a block of granite and transporting it north.

Since its arrival in the Bay Area, this granite has been further cut into pieces and redistributed by the **San Gregorio fault**, a part of the larger San Andreas Fault System (SAFS). (The SAFS is an ~ 40 mile wide system of parallel, right-lateral strike-slip faults, the SAF as the central, longest, and most active.) Because of this redistribution, this same granite is also found in Point Reyes and on the Farallon Islands.



<u>Coastal Planning</u> *(This section is from NOAA's Coastal Management Website)*
Pacifica State Beach Adopts Managed Retreat Strategy

In San Mateo County, California, the City of Pacifica had long battled chronic coastal flooding and beach erosion. For decades, the city had employed structural stabilization techniques to armor Pacifica State Beach and channelize San Pedro Creek. Despite these earlier stabilization activities, the City continued to face three main shoreline management issues: flooding of homes and businesses; erosion of Pacifica/Linda Mar State Beach; and maintaining habitat for the steelhead trout in San Pedro Creek.

In 1982, a major flood damaged more than 300 homes. One home was eventually lost, and two homes and a restaurant remained threatened by storm surges and erosion. Therefore, the U.S. Army Corps of Engineers and the City's Flood Control Committee supported proposals to further harden and channelize the creek to reduce the risk of flooding.

At the same time, community members were also concerned about on-going erosion at Pacifica/Linda Mar State Beach—a popular surfing location. The surfing community, led by Pacifica's mayor, favored shoreline restoration and argued that shoreline armoring was accelerating long-term erosion at the community's beach.

Further complicating the issue, San Pedro Creek supports a native population of steelhead trout. The California Coastal Conservancy and other partners therefore argued for restoration of the lower channel and creek mouth to improve habitat for steelhead and other species.

In the early 1990's the City of Pacifica, the California Coastal Conservancy, and the Pacifica Land Trust decided to collaborate to work toward a managed retreat strategy that combined "soft" stabilization techniques to enhance steelhead habitat, reduce flooding threats and preserve the sandy beach, with the removal of vulnerable structures along the beach.

During the 1990's, the City of Pacifica partnered with the California Coastal Conservancy, the California Department of Fish and Game, the Army Corps of Engineers, and the State Water Resources Control Board to expand and enhance the tidally influenced wetlands at the creek mouth and restore more than 1900 feet of eroding creek banks. This restoration both enhanced steelhead habitat and achieved 100-year flood protection for the nearby community. The wetland project also cost the community significantly less than other proposed flood control measures because it required less physical construction.

To address the remaining flood threat to homes and businesses, the City also removed the most vulnerable structures. In 2002, the City partnered with the Pacifica Land Trust and the California Coastal Conservancy to purchase two homes and their surrounding acreage for $2.2 million. They demolished and removed the homes and excavated concrete, rubble, asphalt, reinforcing steel, and tires. They also delivered 4,000 cubic yards of sand to rebuild dunes and restore four acres of beach and the nearby estuary. The city plans to relocate the one remaining shoreline structure—a Taco Bell restaurant—to the other side of Highway 1 as part of a planned retreat strategy.

Creative partnerships at the local and state level helped leverage the public support needed to implement a project that cost millions of dollars and took a decade to complete. Support of local government leaders, particularly the mayor, helped finance the up-front expenses for the ongoing project. Finally, a planned retreat strategy was made more politically viable because project partners had the capital necessary to purchase threatened structures outright.