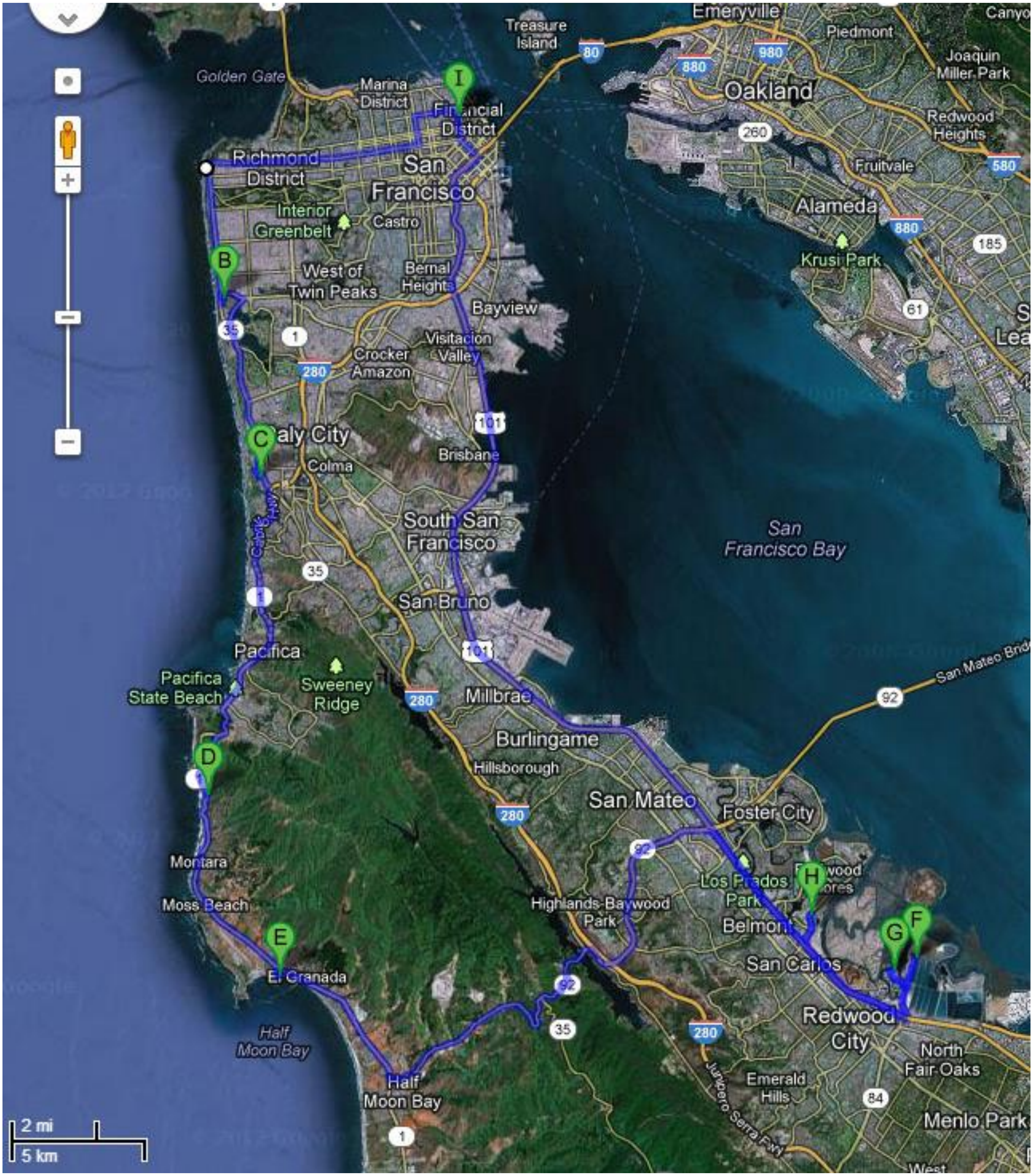
ROUTE MAP & TENTATIVE SCHEDULE
OPTIONAL June 17th Field Trip



Princeton Harbor(E) in route picture

Redwood Creek Salt Ponds (F in route picture)

Tidal info: Ocean Beach: Low 11:38 AM 1.4 | Redwood City Creek Entrance Tides: Low 1:51 PM 1.5 | High 8:22 PM 7.7

Tentative stops (weather and time permitting) include:

8 am -- pick up in front of Chinatown Center (CCSF) - 808 Kearny
8-8:30 am - Drive to Great Highway & Sloat (Ocean Beach)
8:30-9:15 am - Ocean Beach - dune formation and migration, coastal erosion, control structures
9:15-9:30 am - Drive to Mussel Rock
9:30-11 am - Mussel Rock - San Andreas Fault and coastal erosion
11 to 11:15 am- Drive to Gray Whale Cove Beach
11:15-12:15 pm - Gray Whale Cove Beach - sand formation and Montara Granite
12:15-12:30 - Drive to Pillar Point
12:30-1:30 pm - Pillar Point - LUNCH + HMB breakwater and reef
1:30-2:30 pm - Drive to South Bay Salt Ponds
2:30-3 pm - South Bay Salt Ponds -- development and reclamation
3-3:15 pm - Drive to Marine Science Institute
3:15-5:30 pm - Marine Science Institute - South Bay Educational/Research-Vessel Cruise
5:30-5:45 pm - Drive to restaurants
5:45-7 pm - Dinner (on own dime)
7-8 pm - Drive back to 808 Kearny

What are the ways we engage introductory level oceanography students students in the field?
Are there different questions we ask majors versus nonmajors?
What skills do we want them to learn? What outcomes do we want to achieve?

On this field trip, we will break into groups at each field stop and together, the groups will investigate the field area with the goal to uncover activities and questions that can engage students. Please discuss in your group, and have one recorder keep a record for later uploading to the workshop website.

SAMPLE OUTCOMES FOR AN INTRODUCTORY-LEVEL OCEANOGRAPHY FIELD TRIP:
After completing a field trip in an introductory oceanography class, students will be able to:

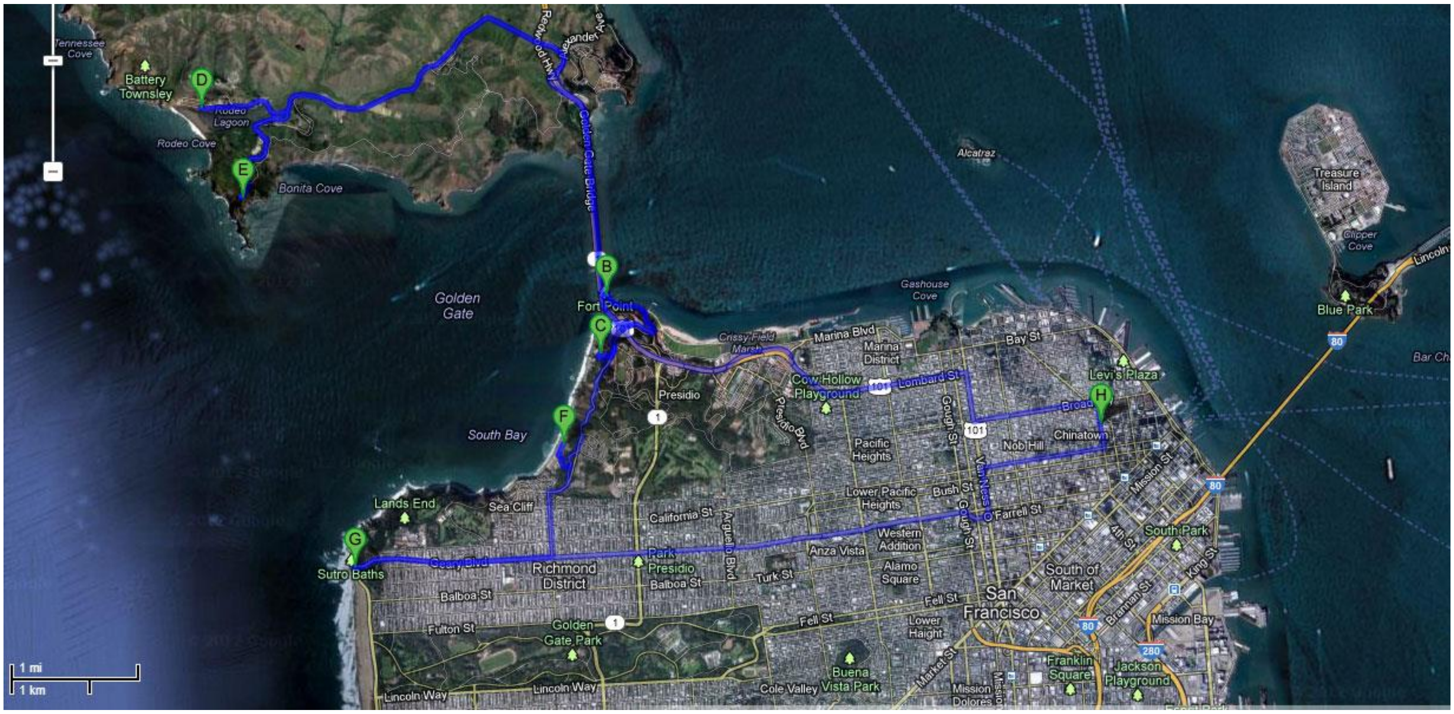
- Make and record field observations
- Recognize characteristics of a variety of natural process at work in the field around them
- Consider important questions that could be answered by scientists working in this environment
- Consider impacts of human interactions with this environment
- Recognize the value of working together
- Recognize the value of engaging in the local environment
- *Add more below and refine those above:*

SAMPLE ACTIVITIES AND QUESTIONS
TO ASK OUR STUDENTS IN A VARIETY OF SETTINGS:

- Can you find any landslides? (new or old)
- If so, how do you recognize them?
- How big are they? (And what are some good techniques for determining scale)?
- Why are they here? What contributed?
- Do you notice horizontal color stripes in the intertidal? What causes it? Why?
- Look at the sand -- describe its color, size, and texture. Is it the same everywhere? Where is it from? What affects it?
- Do you see any evidence of erosion? Where? What are the causes? What are some local sources of erosion?
- Do you see any evidence of weathering? Where? What are the causes? Do some rocks weather more than others? Describe those. Why do you think this happens?
- How are humans interacting with this environment? Why? Impacts?
- In this quarry, there are two rock types. Sketch them with a scale. What are the primary differences between them?
- *Add more in the appropriate sections below:*

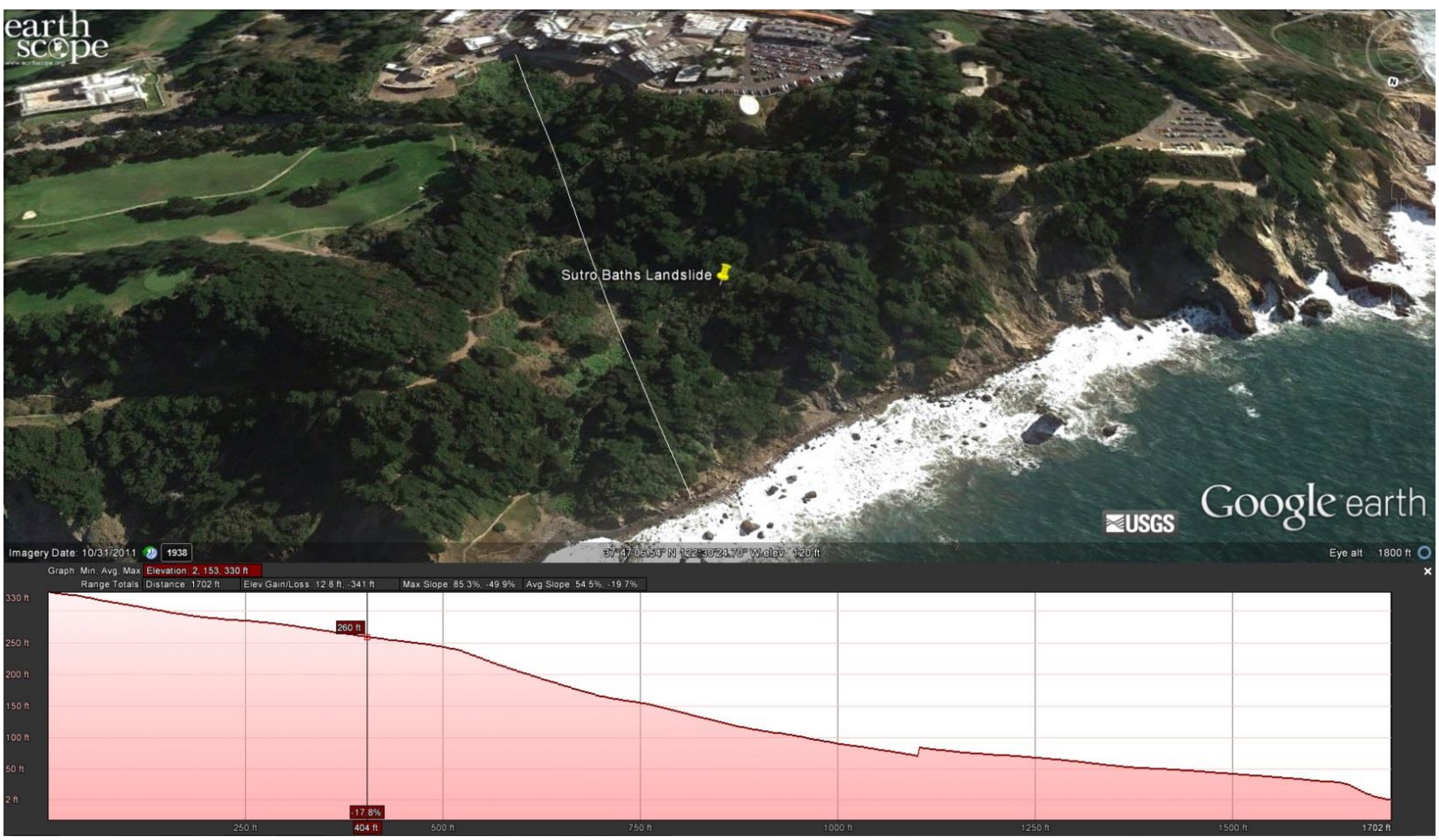
Teaching Oceanography in the Field – Intro Level
OPTIONAL June 21st Field Trip

ROUTE MAP



Looking north across the southwest tip of Marin Headlands (Pt Bonita Lighthouse and Rodeo Beach – D & E in route picture)

Looking east across the northwest corner of San Francisco (Lands End & Sutro Baths – with Golden Gate Bridge in top left corner – B, C, F, & G in route picture)



Looking south across the Lands End landslide – under the Veteran's Hospital – northwest corner of San Francisco – G in route picture)

Rodeo Beach Tides: High 11:17 AM 4.7 | Low 3:49 PM 2.3.

Tentative stops (weather and time permitting) include:

8 am - pick up in front of Chinatown Center (CCSF) - 808 Kearny
8-8:30 am - Drive to Rodeo Beach
8:30-9:50 am - Rodeo Beach & Lagoon -1-mile lagoon and beach trail/walk (roundtrip) - wetland ecology, coastal erosion, landslides, sand formation
9:50-10 am - Drive to Pt. Bonita Lighthouse
10-11:30 am - Pt. Bonita Lighthouse - 1-mile round trip trail - pillow basalts, maritime history, offshore bathymetry
11:30-11:40 am - Drive to Rodeo Beach Quarry
11:40 am - 12:10 pm - Chert Quarry
12:10-12:15 pm - Drive to Rodeo Beach
12:15-12:45 pm - LUNCH Rodeo Beach
12:45-1 pm - Drive to Battery Godfrey
1-1:55 pm - Battery Godfrey + Coastal Trail (Golden Gate Bridge) - 0.5-mile walk -- serpentinite, tidal currents, and maritime history
1:55-2:05 pm - Drive to Ft. Point
2:05-2:35 - Ft. Point - Golden Gate Bridge History - serpentinite - tidal currents
2:35-2:45 pm - Drive to Baker Beach
2:45-3:30 pm - Baker Beach -- sand migration, Pleistocene sand dunes, terranes
3:30-3:45 pm - Drive to Lands End
3:45-5 pm - Sutro Baths + Coastal Erosion + Terraces (~1.5 to 2 mile loop trail)
5-5:30 pm - Drive back to 808 Kearny

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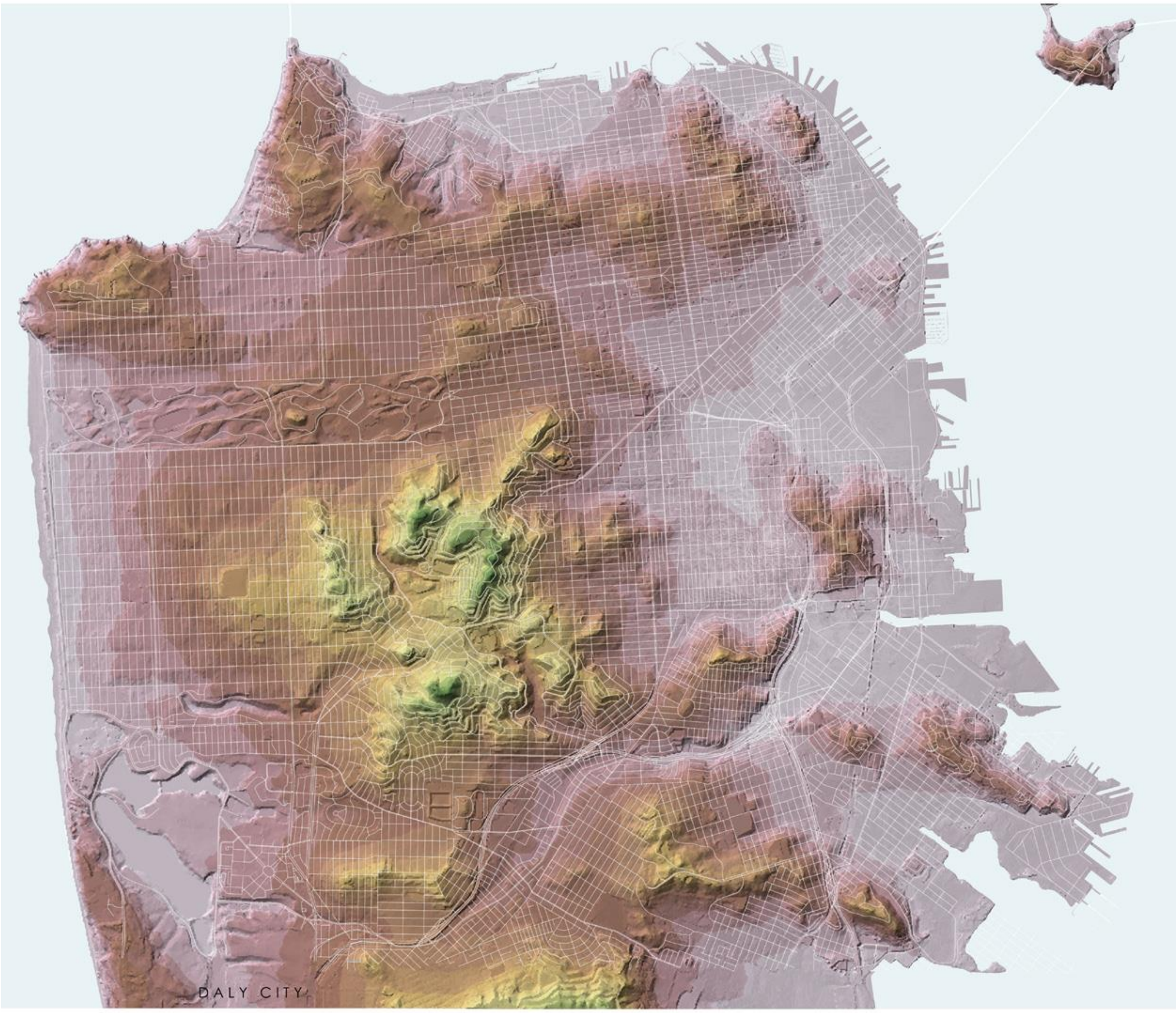
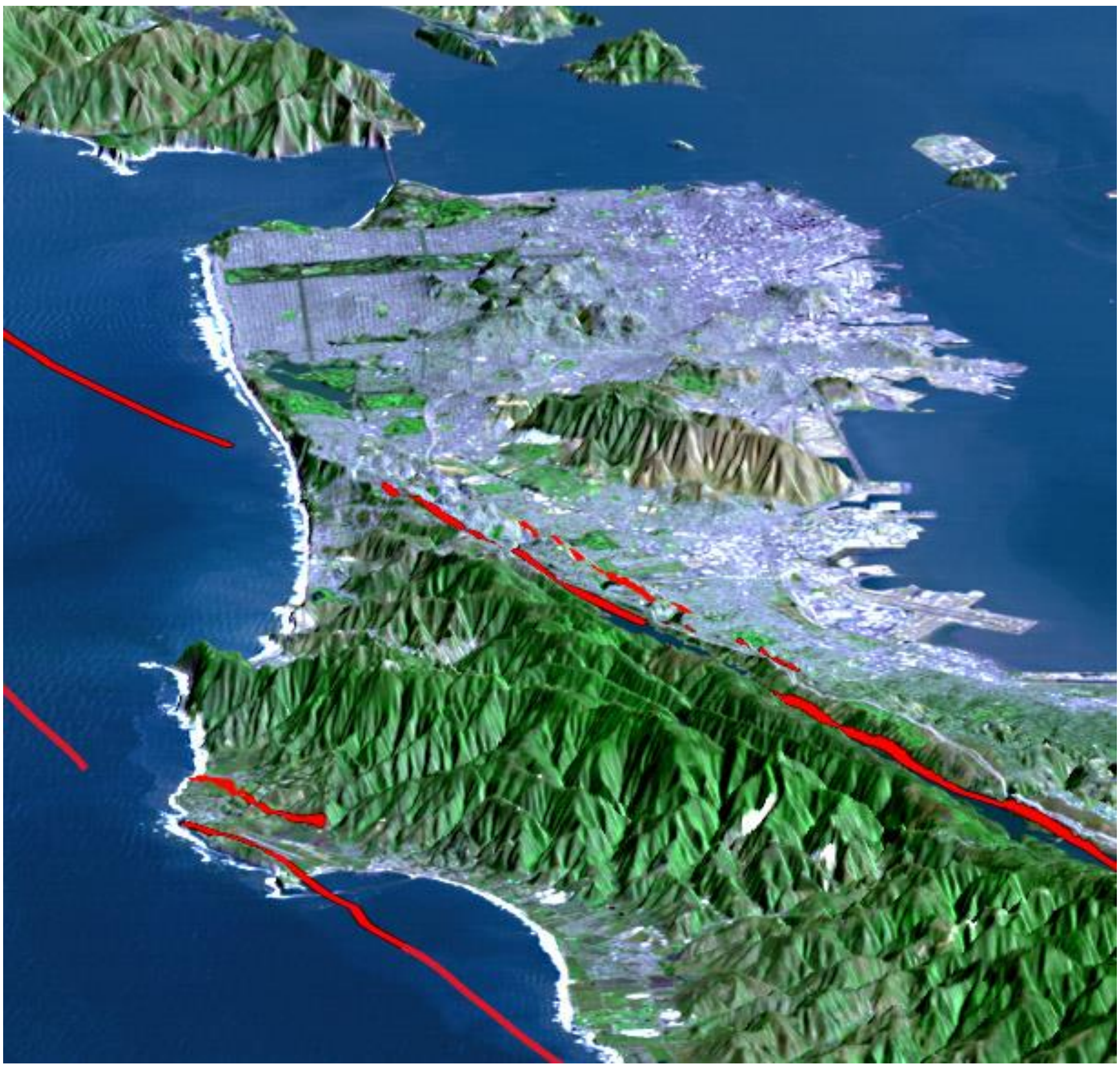
Golden Gate National Rec. Area
Point Bonita
Golden Gate Bridge
Alcatraz Island
Treasure Island NAS
San Francisco/Oakland Bay Bridge
Yerba Buena Island
Fort Point Nat'l Hist. Site
Palace of Fine Arts
Fisherman's Wharf
Aquatic Park
Fort Mason
Marina
Coit Tower
Ferry Building
Baker Beach
Lincoln Blvd
Doyle
Bay
Lombard
Broadway
Columbus
The Embarcadero
The Presidio of San Francisco
Presidio
California
San Francisco
Franklin
Van Ness
Leavenworth
Mason
Kearny
Golden Gate National Rec. Area
Lincoln Park
Pt Lobos
Geary
Cliff House
Balboa
Fulton
42nd Ave
36th Ave
30th Ave
25th Ave
19th Ave
Park Presidio
7th Ave
Arguello
Turk
USF
Masonic
Divisadero
Fillmore
Laguna
Civic Center
Market
Mission
Howard
3rd St
6th St
8th St
10th St
Townsend
China Basin
San Francisco Bay
Ocean Beach
Golden Gate Park
Stow Lake
Stanyan
Fell
Oak
Ashbury
Duboce
Lincoln Way
Judah
Lawton
Noriega
16th St
17th St
Parnassus
UCSF
Clarendon
Dolores
Guerrero
Mission
S Van Ness
Potrero
De Haro
3rd St
Great Hwy
42nd Ave
Sunset
28th Ave
24th Ave
19th Ave
14th Ave
Castro
24th St
Clipper
Army
James Lick Fwy
Taraval
Dewey
Woodside
Diamond Hts
Vicente
Sloat
Portola
O'Shaughnessy
Cortland
Evens
Stern Grove
San Francisco Zoological Gardens
Sloat
Santa Clara
Monterey
3rd St
Oakdale
India Basin
Innes
Golden Gate National Rec. Area
SFSU
Junipero Serra
Silver
Lake Merced
Font
Ocean
University
Bayshore Blvd
Persia
Mansell
Gilman
Fort Funston
South Basin
Jamestown
Candlestick Park
Bayview Park
San Jose
Mission
Skyline
Geneva
Cow Palace
Candlestick Point State Rec. Area
John Daly
Hillside
Guadalupe Cyn
Bayshore Fwy
Daly City
San Bruno Mtn. State & County Park
Eastmoor
Colma
Brisbane

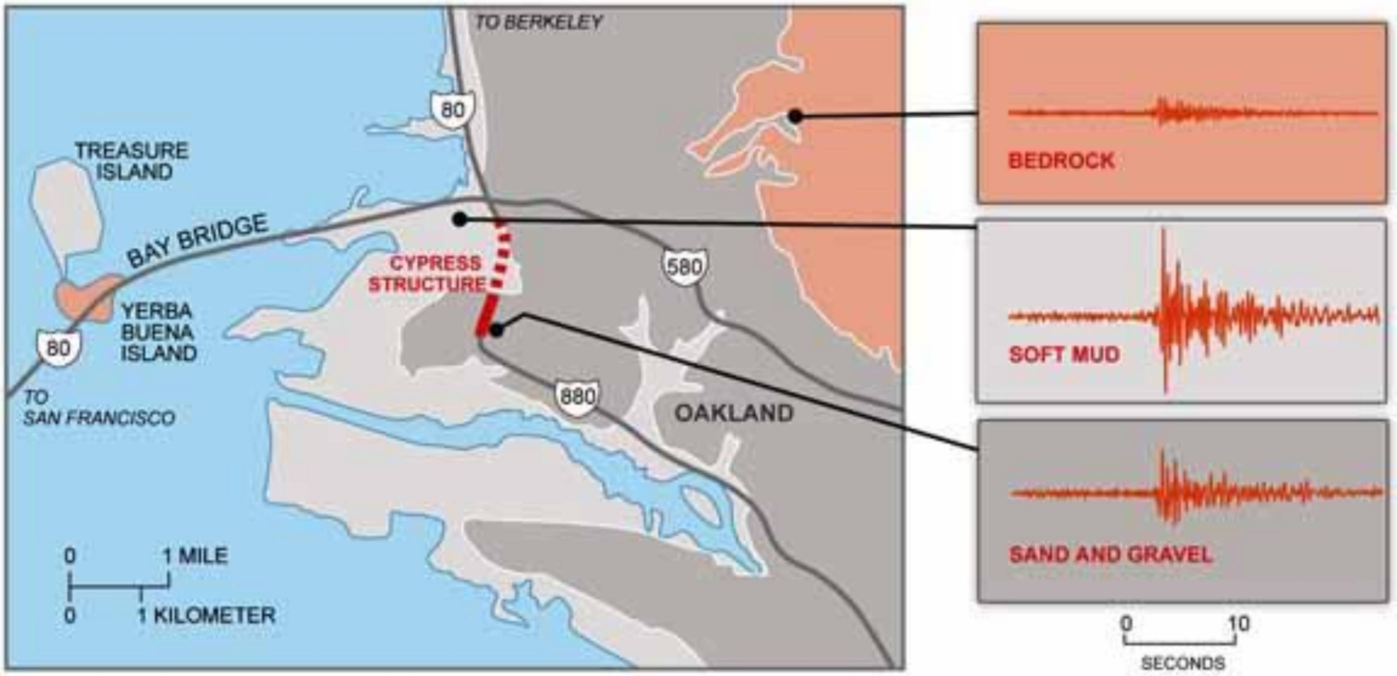
Google Maps

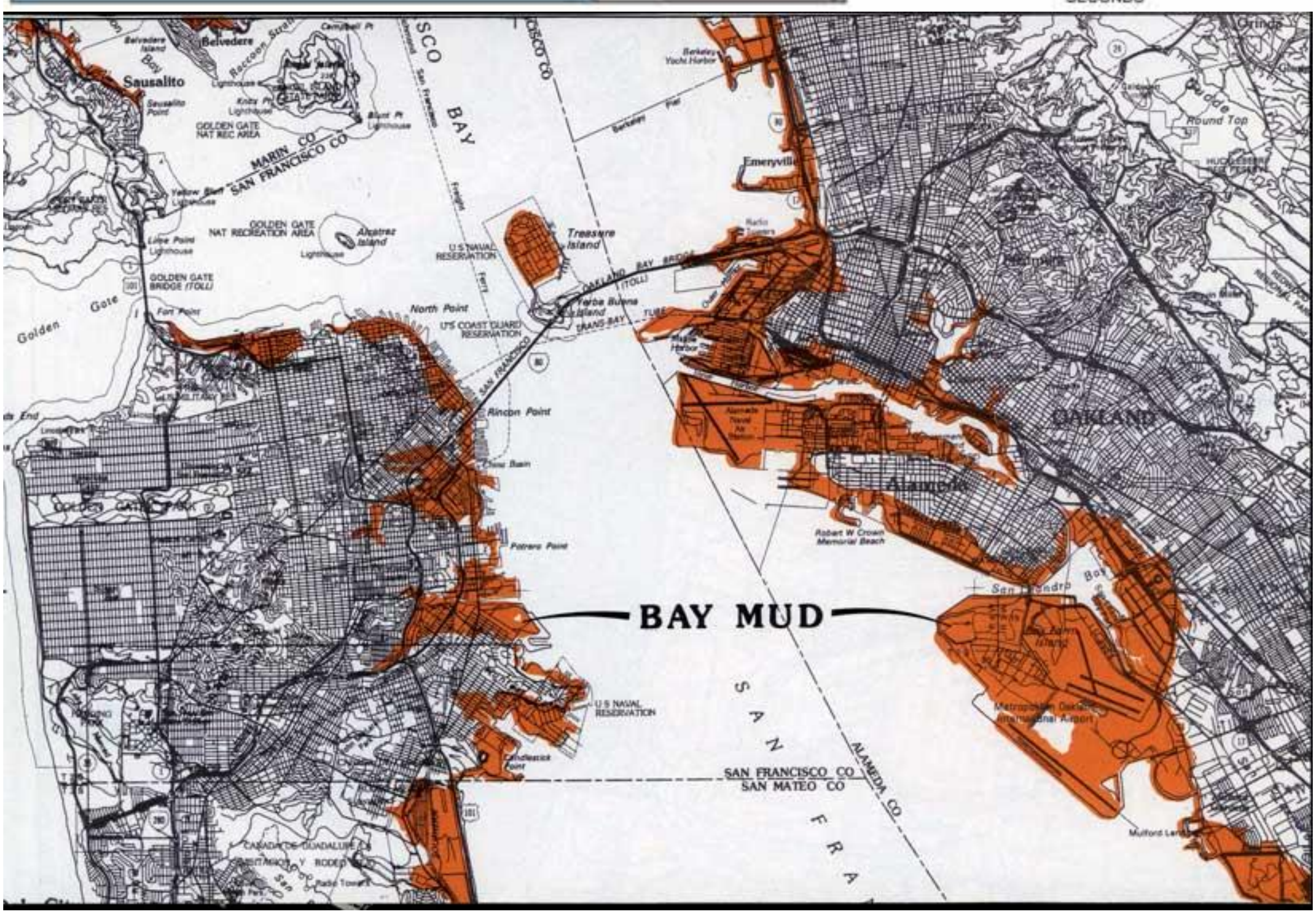

DALY CITY

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. (USGS)

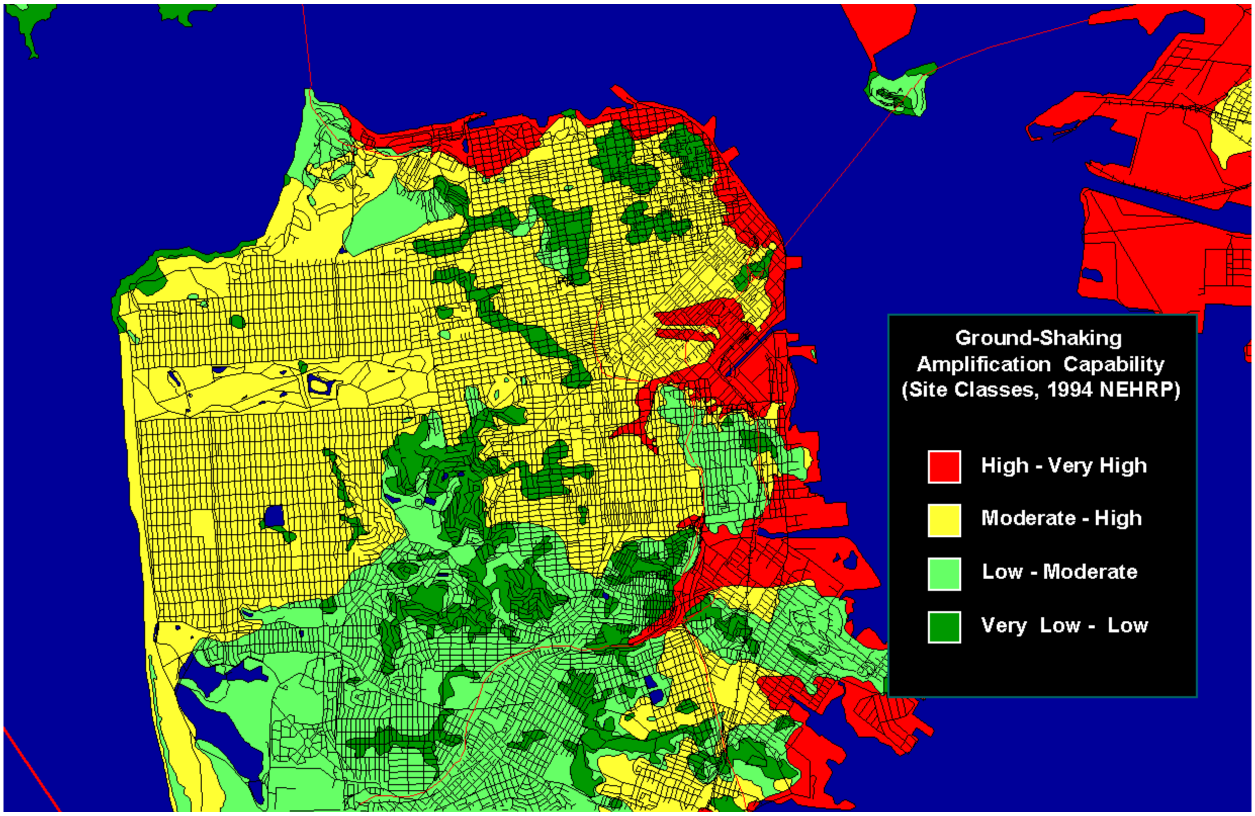


Notice that the region around San Francisco Bay is uplifting (mountainous), while the Bay itself is subsiding. (USGS)



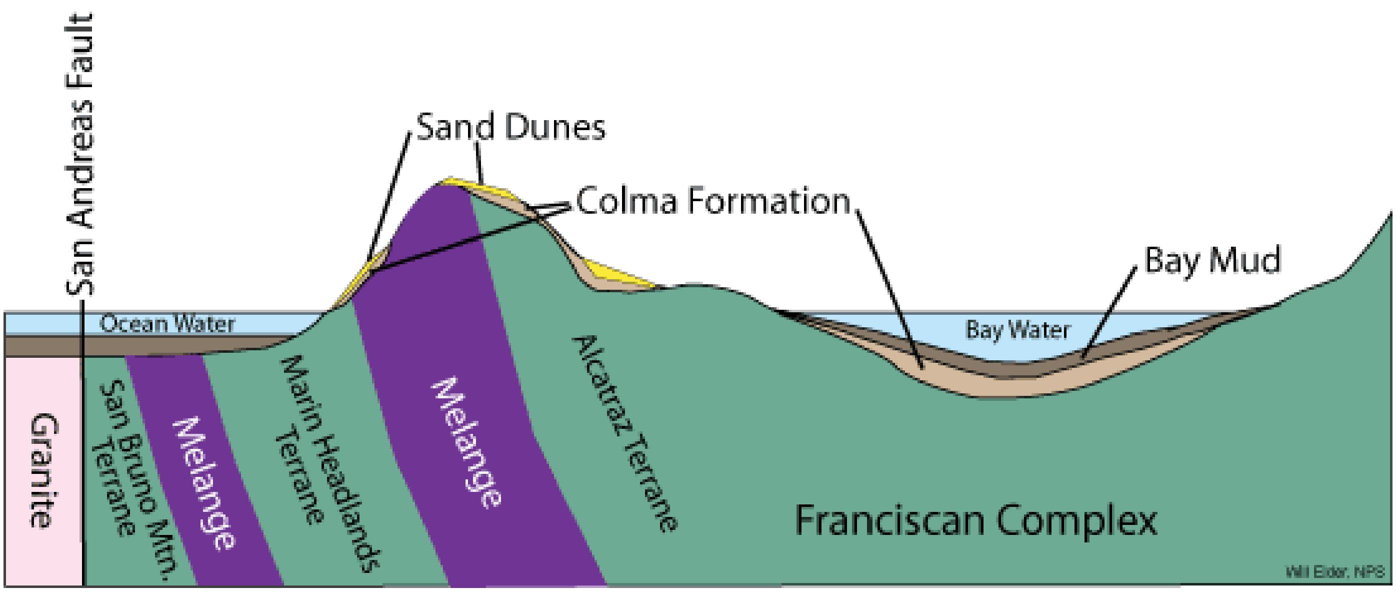


Maps and images above from USGS

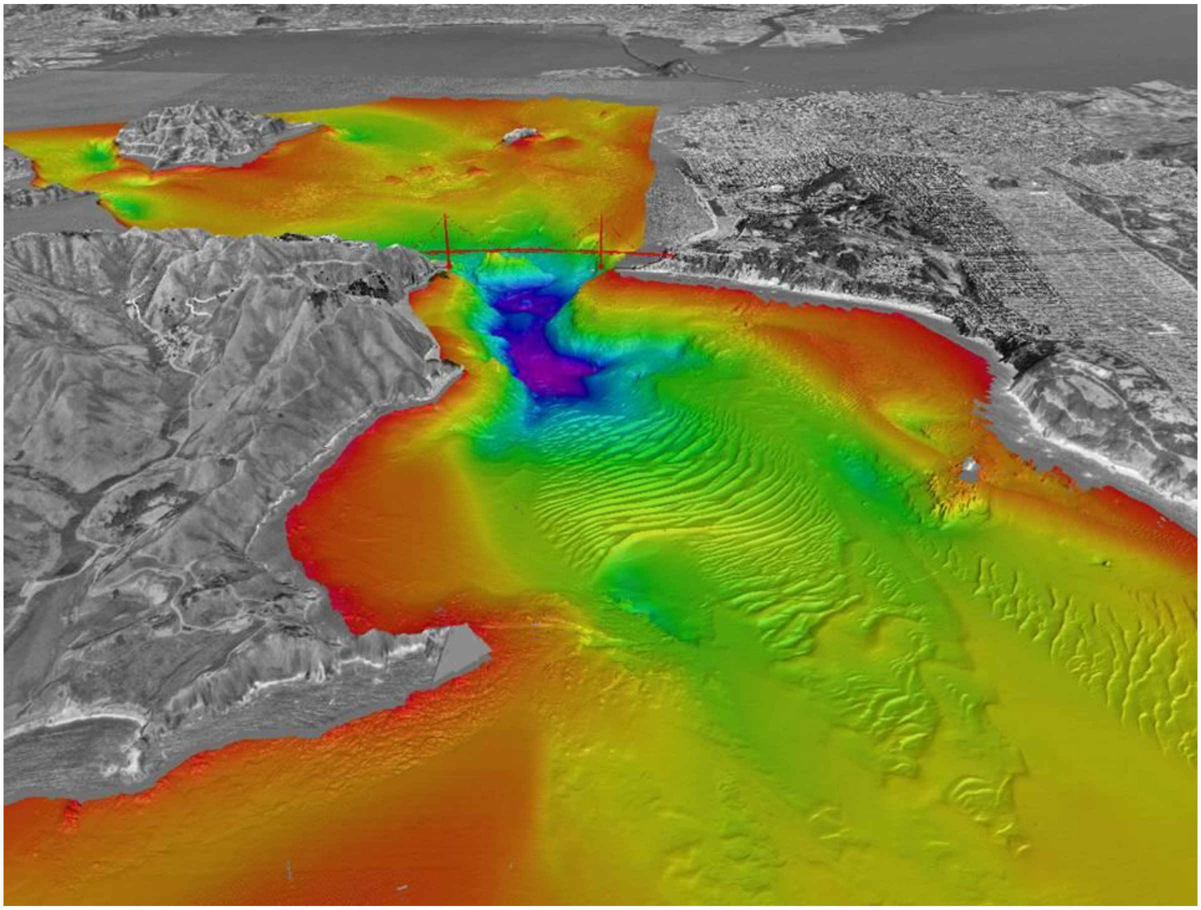


West - East X-Section

Northern San Francisco Peninsula to Oakland

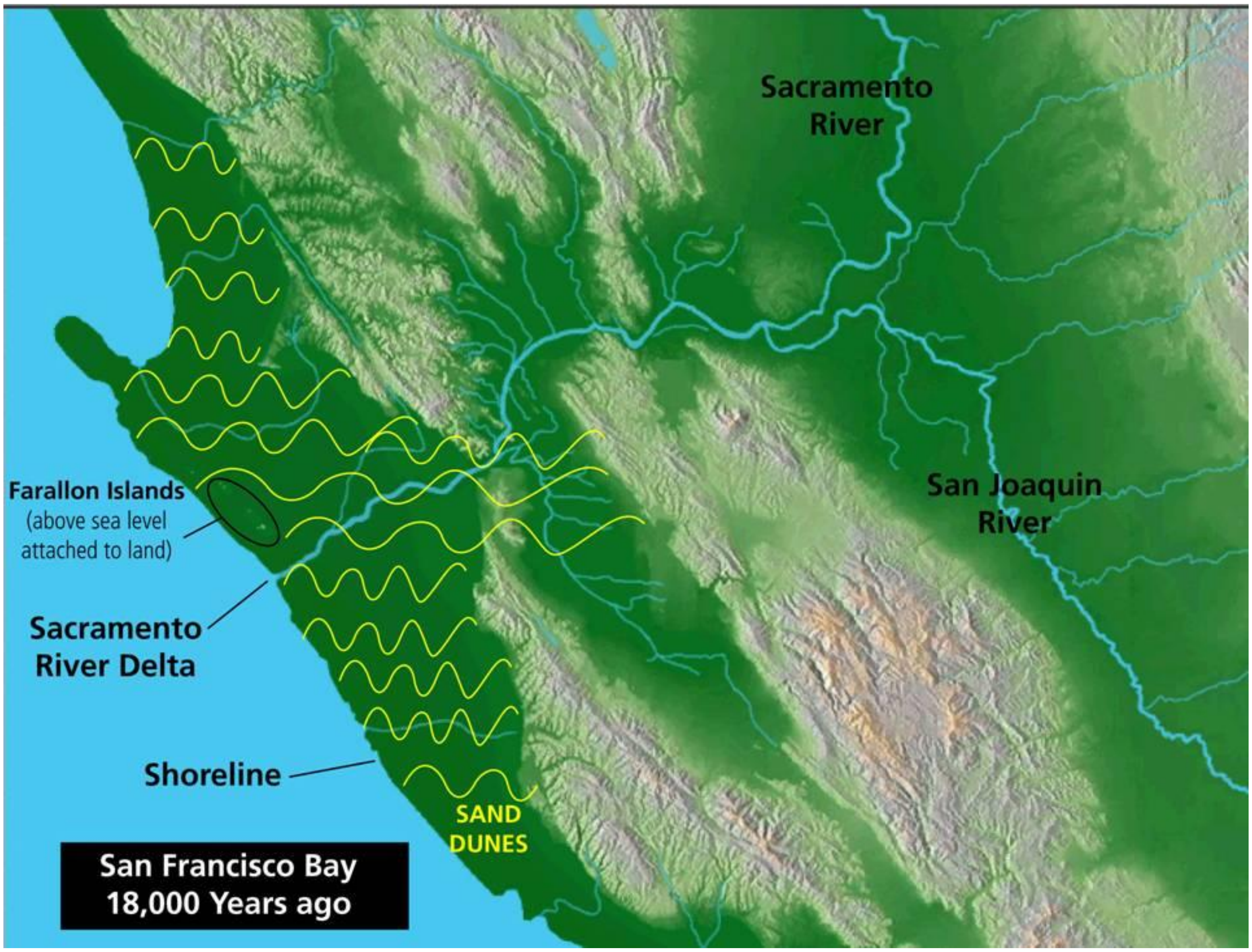


Will Elder, NPS



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. (USGS)

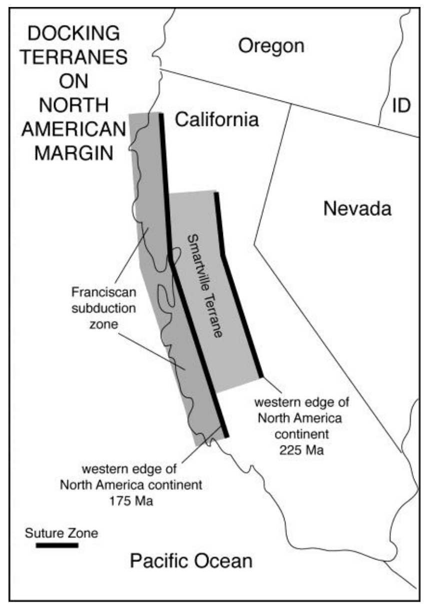
Sand excavated from below a home in the Mission District.
These were the sand dunes that covered San Francisco before we built a city here. (K. Wiese)



Modified by K. Wiese from maps available at the website of Tanya Atwater

The Sunset District around 1900 (Greg Gaar photo)

California Geology – Franciscan Assemblage

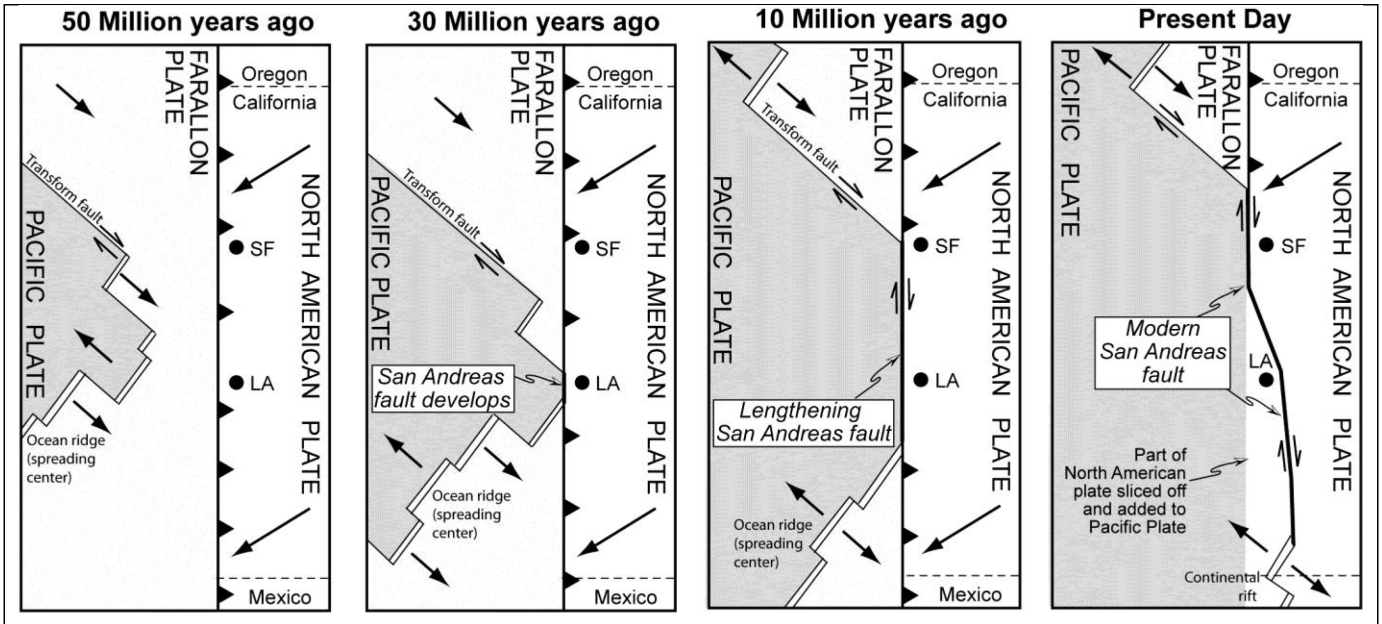


For much of the past 500 m.y. the west coast of North America was a subduction zone. The lower portion of the subducting plate descended into the mantle and was assimilated. The upper portion, however, was scraped off in slivers and accreted. From 375 Ma to 225 Ma, the Sonomia terranes accreted to the North American continent, plugging up the subduction zone and moving it (and the continental margin) about 100 miles westward.

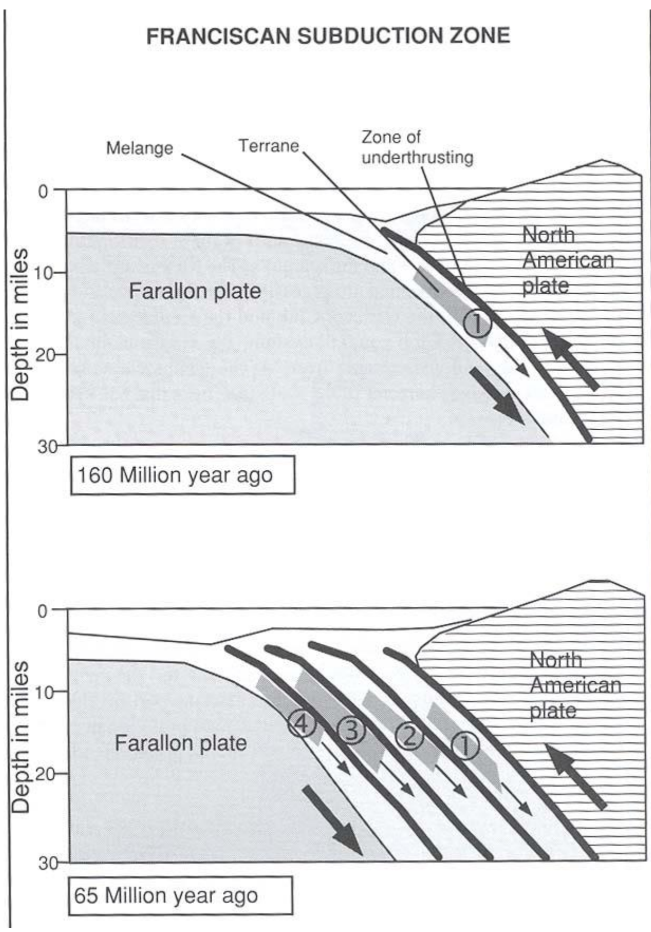
About 225 Ma, the western edge of the North American plate was near the present-day Sierra Nevada foothills. For 50 m.y., the Smartville terranes accreted, again plugging up the subduction zone and moving it farther west.

Around 175 Ma, the Franciscan subduction zone formed, and for 140 m.y., the Franciscan Assemblage terranes accreted along the North American continental margin.

During the Franciscan accretion, tens of thousands of feet of rocks accumulated in the subduction zone and accreted to the continent in successive near-vertical slivers that extended up to 30 miles below the surface. Continental sediments moved into the offshore trench and were themselves caught up in the accretion process. By 65 Ma, much of the Farallon plate was entirely subducted: the North American plate was now overrunning the spreading center that separated it from the Pacific Plate. The plate boundary began changing to a transform plate boundary between the Pacific and the North American plates.



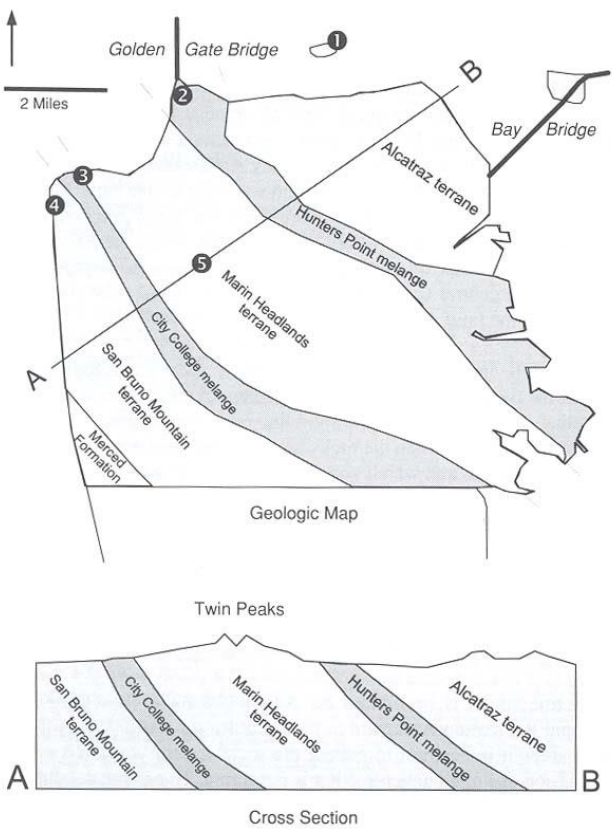
From 140 m.y. the Farallon plate moved eastweard into the Franciscan subduction zone during which time the Franciscan Assemblage formed. The East Pacific Rise spreading center also moved eastward and at ~30 Ma the ocean ridge entered the subduction zone at the latitude of Los Angeles. Consequently the San Andreas fault began to form due to oblique divergence between the North American plate and the northward-migrating Pacific plate.	*For the next 20 m.y. (30-10 Ma), continued subduction of the East Pacific Rise caused the San Andreas fault to grow in length toward the north and the south, and by ~10 Ma the San Andreas fault had reached the latitude of San Francisco. Over the next 10 m.y. the San Andreas continued to lengthen and stepped eastward near Los Angeles slicing of a part of the North American plate. This former piece of the North American plate is now a part of the Pacific plate and moves northward at a rate of 2 in/yr.*



The Franciscan rocks in San Francisco consist of five distinctly different terranes that accreted one after the other. As the Farallon plate subducted under North America, it would periodically either get scraped off or stuck and broken off. That portion of the subducting plate would then become part of the North American plate (accretion). The subduction zone would move westward and begin subducting under the newly accreted margin of North America. In such a manner, each terrane was progressively shoved under the preceding one, and the North American margin moved westward.

The boundaries between terranes are called shear zones; they display textures and mineralogy associated with the results of severe shearing as one terrane was thrust against another.

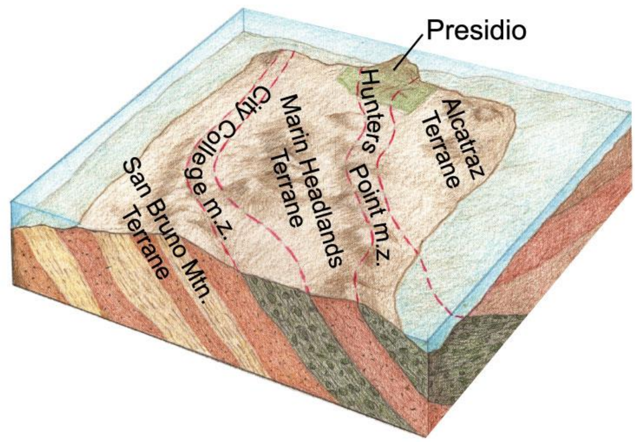
The Franciscan subduction zone stopped 65 Ma. 25 Ma, the San Andreas fault system developed to accommodate the transform motion connecting the seafloor spreading centers off Northern California and in the Gulf of California. Since 65 Ma, the region has been slowly uplifting and eroding, exposing the Franciscan rocks at the surface. Now we see the top edges of these terranes (slivers that still extend to great depths below us). These edges appear as parallel stripes that run diagonally



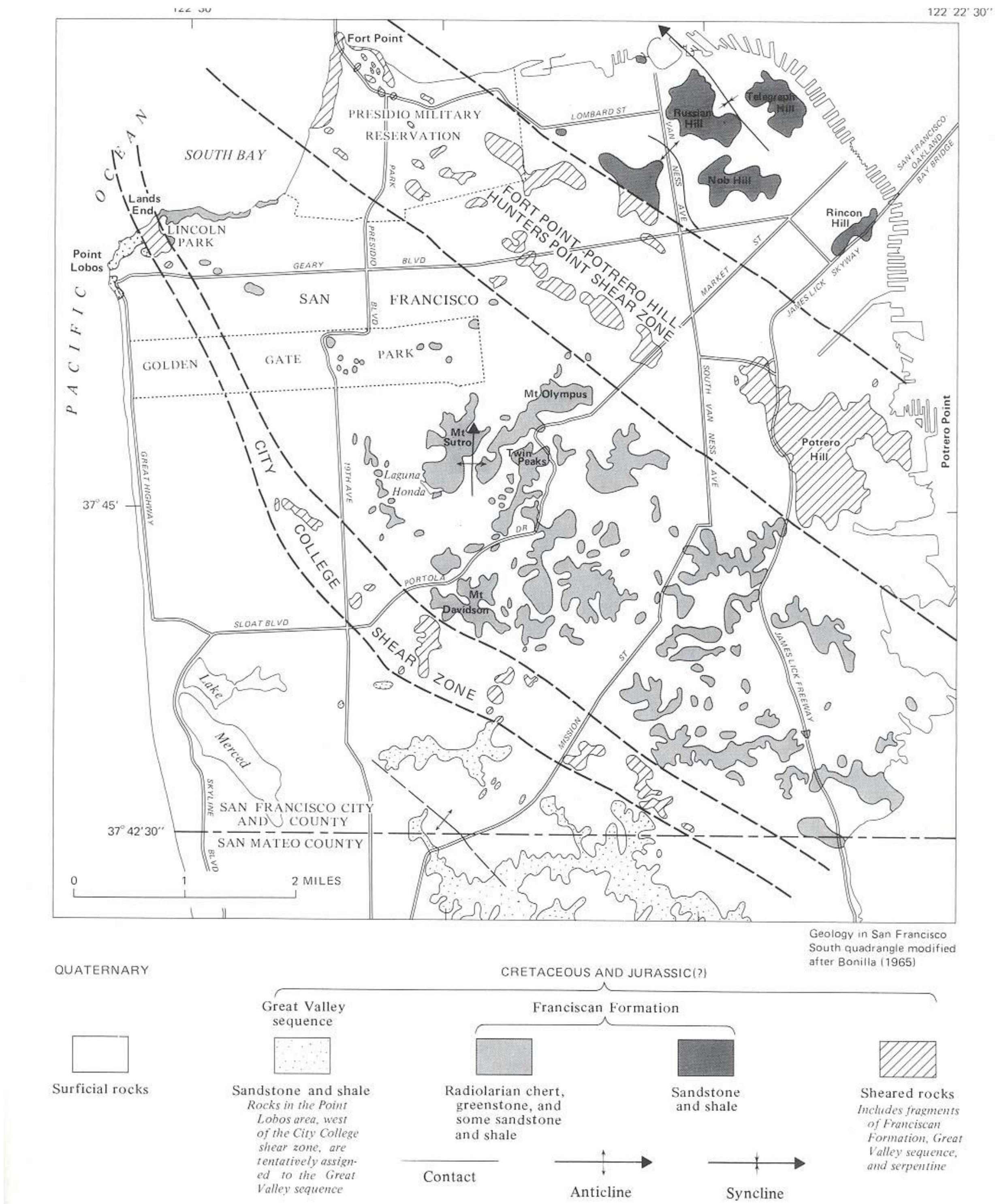
northwest across the city.

Because of their accretion order, the slivers farther inland are the oldest; the ones closer to the plate boundary are the youngest. (Imagine a stack of pancakes tilted parallel to the angle of the subducting oceanic plate. The oldest pancake – first one accreted – is on top!)

Figures from 1998, T. Konigsmark, *Geologic Trips: San Francisco and the Bay Area*.



(Figure courtesy of Golden Gate National Recreation Area.)



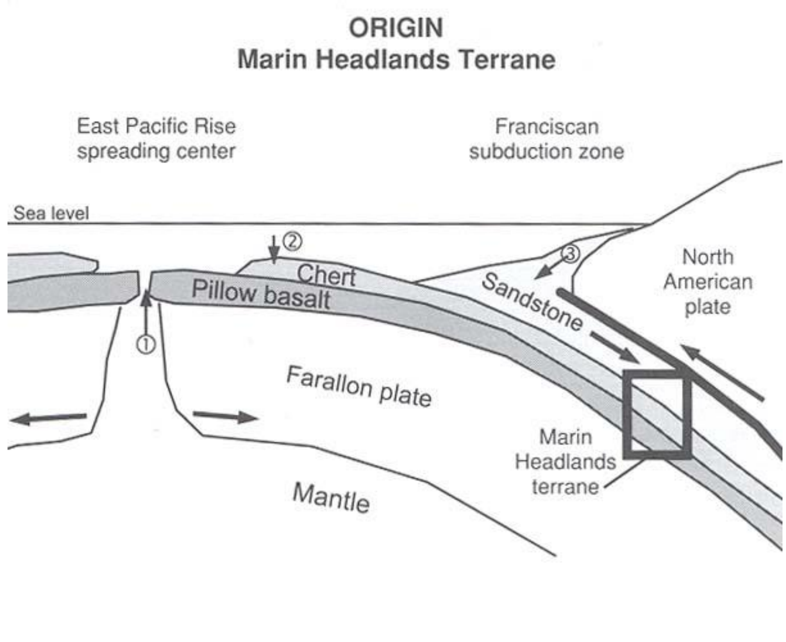
Note that most of San Francisco is covered by surface soils, landfill, and sand. Only the patterned areas above contain bedrock. To see into the Franciscan Assemblage, we must look for these outcrops of underlying rock; we must find areas where the surface sediment deposits have been eroded (usually the tops of hills).

Five Franciscan Assemblage terranes that you find around San Francisco (listed in order from oldest to youngest):

Terrane	Description	History
Alcatraz	Thick-bedded sandstone	Grains were derived from many different rock types eroded along the North American continental margin and carried by rivers to the ocean and into the trench by turbidity currents (avalanches of sediment) down submarine canyons (deeply carved features that extend off the continental shelf). Transportation, deposition rapid.
Hunters Point	Melange: large blocks of serpentinite in soft clay and serpentine matrix.	Formed along the zone of thrusting between the rocks of the Marin Headlands terrane and the Alcatraz terrane, while those rocks were in the subduction zone. Serpentinite forms at a spreading center where mantle rocks are altered by hot seawater that reaches the deep rocks through cracks formed during spreading. (Serpentinite forms the lower part of the earth's oceanic crust worldwide.) Small isolated blocks represent pieces of oceanic crust that were broken up and squeezed upward through the overlying host rock like watermelon seeds.
Marin Headlands	Pillow basalt, red chert, shale, and sandstone, typically in thin fault slices.	Record of the 100 m.y. migration of mid Mesozoic Pacific Ocean floor from its eruption, close to the equator, on a spreading ridge, to its accretion by subduction thousands of km to the northeast. Pillow basalt overlain by ribbon chert (hardened silica-shelled muds, formed when planktonic silica-shelled organisms die, and their shells slowly rain down to the ocean floor (1 cm/1000 yr) and collect over time), overlain by turbidity-current-transported sandstone of continental origin, deposited just prior to accretion.
City College Melange	Melange: blocks of basalt, chert, serpentinite, schist, gabbro, and sandstone in soft clay and serpentine matrix.	Formed along the zone of thrusting between the rocks of the San Bruno Mountain terrane and the Marin Headlands terrane, while those rocks were in the subduction zone. The rocks are thoroughly ground up by thrusting. Blocks in the melange are pieces of hard rock that survived grinding.
San Bruno Mountain	Sandstone	Grains were derived from many different rock types eroded along the North American continental margin and carried by rivers to the ocean and into the trench by turbidity currents (avalanches of sediment) down submarine canyons (deeply carved features that extend off the continental shelf). Sand and seafloor mud in layeRs.

MARIN HEADLANDS TERRANE DISCUSSION

The Marin Headlands terrane is the upper portion of oceanic crust. It consists of pillow basalt, red ribbon chert interlayered with shale, and sandstone. These rocks were once part of the ocean floor of the Farallon plate. Around 100 Ma, they were crammed into the subduction zone and broken into numerous thin fault slices, so now they lay scattered around the Marin Headlands in pieces.



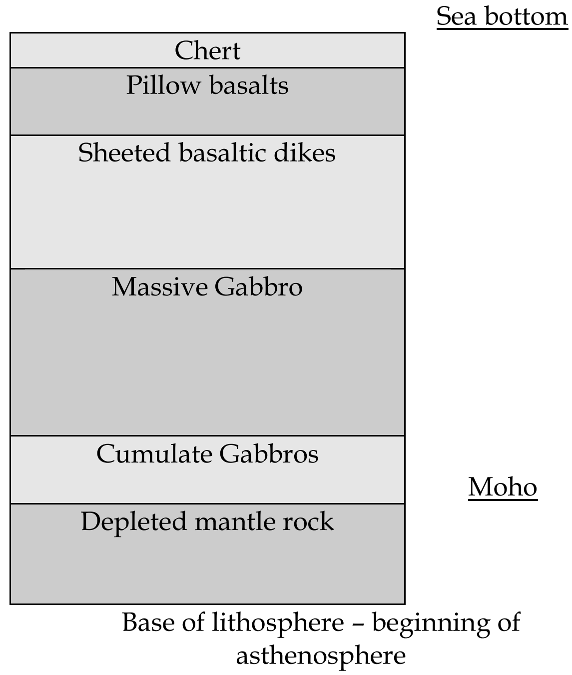
Ophiolites

Ophiolites are pieces of ocean crust that were trapped in convergent plate boundaries and accreted to continental crust. Ophiolites are rare and unique opportunities to study ocean crust without having to drill or dive. We are lucky to have some good samples along the western margin of North America. The Marin Headlands terrane is part of an*ophiolite* sequence, containing only the top three layers of ocean crust. (See following stratigraphy.)

Review of how ocean crust forms

1. Deep mantle rock melts due to drop in pressure under spreading centers. Melts remove certain elements preferentially from the mantle rock, leaving behind depleted mantle rock.
2. Melts migrate upwards and accumulate in magma chambers. Over time, the magmas cool. They form minerals that drop to the bottom of the magma chamber becoming cumulate gabbros.
3. As new magma enters the magma chamber, the pre-existing magma is pushed upward to erupt. It breaks through the surrounding rock, forming dikes (conduits for the magma to move upward).
4. The erupted material becomes pillow basalt. The dikes eventually crystallize, and new ones form.

OPHIOLITE STRATIGRAPHY



CHERTS

Cherts form from the lithification of silicic muds (oozes) that cover the basalts. Silicic muds form through the continual accumulation of microscopic glass shells of oceanic plankton (radiolarians). These shells rain down slowly through the open ocean when the plankton die. In addition, some of the silica in these muds is precipitated directly from saturated ocean water. They form only far from shore, where no land-derived sediments can cover them up. These muds accumulate slowly over time, and so get progressively thicker away from the spreading center (over older rocks).

The layered chert of the Marin Headlands contains interlayered beds of shale (which come from fine mineral dust from the atmosphere that fell into the ocean and accumulated in the silicic muds). The silicic and mud layers segregated themselves after burial. Folds in the beds come from slumping of still soft chert and later deformation in the subduction zone.

The Marin Headland chert comprises one of the largest historical sections represented in a single chert sequence in the world. The chert is full of radiolarian shells, which you can see with a hand lens and which record pelagic deposition well below 4500 meters over a period of 100 m.y. The shells are made entirely of silica. Radiolaria are single-celled organisms that evolve very quickly, geologically speaking. A particular species can show up in the fossil record and become extinct within a few million years. Since radiolarians spread quickly throughout the world's oceans, a particular species shows up in the fossil record at the same time worldwide, making radiolarians excellent index fossils. If you know the age of a rock with a particular radiolarian species, you know the age of any rock that contains that species anywhere in the world. Radiolarians are among the first organisms to show up in the fossil record. Radiolarians still live today, drifting in the ocean currents, new species appearing and some species becoming extinct. Their shells are still falling to the ocean floors, forming new ribbon cherts.

In the 1980s, geologist Bonnie Murchey (of the U.S. Geological Survey) solved the riddle of the Marin Headlands chert formations. She found a spot in the Headlands that had a complete thickness of chert (about 80 meters), and she meticulously removed the tiny radiolarians from all of the layers. She identified all the radiolarian species, and then compared each layer with rocks with known ages in other parts of the world. As a result of her work, we now know the ages of many of the Marin Headlands rocks.

Fred ribbon chert is thinly banded and layered with soft red shale. Red chert fractures into sharp tabular plates a few inches across. You can see much folding and layering. Shale fractures into thin layers, millimeters thick. These layers were deposited over 100 Ma on the deep ocean floor. We can see them now thanks to their accretion in the Franciscan subduction zone over 100 Ma. That means the lowest rocks in the section are about 200 Ma!

Pillow basalt

Pillow basalt forms when basaltic magmas erupt under water, like in rift valleys in seafloor spreading centers. The water surrounds the lava, giving it a bulbous shape and quickly cooling the outside layer to glass. (Liquids that are quickly quenched turn into glass; there are no crystals, no minerals.) Molten lava inside the pillow breaks a small hole in the newly formed bulb and pushes out another bulb. Through this process, the lava creates an ever-growing cauliflower-like pile of pillows. (The crystal size of pillow basalts tends to increase inward, because the centers cooled slowest.) Pillow basalts are usually immediately weathered and altered on the ridge where they formed (altered by percolating hydrothermal solutions, like you see today at deep-sea vents). Such low-grade metamorphosis changes the basalt minerals to others, mostly chlorite, which gives the rocks a green color, and a metamorphic name of **greenstone**.

At Point Bonita Lighthouse, you can see **pillow basalt** in many different states of weathering and metamorphosis. Colors range from dark green on fresh surfaces to red, brown, or yellow where weathered. The first samples we will see, however, are some of the best-preserved formations found anywhere. These pillow basalts originally formed underwater at a seafloor spreading center. You can see them now on land thanks to their accretion in the Franciscan subduction zone. Observe the pillow basalt from the east side of the bridge and close-up from the west side. Notice the gouged-out edges – the waves can more easily weather the edges of a pillow basalt than the centers. This differential weathering results from the brittleness and fragility of the glassy rinds versus the hard, resistant crystalline centers. In the walk back to the car, watch as the pillows get progressively more and more weathered. We will stop at one sample, so you can observe a pillow up close.

Turbidites

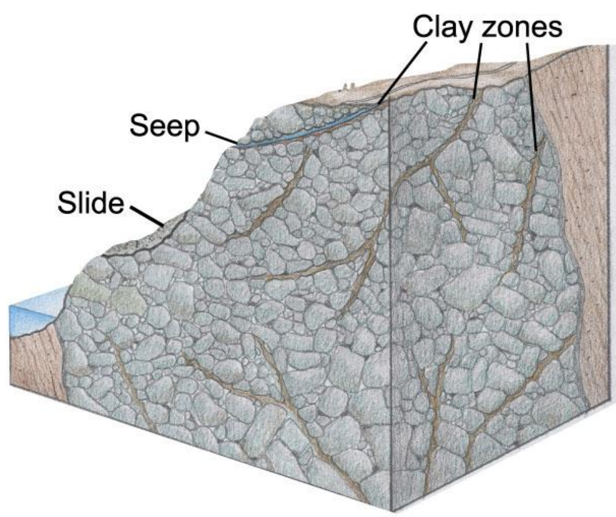
Turbidites are sandstones that formed from deposits of turbidity currents. Turbidity currents are under-water avalanches of sediment that shoot down submarine canyons. The currents are heavy in sediment and when they reach the bottom of the canyons, they drop their load quickly (heavy material first, with the lighter material slowly settling out of the water atop the heavier material). We call this sorting **graded bedding**, and all turbidites display it.

The turbidite sandstones of the Marin Headlands are hard to find, because they so easily weather (though fossil Ammonites have been found in the unit). Those sandstones that are visible are difficult to identify, because of the extreme weathering. The north and south cliffs on Rodeo Beach provide sample outcrops. Go to north edge of beach and look at the sandstone cliff face.

Melanges

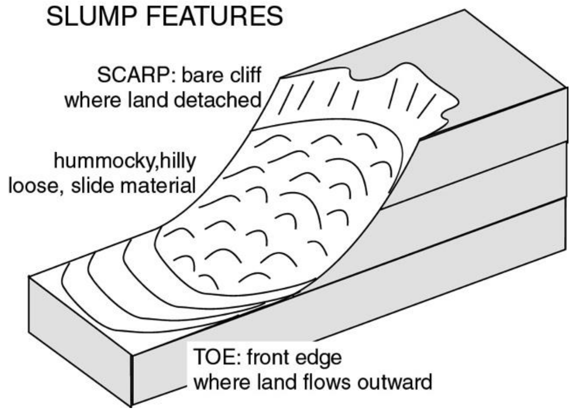
Melanges are common in the Northern California coast ranges: recognized by large random boulders sitting on rolling hillsides. Boulders are hard and stand out from the soft greenish-gray or bluish-gray clay matrix, which is seldom seen. The clay matrix does not have layering. Melanges form because intense shearing in the subduction zone reduces the hard rocks to a sheared paste. Landslides are common where melanges occur on steep slopes.

The Hunters Point Melange is known for its serpentinite. (rock composed entirely of the mineral serpentine). Soils formed from serpentine are characterized by anomalous plant life, due to the composition of serpentine: Fe and Mg silicate. There is almost no Al, 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.



SERPENTINITE:
Figure courtesy of Golden Gate National Recreation Area.

Most common plants avoid serpentinite, but a few hard 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).



On fresh exposures, the rock is pale green, sometimes with dark specks about the size of small peas. These dark specks are remnants of pyroxene crystals that have been altered to serpentine. In places, some large blocks of this serpentinite have broken off and are slowly sliding down hillsides, lubricated by the soft and slippery clay of the underlying mélange. Rainwater accumulates in fractures in the serpentinite and makes its way down to the contact with the clay. Putting water along this contact zone is like putting wax on the bottoms of skis. The fine clay matrix holds water near the surface and is quite slippery when wet. The clay flows downhill, taking roads, buildings, and whatever else has been built on the melange.

Many homeowners think that if they build their homes on solid rocks, they'll have little chance of a landslide. But the solid rocks in mélanges are really just boulders surrounded by a clay matrix. And if the boulder is serpentinite, it will hydrolyze quickly and get weak when in contact with surface water.

About 65 Ma, the tectonics of the California coastline between Northern California and Baja California began a radical change. Prior to that date, it was a convergent plate boundary, with an active subduction zone. But about 65 Ma, the subduction zone plugged up with sediment from the accretionary wedge and the subduction of an active spreading center. Over the next 35-40 m.y., a transform fault boundary arose. This new plate boundary developed into the San Andreas fault system (SAFS) about 25 Ma. Turbidities

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).

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.

Mussel Rock

The sea cliff 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 (see figure).

The flat cliff top seen clearly at places along the coastline north 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.

For the last 2 m.y., San Francisco Bay has alternately emptied and filled as sea level fell and rose with growing and waning ice ages. 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. Wind blew much of this sand inland to form sand dunes that covered most of northern San Francisco. 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.

10-15,000 years ago, sea level was 200 ft lower than today; there was no water in the bay; and the shoreline was 20 miles west of Ocean Beach. As the glaciers melted, sea level rose, and the shoreline, beach sand, and dunes moved eastward. (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.) Note: some of the old beach sands and dunes were covered by the sea. These areas now exist as patches of sand several miles offshore (Potato Patch Shoal off the Golden Gate, for example).

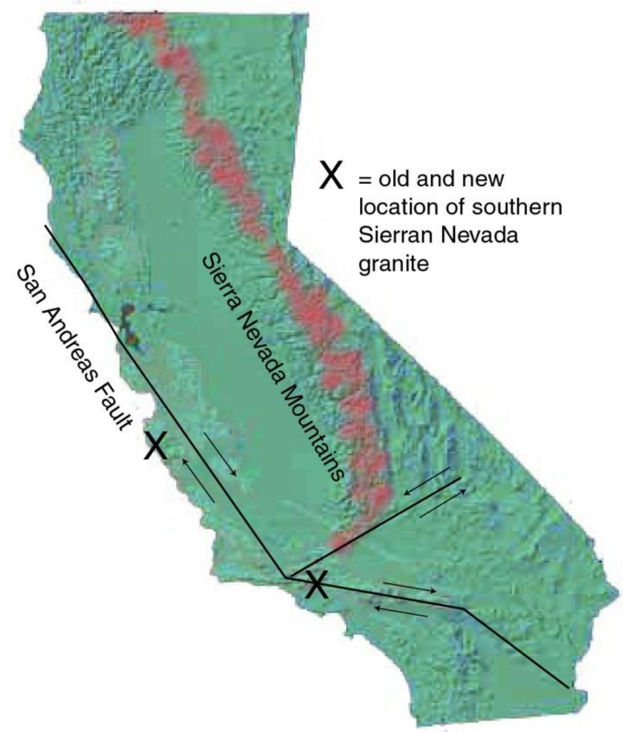
The source of sand hereis Sierra Nevada granite. The sand was deposited along the western shore of the San Francisco peninsula during the last ice age (when sea level was low, the Sacramento River dumped sand in the Pacific – 10 to 15 Ka). Now the sand is pushed ashore by wave action.

Sand is moved along beaches by longshore transport, a process whereby incoming refracted 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 American this push is usually to the south (since most storms happen to the north, generating waves that move to the south).

Sand originates from a few different sources: local biological debris (like coral reefs), local rocks eroding (headlands and cliffs), or eroded material brought from the backcountry via rivers and distributed southwards by longshore transport (for North American beaches). Sand is ultimately removed from beaches and the longshore transport system through two primary methods: wind blows it onshore where it is buried and turned into sandstone or an offshore submarine canyon pulls the beach sand offshore, ultimately leaving it at the base of the canyon in a fan on the continental rise.

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.

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