

San Francisco Geology Field Class

BACKGROUND/REVIEW - FALL 2014

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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

San Francisco 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 <i>quartz</i> (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.

Rock name	Description	Possible formation environment
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.

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 <i>pillow basalt</i> variety forms when oceanic volcanism occurs under water, chilling the lava quickly as it erupts from cracks or vents on the seafloor.

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).
Greenstone	Very fine grained (too small to see crystals); light to yellow green; dull or rough texture (not smooth or rounded or waxy).	Basalt that is subducted and lightly metamorphosed.

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 Sonoma 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.

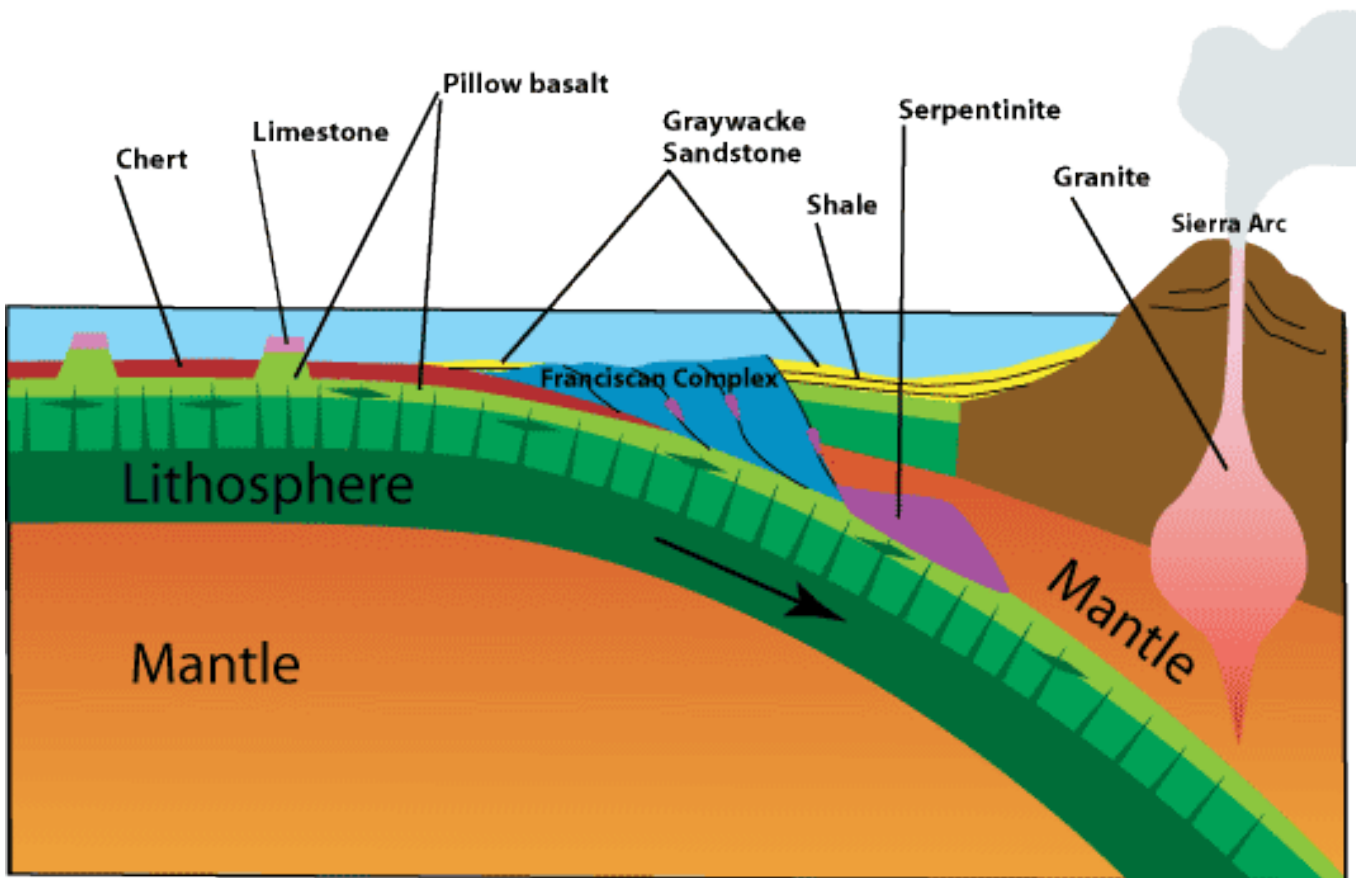
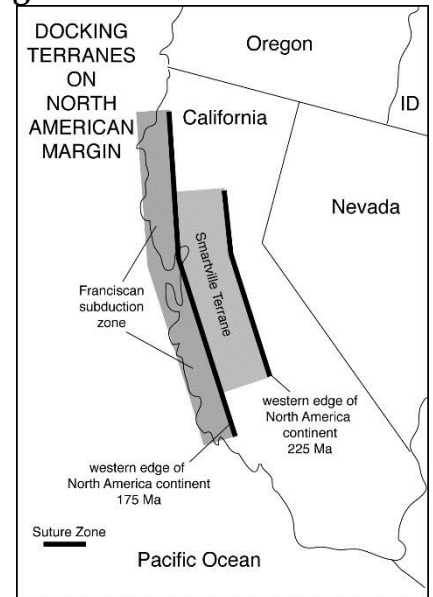
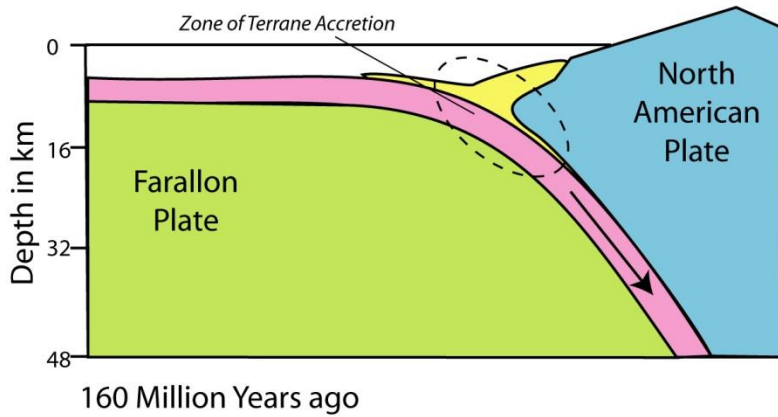
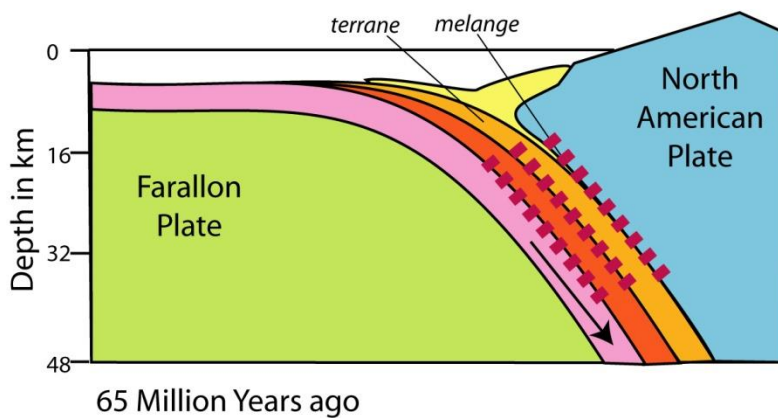


Image: National Park Service

Franciscan Subduction Zone



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.

Terrane accretion along the Pacific continental margin. Note that the mélanges are the shear zones formed between terranes.

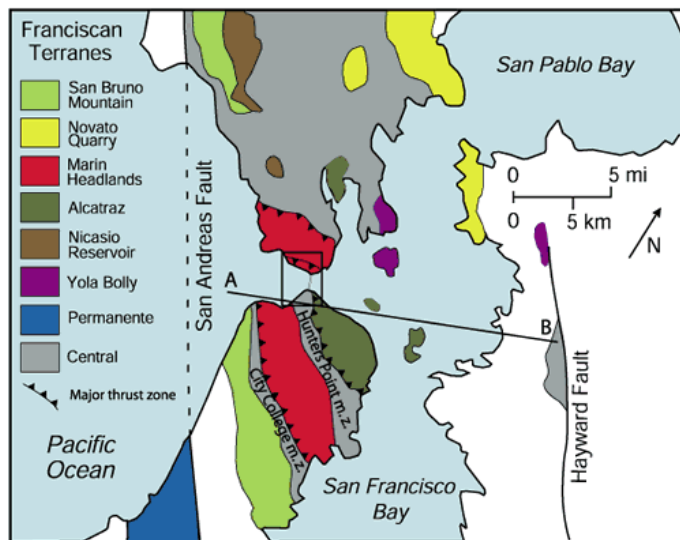
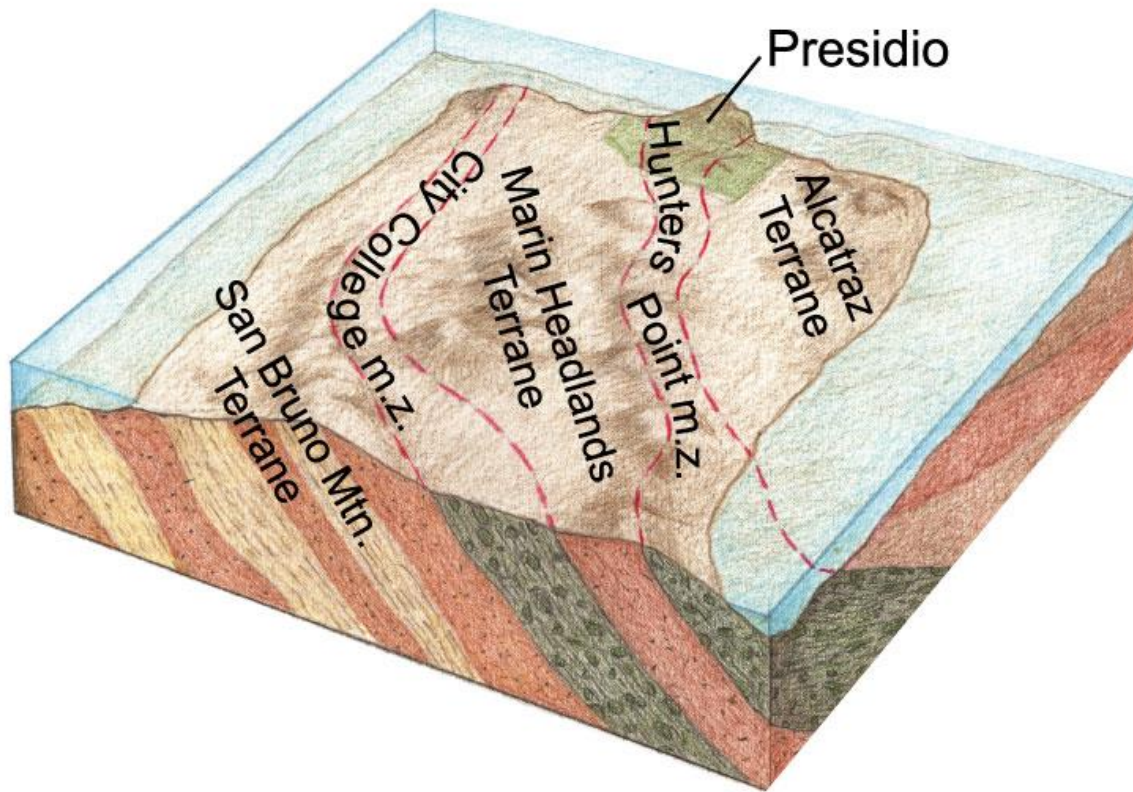


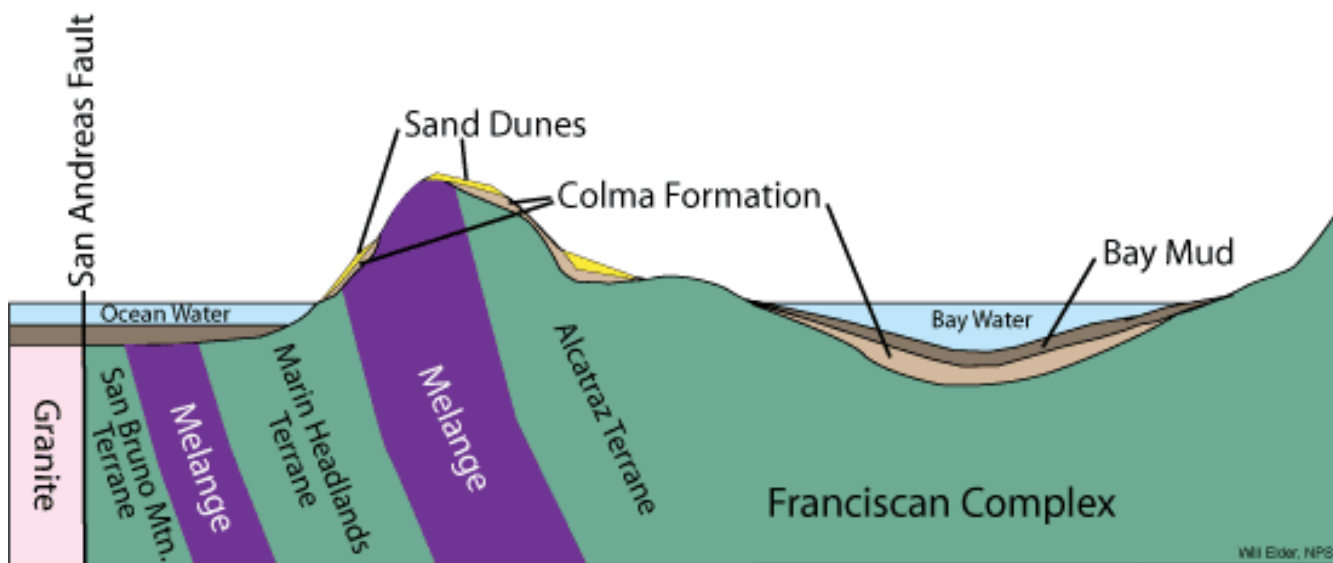
Image: Will Elder, NPS

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!)

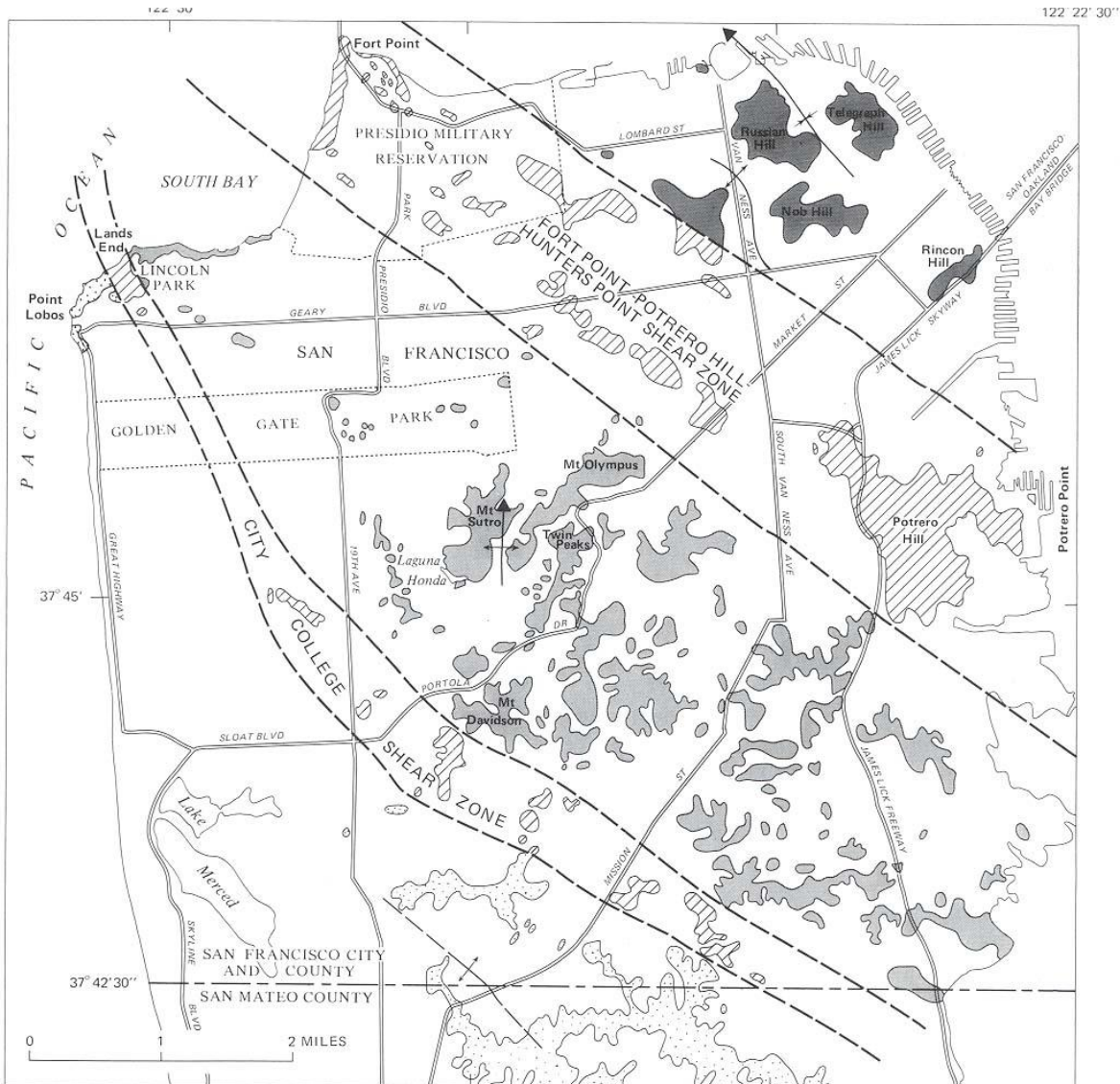


Images: Will Elde, National Park Service

West - East X-Section Northern San Francisco Peninsula to Oakland



Images: Will Elde, National Park Service



Geology in San Francisco South quadrangle modified after Bonilla (1965)

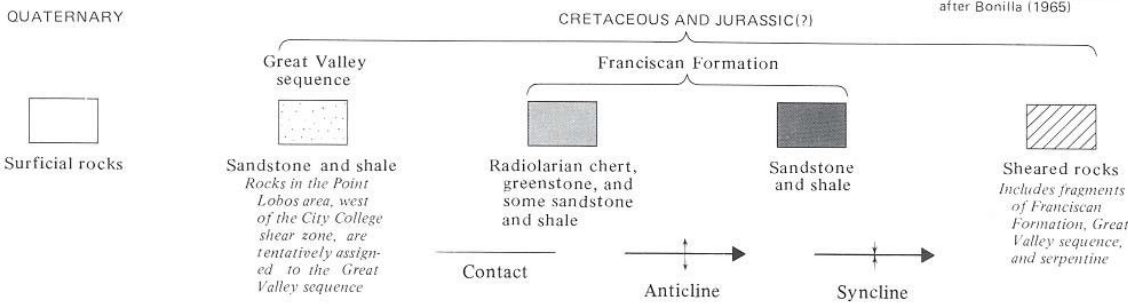


Image: San Francisco Geology: (Bonilla 1965). Note that most of San Francisco is covered by surface soils, landfill, and sand. Only the patterned areas above contain bedrock. To see into the Franciscan Assemblage, we must look for these outcrops of underlying rock; we must find areas where the surface 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 7élange 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 layer.

Melanges

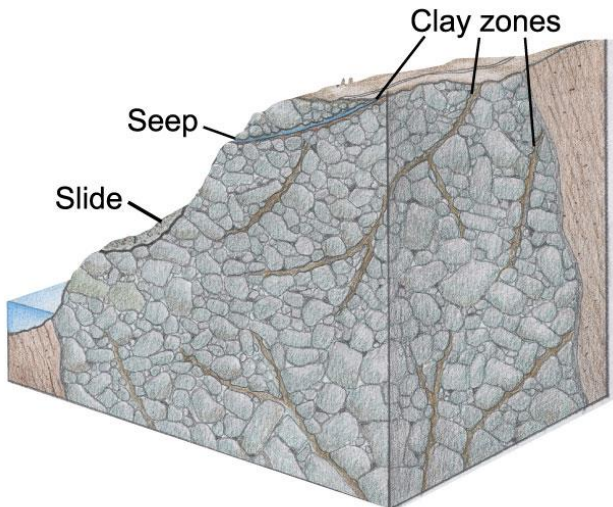
Melanges are common in the Northern California coast ranges: recognized by large random boulders sitting on rolling hillsides. Boulders are hard and stand out from the soft greenish-gray or bluish-gray clay matrix, which is seldom seen. The clay matrix does not have layering. Melanges form because intense 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 serpentinite are characterized by anomalous plant life, due to the composition of serpentinite, 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 serpentinite 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).

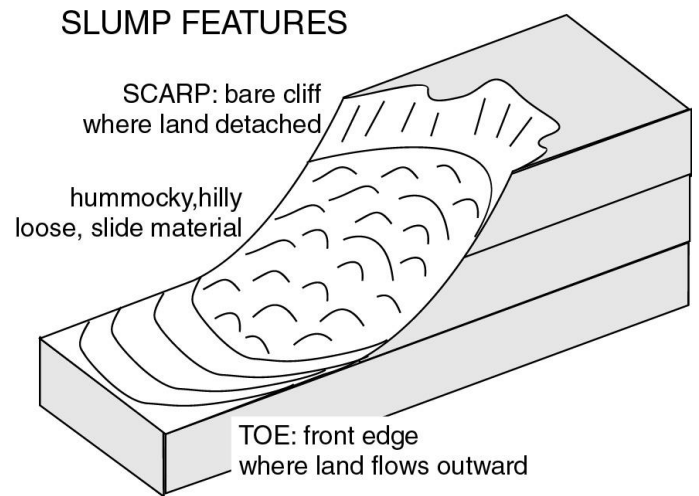
On fresh exposures, the rock is pale green, sometimes with dark specks about the size of small peas. Many homeowners think that if they build their homes on solid rocks, they'll have little chance of a landslide. But the solid rocks are really just boulders surrounded by a clay matrix. And if the boulder 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.



SERPENTINITE:

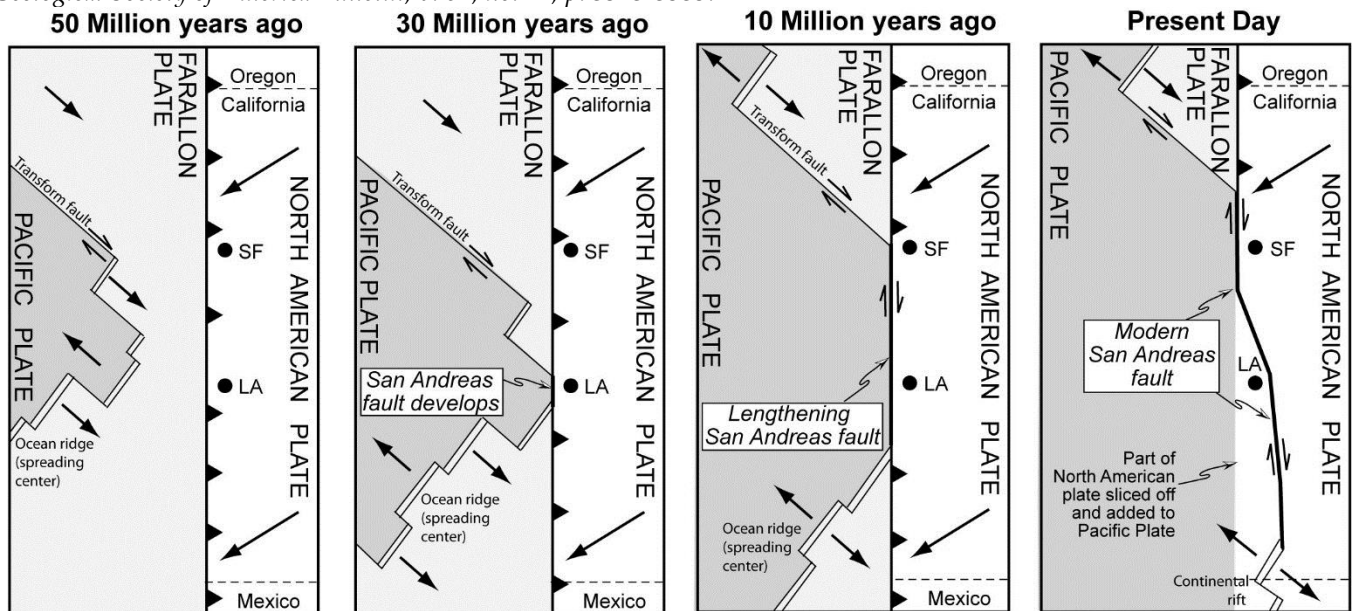
Image: Will Elder, National Park Service



San Andreas Fault System

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.

Image: Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, no. 12, p. 3513-3535.



From 140 m.y. the Farallon plate moved eastward 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.

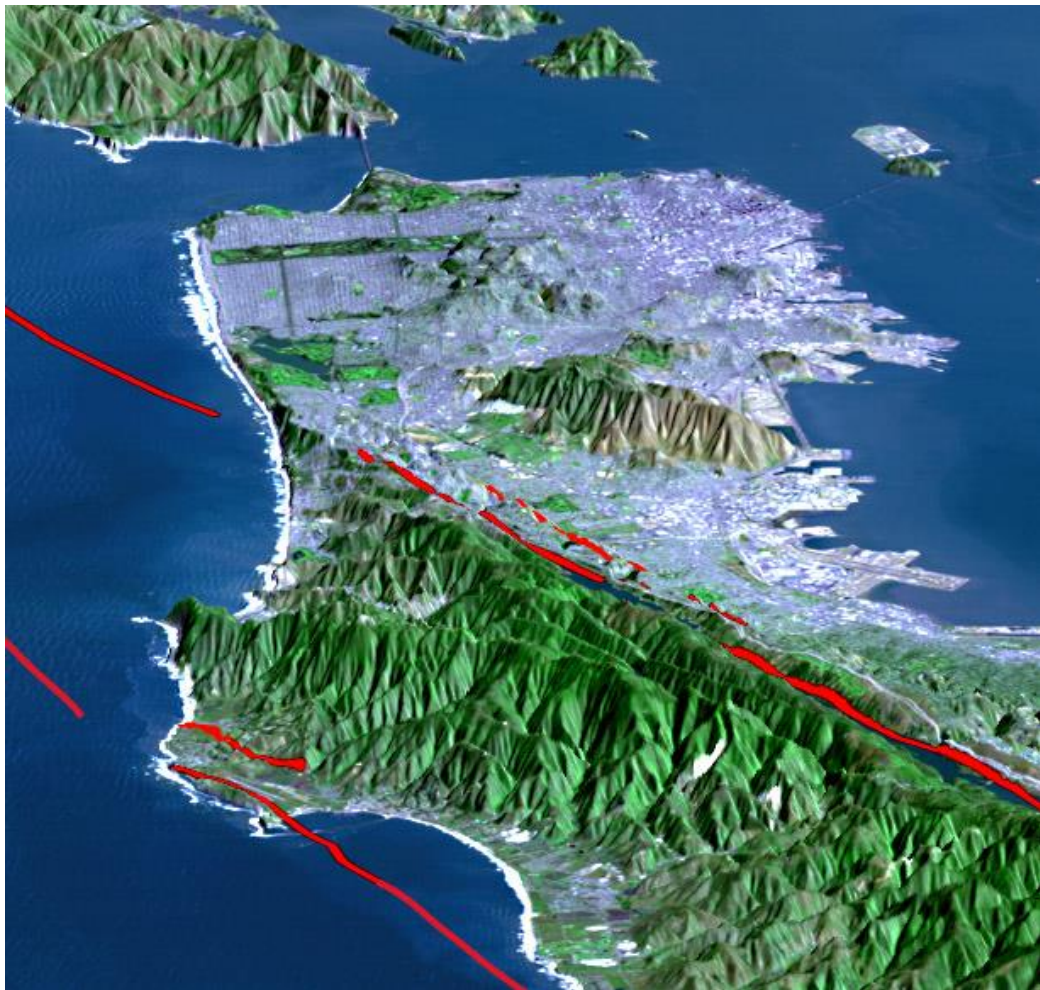
For the next 20 m.y. (30-10 Ma), continued subduction of the East Pacific Rise caused the San Andreas fault to grow in length toward the north and the south, and by ~10 Ma the San Andreas fault had reached the latitude of San Francisco. Over the next 10 m.y. the San Andreas continued to lengthen and stepped eastward near Los Angeles slicing off 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.

Coastal uplift and subsidence

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.



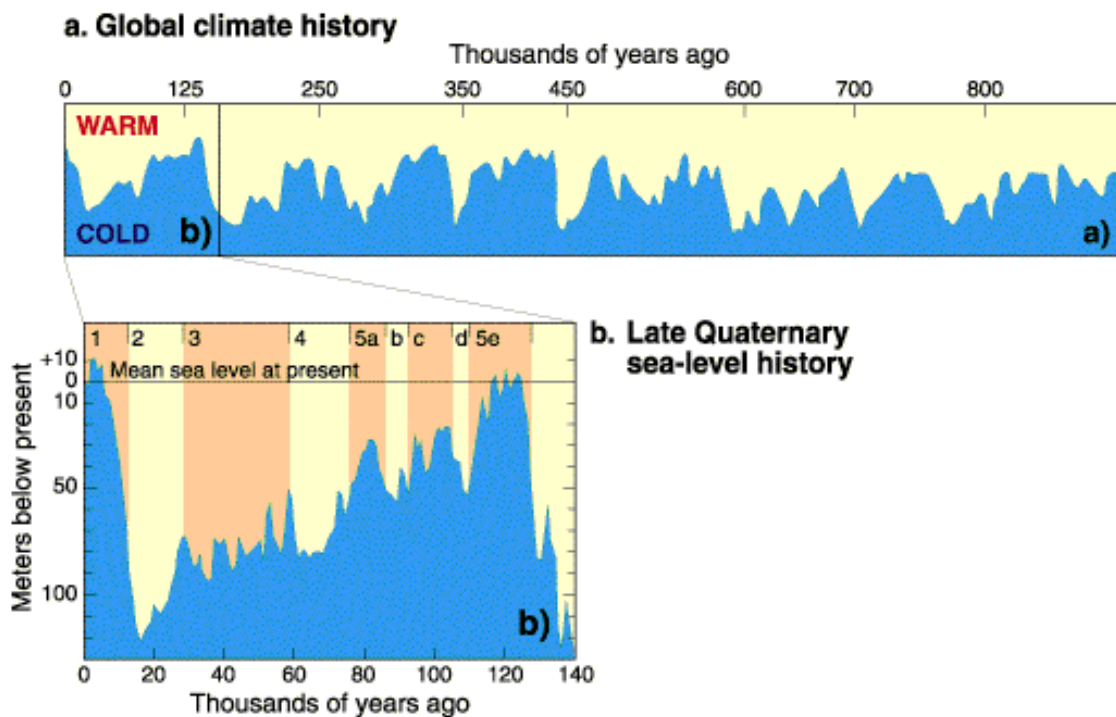
Notice that the region around San Francisco Bay is uplifting (mountainous), while the Bay itself is subsiding.

Ice ages and coastlines

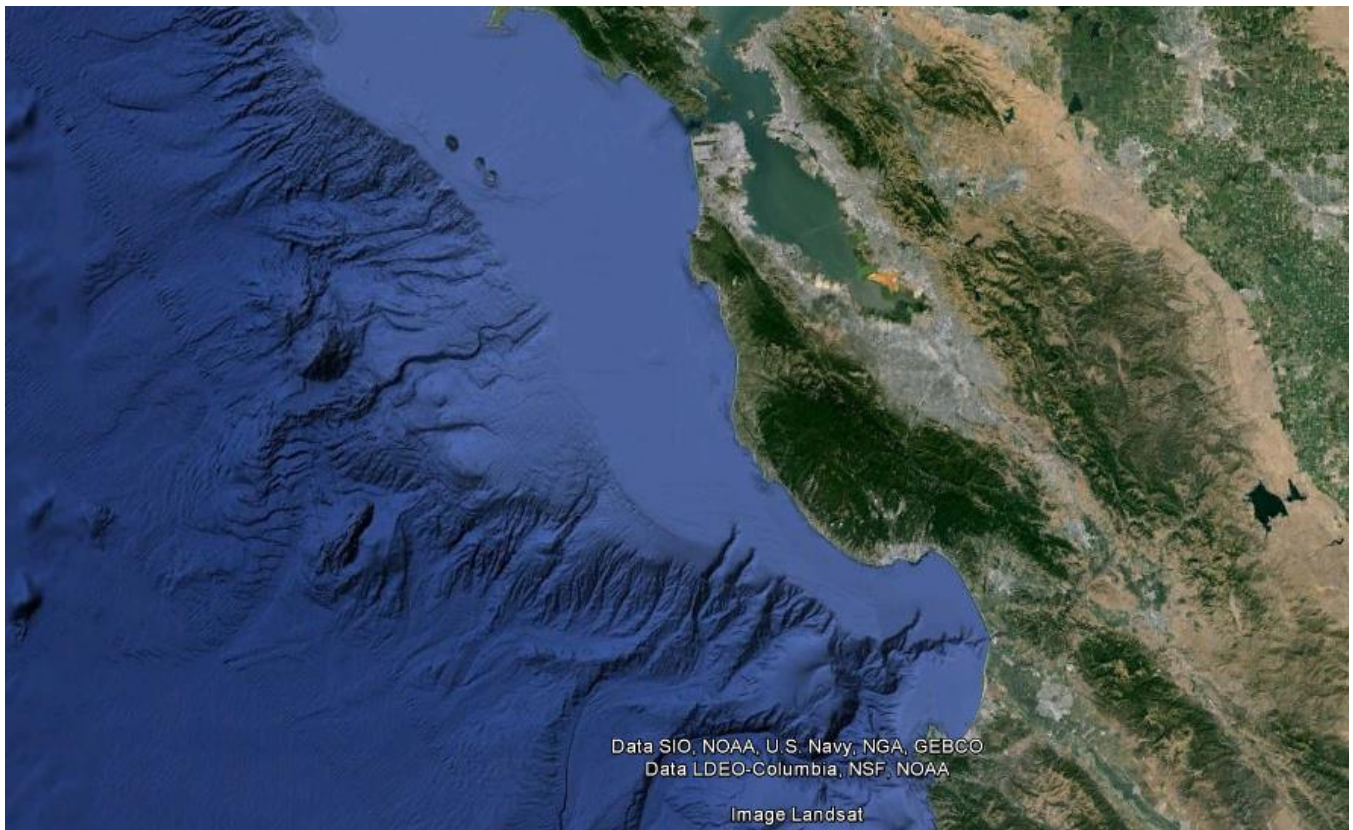
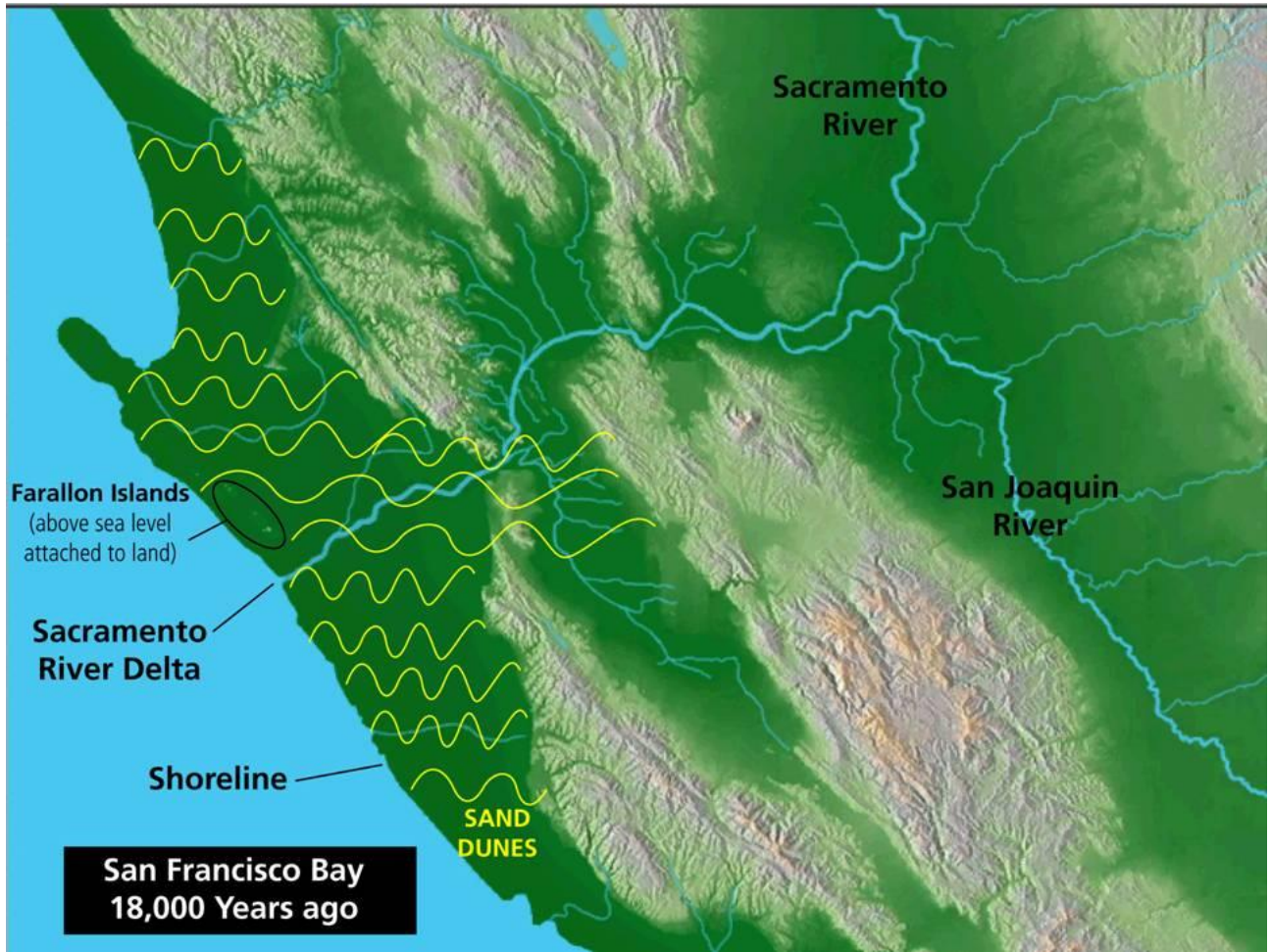
For the last 2 my, San Francisco Bay has alternately emptied and filled as sea level fell and rose with growing and waning ice ages. Such migrations of the coastline occur regularly, which is why it's so common to find fossils of marine animals far to the west (under today's ocean water) and far to the 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.

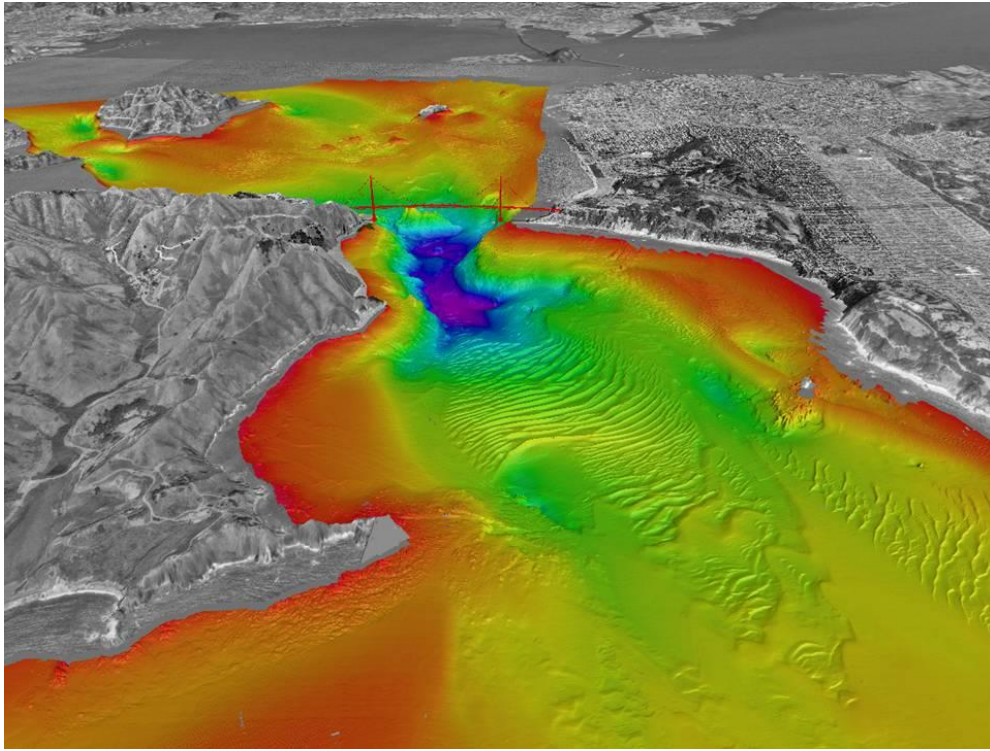
During the last ice age, 10-15,000 years ago, sea level was 300 to 400 ft lower than today; there was no water in the bay; and the shoreline was about 30 miles west of Ocean Beach. Wind blew much of this sand inland to form sand dunes that covered most of San Francisco and the continental shelf. Most 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.)



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



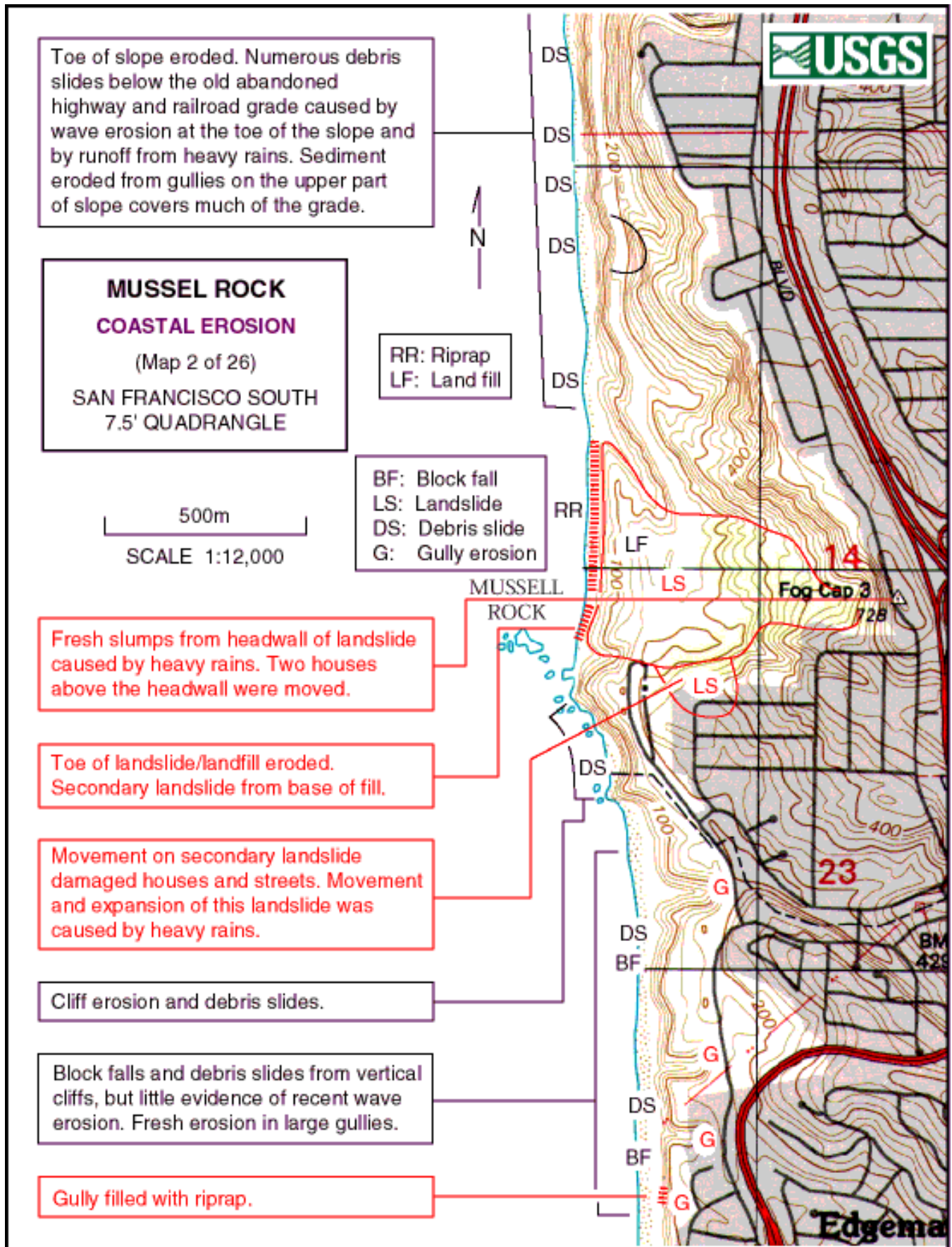
Sand excavated from below a home in the Mission District. These were the sand dunes that covered San Francisco before we built a city here.

Colma Formation

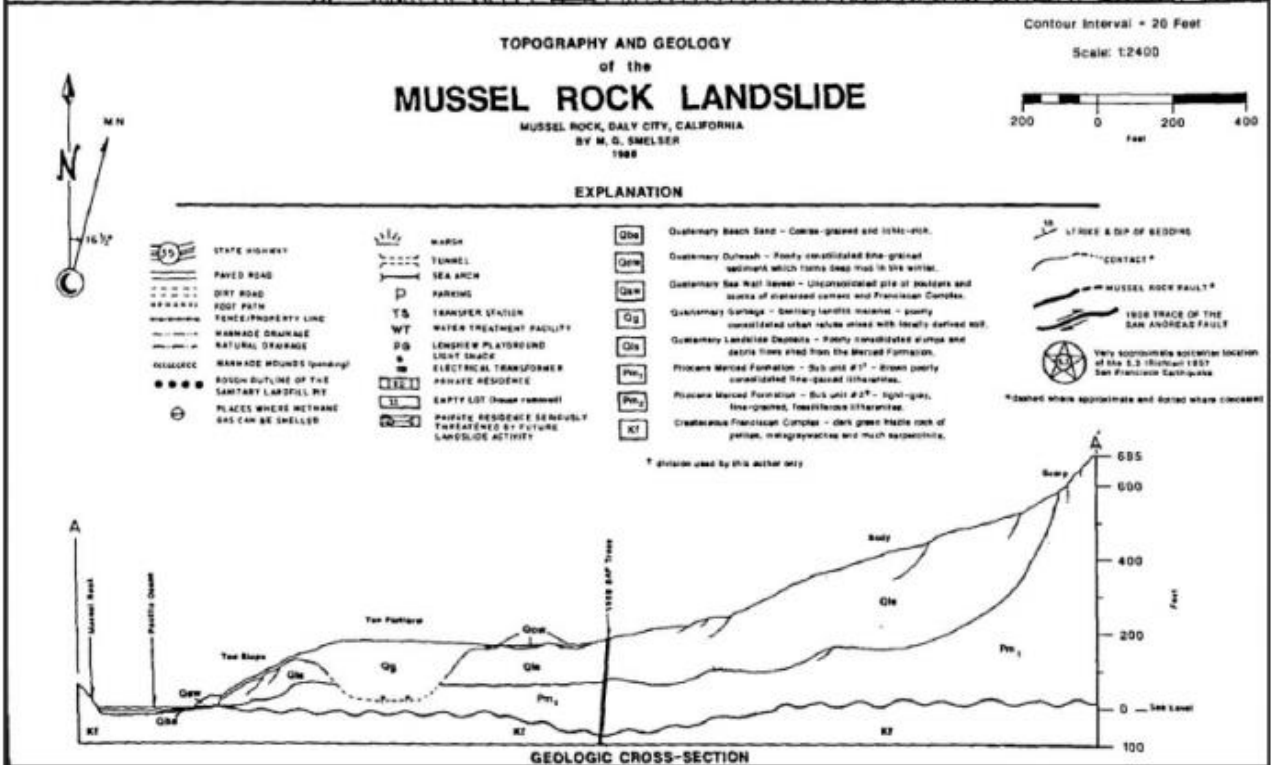
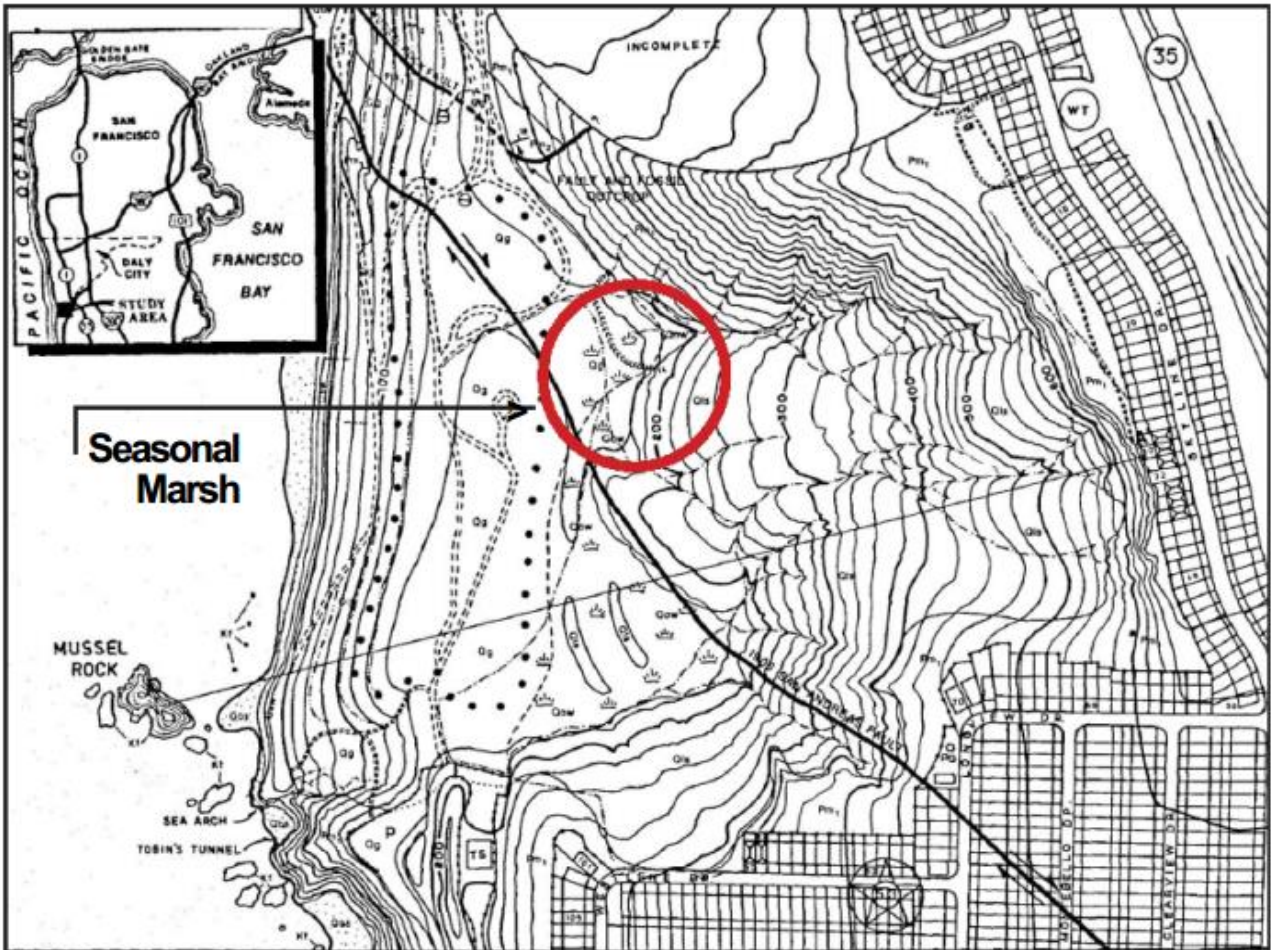
(From Geology of the Golden Gate Headlands, William P. Elder, National Park Service, Golden Gate National Recreation Area, Fort Mason, Building 201, San Francisco, CA 94123) “The Pleistocene Colma Formation locally forms a thin veneer over rocks of the Franciscan Complex on the Golden Gate headlands of the San Francisco Peninsula. The formation extends to Angel Island and to the southern peninsula, where it overlies the Pleistocene Merced Formation from Fort Funston, south. When the Colma Formation was deposited about 125 thousand years ago it was an interglacial period when sea level was slightly higher than today. The area of San Francisco was largely an island at that time, separated from the southern peninsula by the narrow “Colma Strait”. The predominantly poorly consolidated sands probably originated in a variety of environments from shallow bay to dune and valley slopes. The formation extends under the San Francisco Bay and is developed up to 500 feet above sea level. Holocene sand dunes mantle the Colma Formation and Franciscan Complex over large areas of San Francisco.

Mussel Rock

In the Mussel Rock region of Daly City, the San Andreas Fault leaves land and moves offshore to the north. The fault gouge produced is easily eroded by ocean waves, and cliff erosion is a constant problem (see following images of the current Mussel Rock Landslide). The sea cliff north towards Fort Funston consists of layers of sandstone, mudstones, and conglomerates with a variety of fossil marine organisms. These rocks were beaches, lagoons, sand dunes, and headlands 1.2 to 1.6 million-year-old where sediments were laid down almost a mile thick over Franciscan bedrock in a coastal basin alongside the San Andreas Fault. Some sediments were deposited under water (marine); others above (nonmarine) indicating sedimentation during fluctuating glacials and interglacials. . 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.

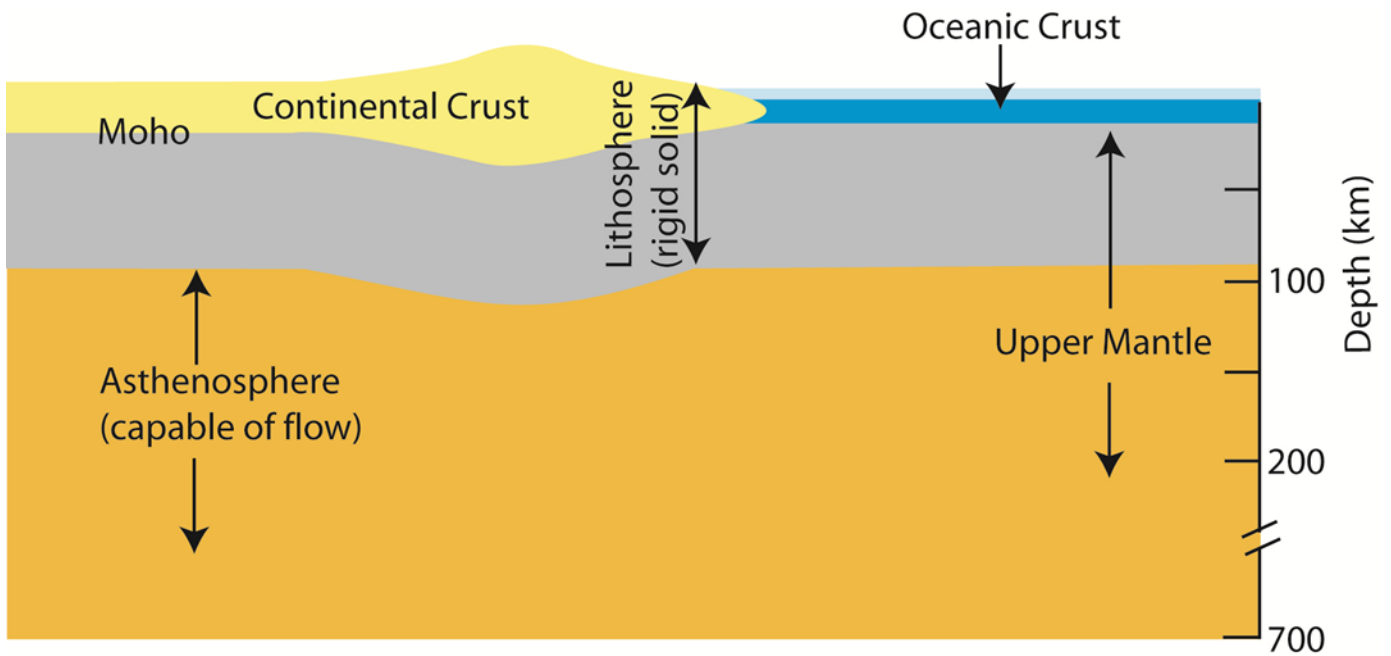


USGS, 1982-83 EL NIÑO COASTAL EROSION MAP

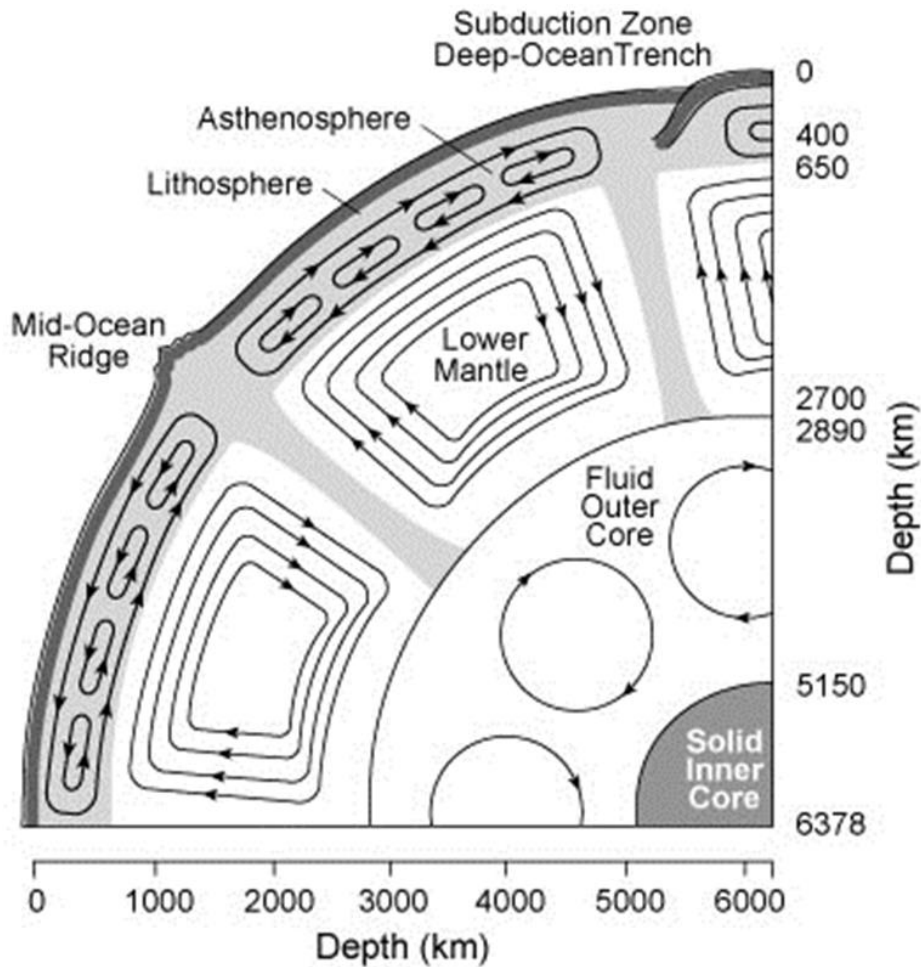


Topography and Geology of the Mussel Rock Landslide, M.G. Smelser, 1987.

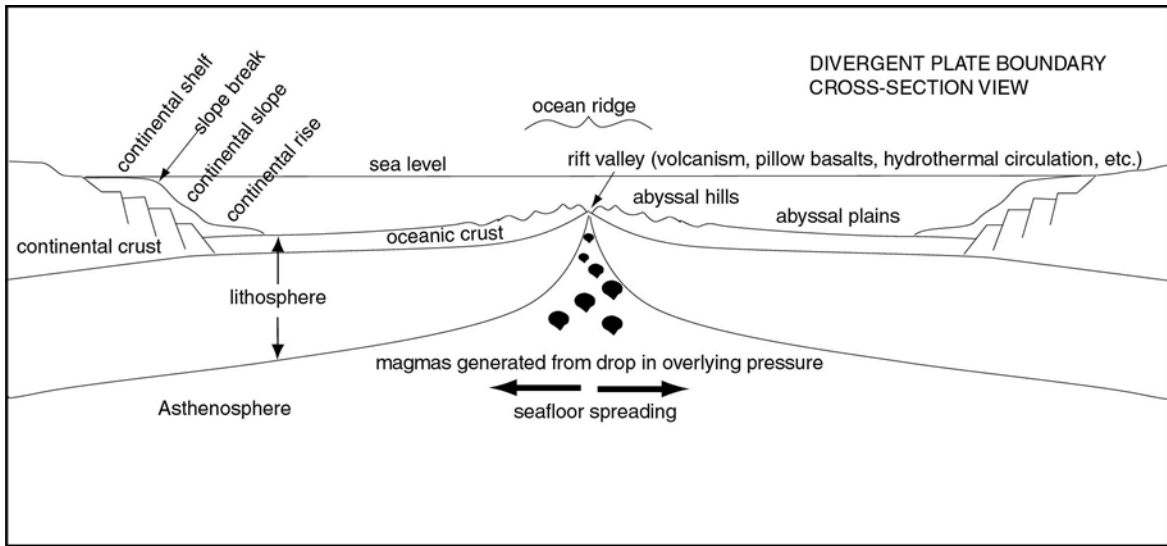
EXTRA IMAGES



Close-up view of the Earth layers involved in plate tectonics. The lithosphere contains ALL the crust plus the uppermost portion of the mantle; it is solid and breaks into pieces called plates, which then move around atop the underlying plastic mantle layer known as the asthenosphere. Convection of the hot plastic asthenosphere directs the motion of the plates above. The MOHO is the boundary between the crust and the mantle underneath. NOTE: The grey layer above has no name.

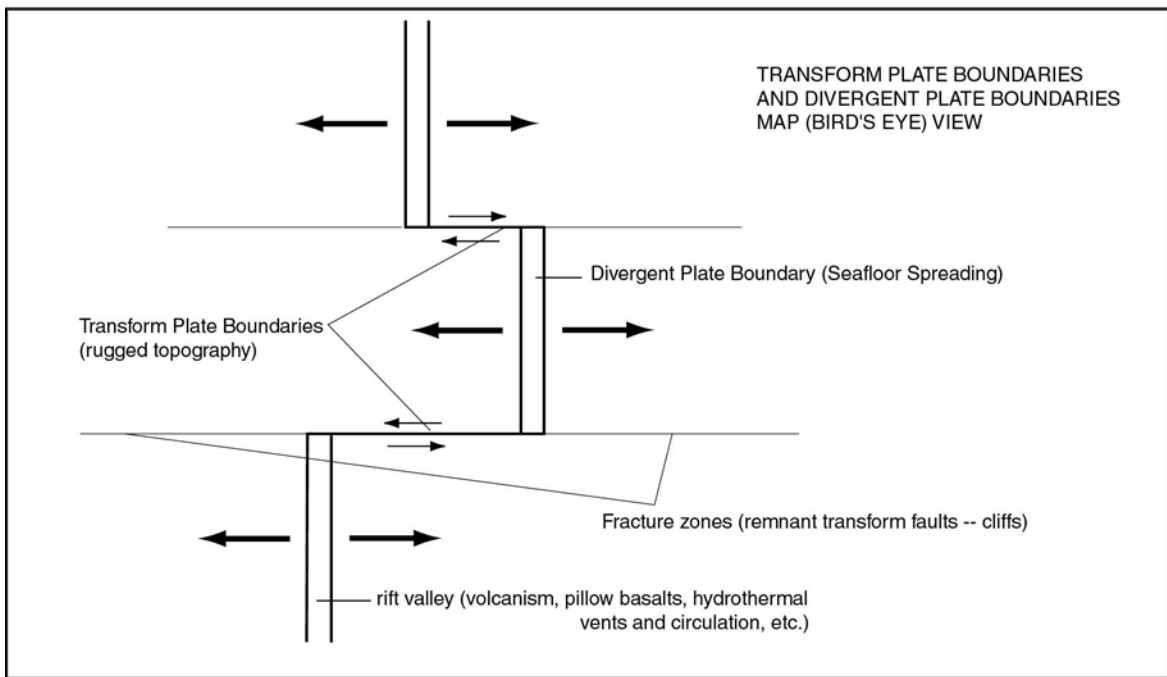


Convection of Earth's mantle, in asthenosphere and lower mantle. Also note the convection of the outer iron core. Image from Kenneth R. Lang's book *The Cambridge Guide to the Solar System*, Second Edition 2011.



DIVERGENT MOTION: Apart

FEATURES: Oceanic ridges. Seafloor spreading. Melted mantle rock due to reduced overlying pressure. Rift valleys with volcanism, pillow basalts, hydrothermal vents, and hydrothermal circulation. Serpentinites form at depth in mantle rocks that are undergoing hydrothermal alteration.



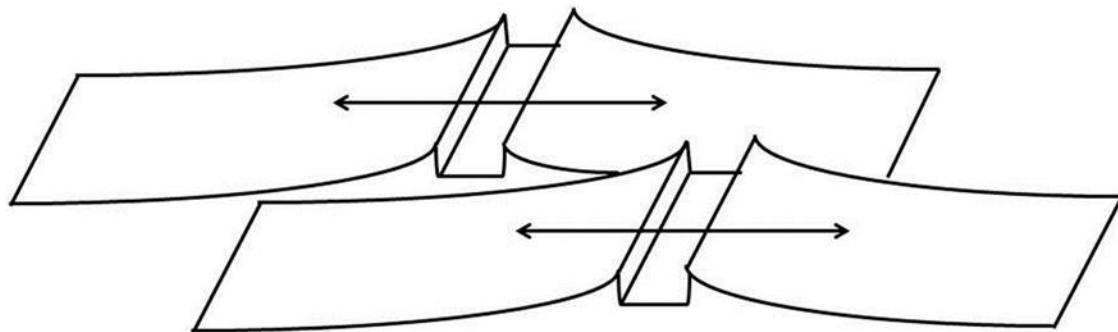
Transform faults (associated with transform plate boundaries) break up divergent boundaries into small sections offset from one another.

WORLD EXAMPLES: Mid-Atlantic Ridge, Iceland.

TRANSFORM MOTION: side by side

FEATURES: Fracture zones (old transform faults, no longer active, because lithosphere on both sides are part of the same plate). Rough topography (cliffs where ridges offset. Oceanic ridges and spreading centers on both sides.

WORLD EXAMPLES: California, Iceland



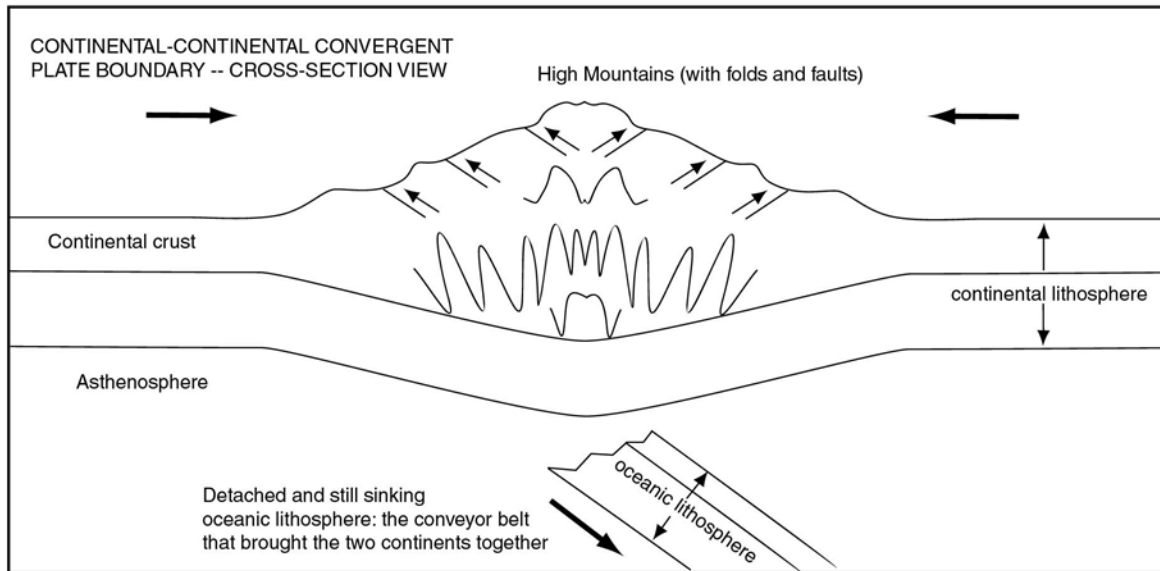
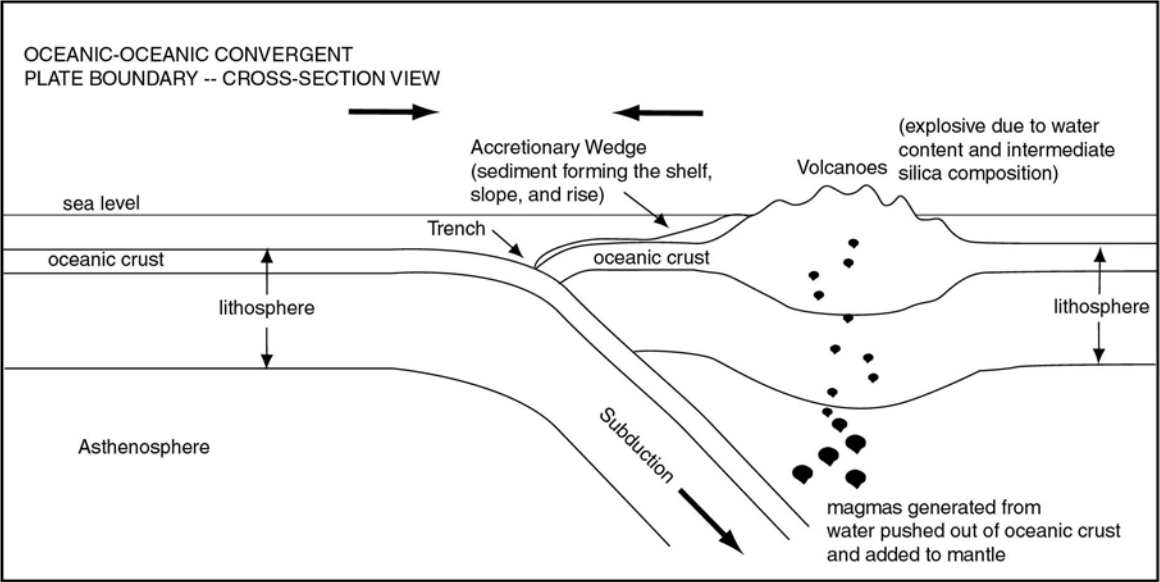
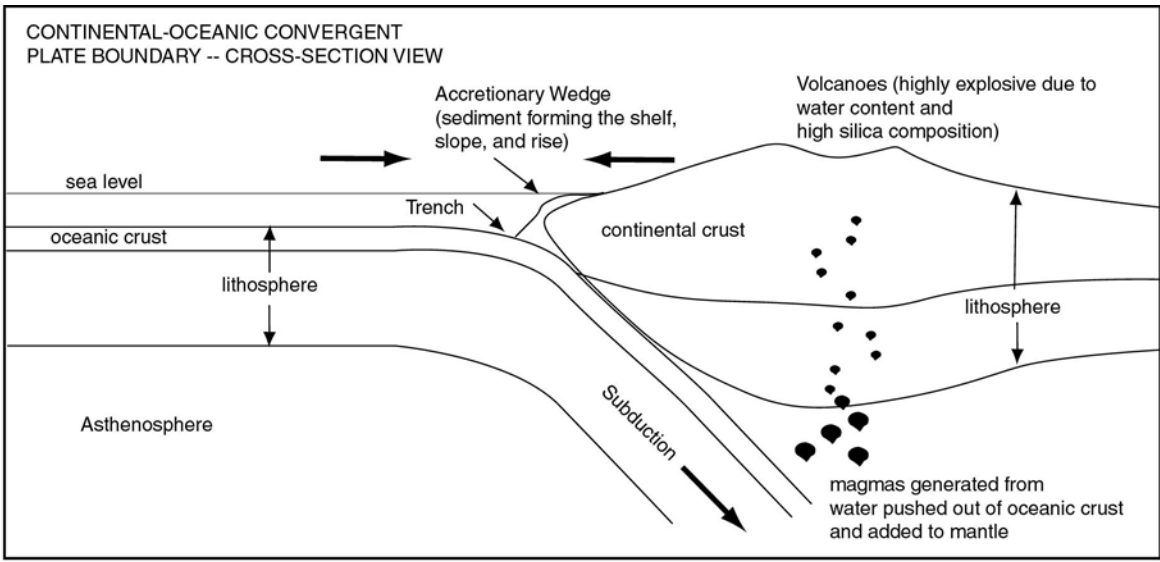
Oblique view of seafloor spreading centers and transform boundaries.

CONVERGENT MOTION:

Towards each other
FEATURES:
Continent-Ocean
 Subduction zones (ocean crust sinks back into mantle). Melted mantle rock due to addition of water, which drops the melting point of the underlying mantle. Volcanoes above subduction zone where magmas move upward. Trenches on ocean floor where ocean crust begins subducting. Volcanism is granitic mostly, because it moves through thicker continental crust.
WORLD EXAMPLES:
 W. coast S. America
 Pacific Northwest

Ocean-Ocean
 Subduction zones (ocean crust sinks back into mantle). Melted mantle rock due to addition of water, which drops the melting point of the underlying mantle. Volcanoes above subduction zone where magmas move upward. Trenches on ocean floor where ocean crust begins subducting. Volcanism is basaltic mostly, because it moves through thinner oceanic crust.
WORLD EXAMPLES:
 Japan, Philippines, Aleutian Islands

Continent-Continent
 Fold and thrust mountains, thickened lithosphere.
WORLD EXAMPLES:
 Himalayas (India)
 Alps (Europe)



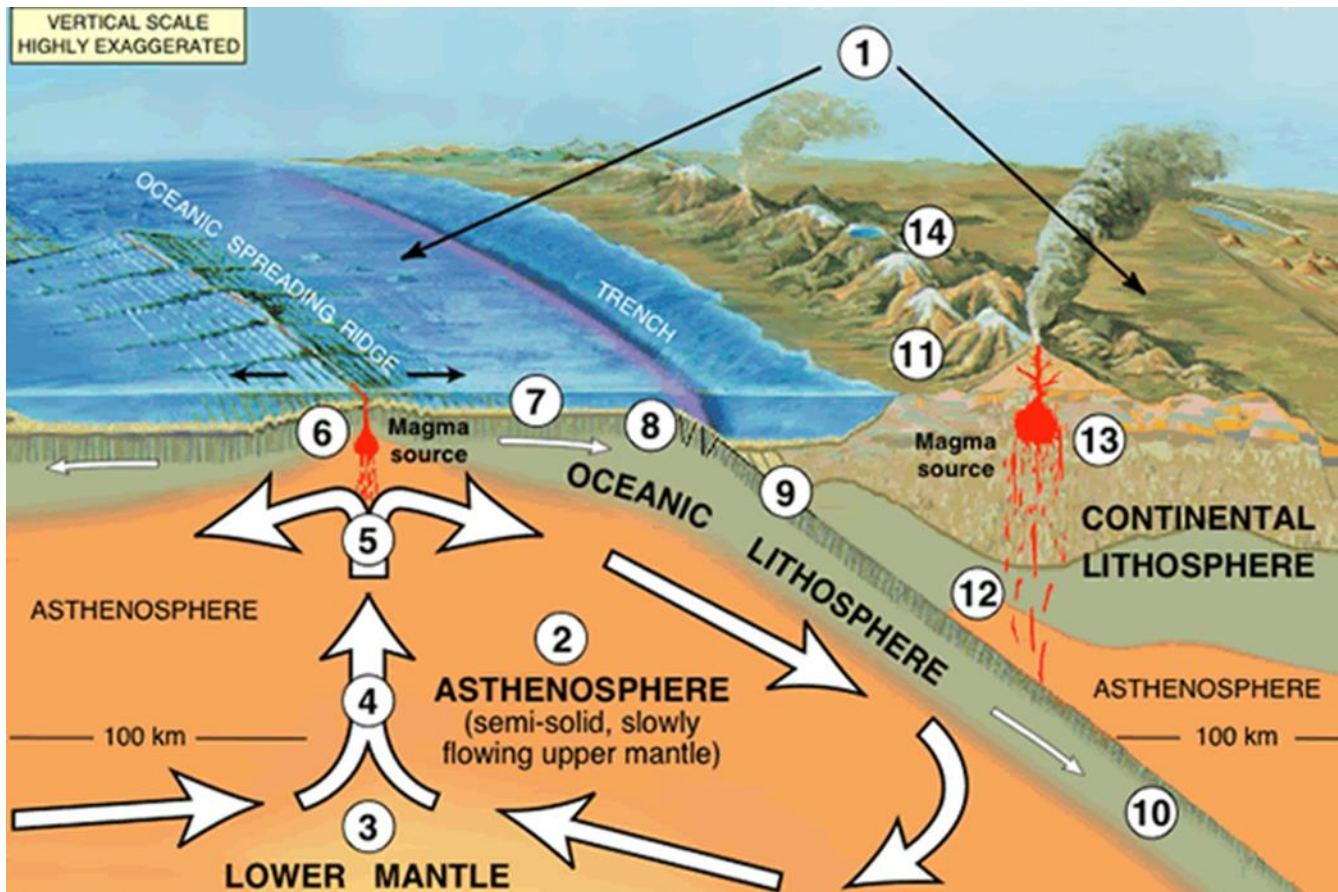
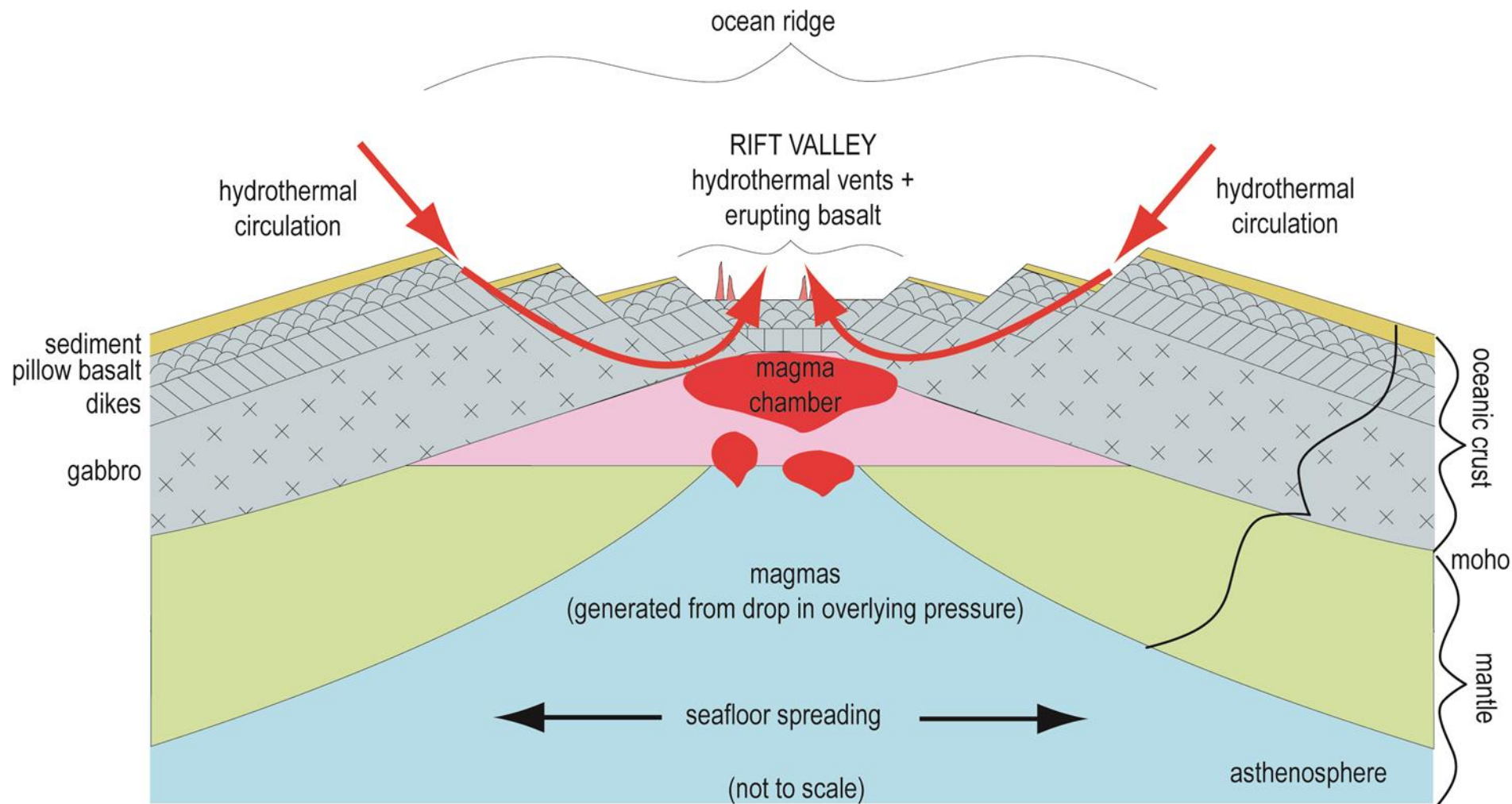
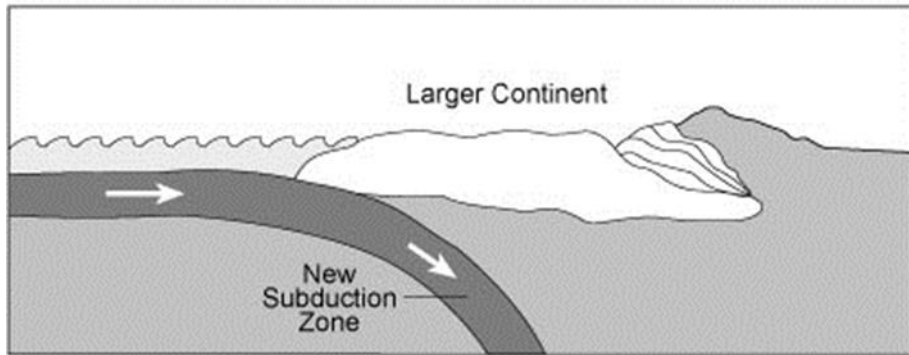
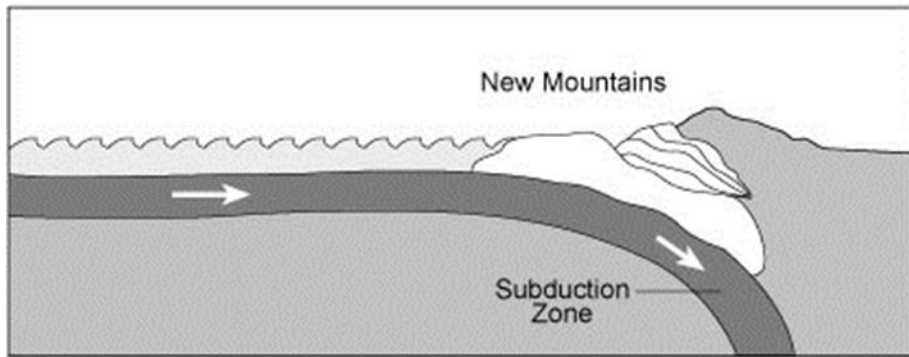
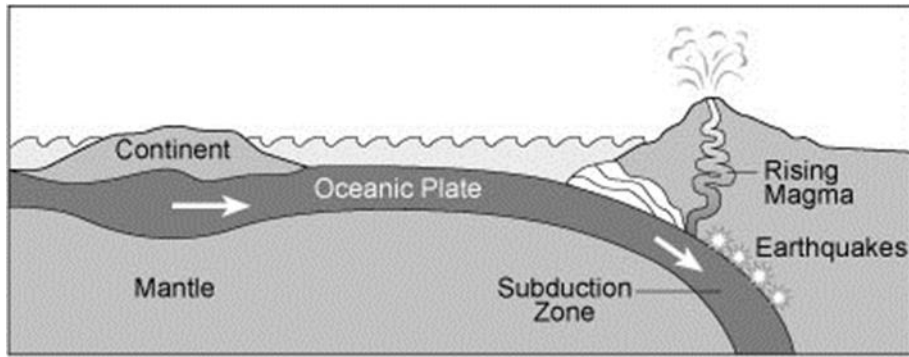


Image from USGS – This Dynamic Earth. (Text below is also from this website.)

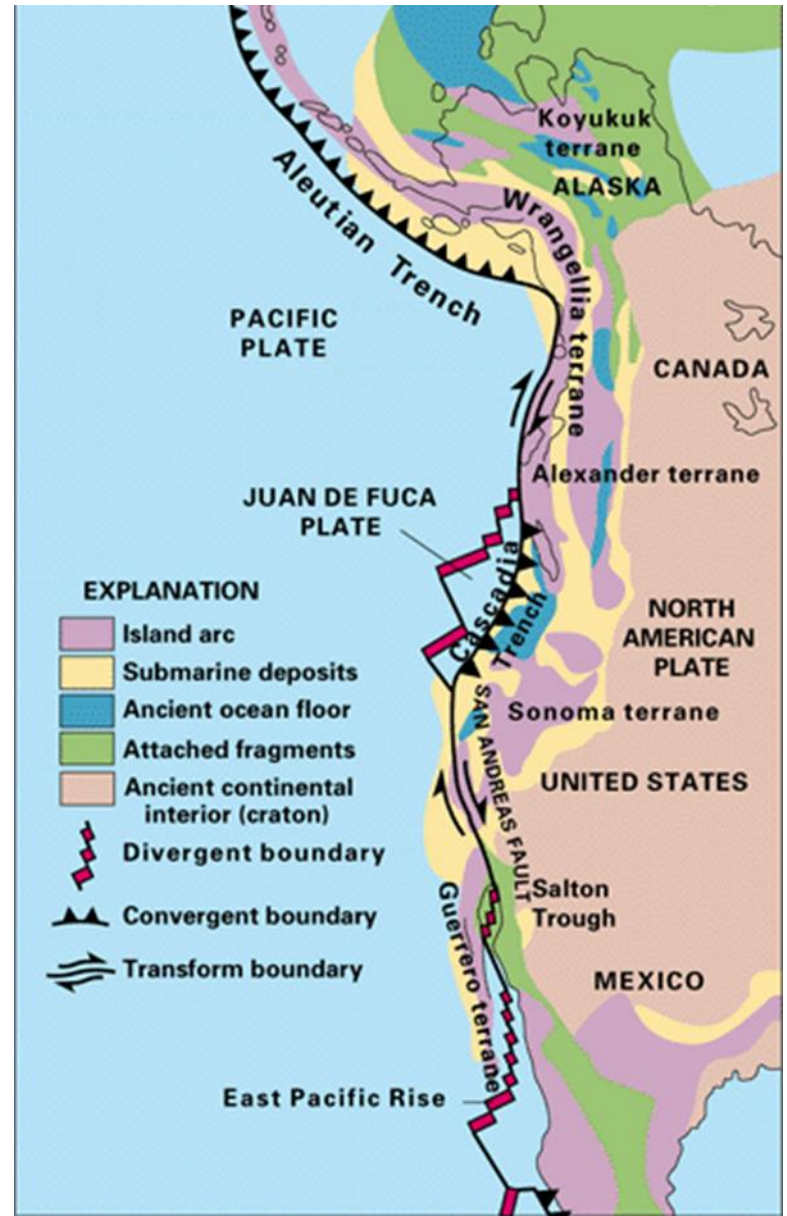
1. Continental and Ocean crust sit atop mantle rock that together create plates (or lithosphere). Some plates are 100% oceanic lithosphere; others 100% continental; others a combination of both side by side, fused together. (See the divergent plate boundary cross-section in a previous image for an example.)
2. Hot plastic convecting asthenosphere – close to its melting temperature but not quite there – capable of flow over time..
3. Convection currents form when mantle melts, becomes less dense and rises.
4. Rising magmas.
5. The pile up of rising magmas causes the plate to push upwards creating a ridge (mountain system), and the material spreads outward to make room for new rising material. This creates a DIVERGENT PLATE BOUNDARY.
6. Atop the ocean ridge is a down-dropped rift valley through which erupt pillow basalts and hydrothermal vents.
7. Older rock is pushed away from the ridge and it slowly subsides and collects sediment, which covers its surface and hides any rough topography – producing the ocean’s abyssal plains.
8. When ocean plate gets old and dense, it collects more and more solid mantle at its base, weighing it down. Eventually the entire plate is denser than the material under it and it sinks or subducts.
9. Subducting ocean plate creates a deep trench on the seafloor. Sediment is scraped off the subducting plate and accretes to the edge of the nonsubducting plate.
10. Subducting plates can sink, unmelted, all the way to the core mantle boundary. (In this image there is no plate melting.)
11. The plate boundary at this location is called a CONVERGENT PLATE BOUNDARY (in this case, ocean-continent convergence).
12. Water is squeezed from the subducting plate (due to high pressures at depth) and drops the melting point of the mantle rock around it, causing it to melt. This magma is less dense and hence rises to the surface.
13. As magmas rise, they collect in magma chambers in the crust. They might sit her for a few hundred or thousand years before new magmas rise beneath them and force them to erupt.
14. A chain of volcanoes form from layers of lava flows and ash debris created by hundreds of thousands or millions of years of erupting volcanoes. (We call this a volcanic arc.)



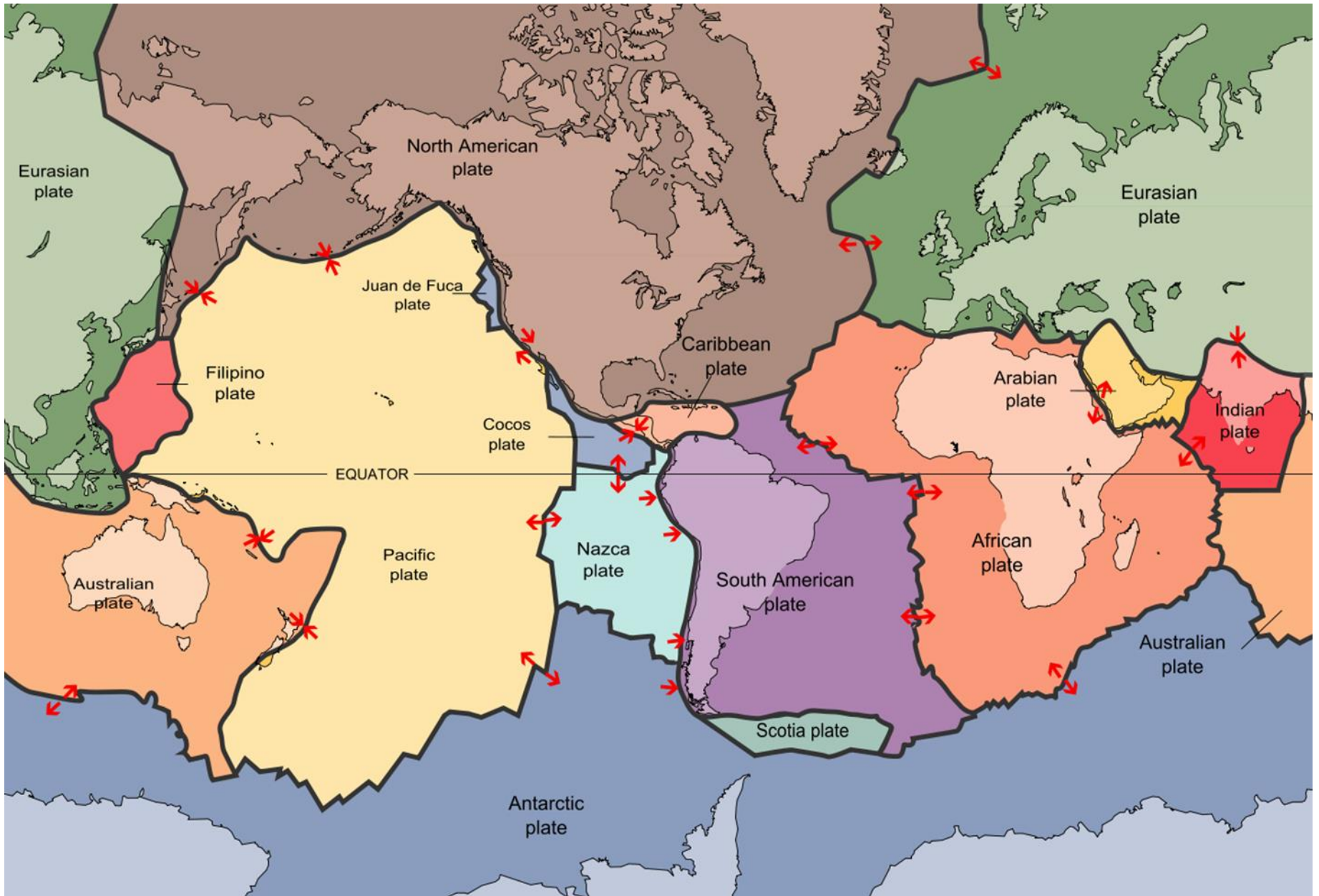
At seafloor spreading centers, magmas form as mantle melts under the thinned crust (a drop in pressure causes melting). Magmas rise to the surface and erupt under water as pillow basalts. The vertical cracks that formed between the top of the magma chamber and the bottom of the seafloor to allow the basalt through will then solidify under the pillows and form basalt dikes. Both of these are spread aside to make room for the next series of pillow basalts and dikes, and as they spread away from the rift valley, they collect sediment on their top and beneath, the edges of the magma chambers cool slowly underground to form gabbro. Seawater will descend through the cracks formed from spreading, leach elements from the ocean crust, get heated by the magma chamber and rise back up in the center of the rift valleys producing hydrothermal vents made of chimneys of metal sulfides precipitated from the hot fluids as they exit the ground and enter the cold ocean (much like mineral deposits that form on the inside of plumbing pipes).



Terrane accretion. Image from Kenneth R. Lang's book *The Cambridge Guide to the Solar System, Second Edition 2011*.



Terrane accretion along the western margin of North America. USGS.



Global Plate Boundaries, USGS

Fort Funston

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.

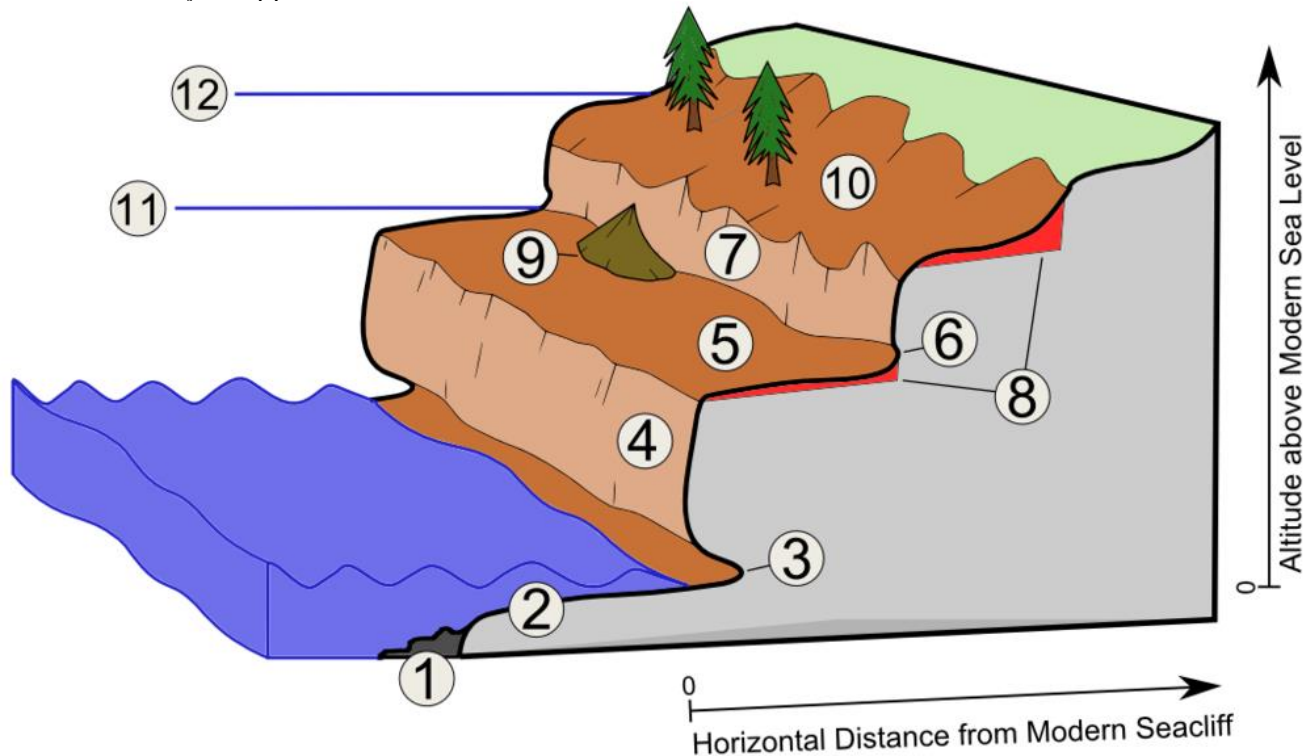


Image: Shekk12 Creative Commons: CC BY-SA 3.0.

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.