San Francisco Bay – Tutorial Script

The city of San Francisco is surrounded on three sides by coastline. The west coast opens to the Pacific Ocean. The north and east coasts, to the San Francisco Bay estuary.

Let's move inside San Francisco Bay and observe some of the processes at work in this embayment where salt water and fresh water mix. This satellite image of San Francisco Bay shows the sediment plume from the Sacramento River, which dumps its sand-sized sediment way up near Sacramento. Its mud-sized sediments, however, stay in suspension and settle in shallow low-energy tidal wetlands along the edges of the estuary. Over 100 years ago, San Francisco Bay was surrounded by muddy tidal wetlands, which are nurseries for invertebrate and fish populations. They also help to clean up the water by providing a place where heavy pollutants can settle out into sediment and salt marsh plants can transform wastes and other pollutants into harmless substances. Estuaries are an important part of coastal habitats, and when humans live in these estuaries, they bring with them many changes. All the red areas in this image represent old wetlands, now filled in and built up with a combination of bay mud and old building debris. These regions were built up to extend the land into the bay and provide more room for residential communities, businesses, airports, and shipyards. This close up of the Sacrament River Delta in the North Bay shows islands that were created by building an extensive dike structure to keep the water out. These were built to increase the land available for agriculture and now are maintained by the state of California. This image of South San Francisco Bay shows a close up of the salt ponds developed for industrial salt production over a hundred years ago. About 95% of the wetlands that originally surrounded San Francisco Bay are now gone. Other changes to our estuary include reduced water quality, increased pollutants, diversion of freshwater to agriculture, and the addition of invasive or exotic species, which are changing our ecosystem by outcompeting the natives. One of the largest impacts humans have had on our estuary was the large amount of mercury-laden sediment carried down the Sacramento River and dumped into the Bay during the gold rush in the mid and late 1800s. That pollution legacy still impacts our communities today making it unsafe to eat many of the fish that make our bay their home.

What about the natural processes that have impacted our bay? San Francisco's North Bay originally formed as a **drowned river valley**. During the last ice age, about 20,000 years ago, the Sacramento River ran all the way out to the Pacific Coastline, which would have been about 30 miles offshore where it is today. Increased erosion in the Sierra Nevada by mountain glaciers filled the river with water and sands which were carried to the ocean and deposited in a large delta. Onshore winds picked up those sands and distributed them in a massive sand dune province that covered the continental shelf and low-lying coastal areas. As you can see, the tip of the San Francisco Peninsula is one of those low-lying areas, and the sands collected across and covered most of San Francisco. When the ice age ended, about 10,000 years ago, sea level rose and drowned or pushed inland the Sacramento River Delta. Most of the sand dunes were covered by water. Today we see sands at Ocean Beach, which are the result of waves pushing sand from the offshore underwater dunes up onto the beach. These are not sands from the modern day Sacramento River, but from the ice age Sacramento River deposits. Along the north edge of San Francisco, you will also find some of these ice age sands coming in under the Golden Gate Bridge with the tidal currents. But where the coastline is quiet and wave activity is low, such as the northeast and east sides of San Francisco, the only sediment available to settle out or deposit are the suspended muds carried south from the modern day Sacramento River (muds are so fine they only settle out in areas where there's no current).

Over the last 2 million years of Earth's history, known as the Pleistocene, sea level has risen and fallen as we've gone in and out of ice ages. When sea level is high, we see muds settling around most of San Francisco Bay creating our salt marsh wetlands. When sea level is low, during an ice age, the Sacramento River rushes out to the new coastline, and sands are deposited. As this image shows, when we look at a cross-section of surface sediment across San Francisco Bay, we see alternating layers of sand and mud. These layers provide us evidence of how San Francisco Bay has been changed by natural processes over its history.

So North San Francisco Bay is a drowned River Valley, but how did South San Francisco Bay form? Let's look closer. Studying this picture of South San Francisco Bay, what observations do you make? Do you notice, for example, that there seem to be two parallel linear features marking the east and west edges of the bay? And do you notice that there appear to be hills and mountains on the outside of these boundaries, but mostly shallow flat

land between? South San Francisco Bay is a fault-bounded, tectonic estuary. It sits between the Hayward and San Andreas Faults and represents a down-dropped basin that filled with water and sediment. Refer to the Plate Tectonics and California Geology video tutorial to learn more about the plate tectonics history of our region. For this video, it's sufficient to know that these faults are the two largest faults in the San Francisco Bay Area and are where the North American and Pacific Plates slide past each other. Normally, two plates sliding past each other would produce no uplift, only sideways motion. However, the California Coastline maintains a small amount of compression stress related to the geometry of the two plates and their motions. The uplift produces the coastal Santa Cruz Mountains and the East Bay Hills. As you move north and south from San Francisco, you will see more and more of this uplifted land, creating a coastline marked by erosional cliffs, headlands, and marine terraces.

Two of the largest coastal issues we face along the Pacific Coast of San Francisco are coastal erosion by waves and landslides. This image of an active landslide just south of San Francisco in Daly City shows a pile of rip rap, large boulders placed at the base in an attempt to prevent the slide from continuing to move seaward. The waves come in daily and hit the base of the cliff, removing land, and the land behind it slides down.

The **wave-cut bench or platform** is created when waves reach shallow water and touch bottom. As the waves drag across the bottom of the seafloor, they erode the rock and create a flat surface atop which sand is pushed and pulled in and out and along the shoreline. Normally the wave-cut bench or platform is covered by sand, but in some instances especially in winter when waves have removed much of the sand, it is exposed as bare rock. When the wave-cut bench or platform is uplifted or when sea level drops, it can sit as a flat terrace above a new wave-cut bench. These older benches are called **marine terraces**. Marine terraces are common features of the California Coastline, because our coastline is continually lifting up out of the water. The best place to see a marine terrace locally is at Fort Funston. It is the location of the parking lot and take-off point for the hang gliders. This image is looking south from the edge of the terrace where a massive landslide removed a significant amount of the local cliffs. You can see further down, where these houses appear atop the terrace. All of this cliff is prone to landslides and new ones are added yearly to this section of the coastline as waves undercut this softer less resistant rock material. Adding to the instability of this 100,000-year-old marine terrace and cliff is the presence of the San Andreas Fault, which comes offshore right here at Mussel Rock. The shaking associated with movements along this fault add power to the erosional processes at work here.

Let's look more closely at the tip of the San Francisco Peninsula and see how natural forces have shaped its surface. Notice the area of San Francisco between the two fault zones is sinking. What happens to hills when they sink? The waves attack the area from all sides and erode it. Full success would be to erode the area entirely flat, and that's what the waves of the Pacific are trying to do to San Francisco. Sands blow into the low-lying eroded flat lands and cover it in dunes. And what sticks out within these dunes? These hills are what we refer to as erosional remnants – resistant rock that is being eroded by water and wind and waves but has so far remained behind while the other rocks around it have been removed. Why? Because it was more resistant and better protected. So the hills of San Francisco are really islands of rock in a sinking block of sand.

This image shows erosion along the Great Highway at the southern end of Ocean Beach after a high-energy storm removed the sand from under the highway. This sand is easily carved out and erosion is continually battled in this region. This image shows a house's concrete foundation covering sands in the Mission District. This particular property was installing a new foundation, and the excavation provided an excellent opportunity to see the underlying sediment composition of the entire region more closely.

As this image shows, most of the city of San Francisco is built atop sands and bay mud – sediments that have come from the coastal waters and are highly unstable during the earthquakes this region is exposed to regularly as it sits in the middle of the San Andreas Fault System. Sand is shown in yellow. It represents a moderate to high hazard for ground shaking in an earthquake, The only thing worse is mud, shown in red, which greatly amplifies ground shaking and turns to jello during an earthquake. Structures built on bay mud and sand suffer much worse damage than those built on solid bedrock during an earthquake. Where's the solid bedrock? In the erosional remnants – the hills that are found scattered across the city. Of course those are also being actively eroded and landslides are a risk in those areas. No place is risk free.

Pause now.

Coastal California is a beautiful landscape sculpted by a combination of natural and human processes. The intertidal zone is open on all shorelines in California to all people. It is a public resource to which we all have access and for which we all have stewardship responsibility. So get out at the next low tide and explore the coast!

[end credits]

Coastal Video Series:
Part I: Coastlines
Part II: Beaches and Sand Migration
Part III: Estuarine Mixing
Part IV: San Francisco Bay

San Francisco Bay

Produced by Katryn Wiese
City College of San Francisco

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