

Geology of Salt Point State Park

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Cover Photo: Tafoni formation at Salt Point State Park

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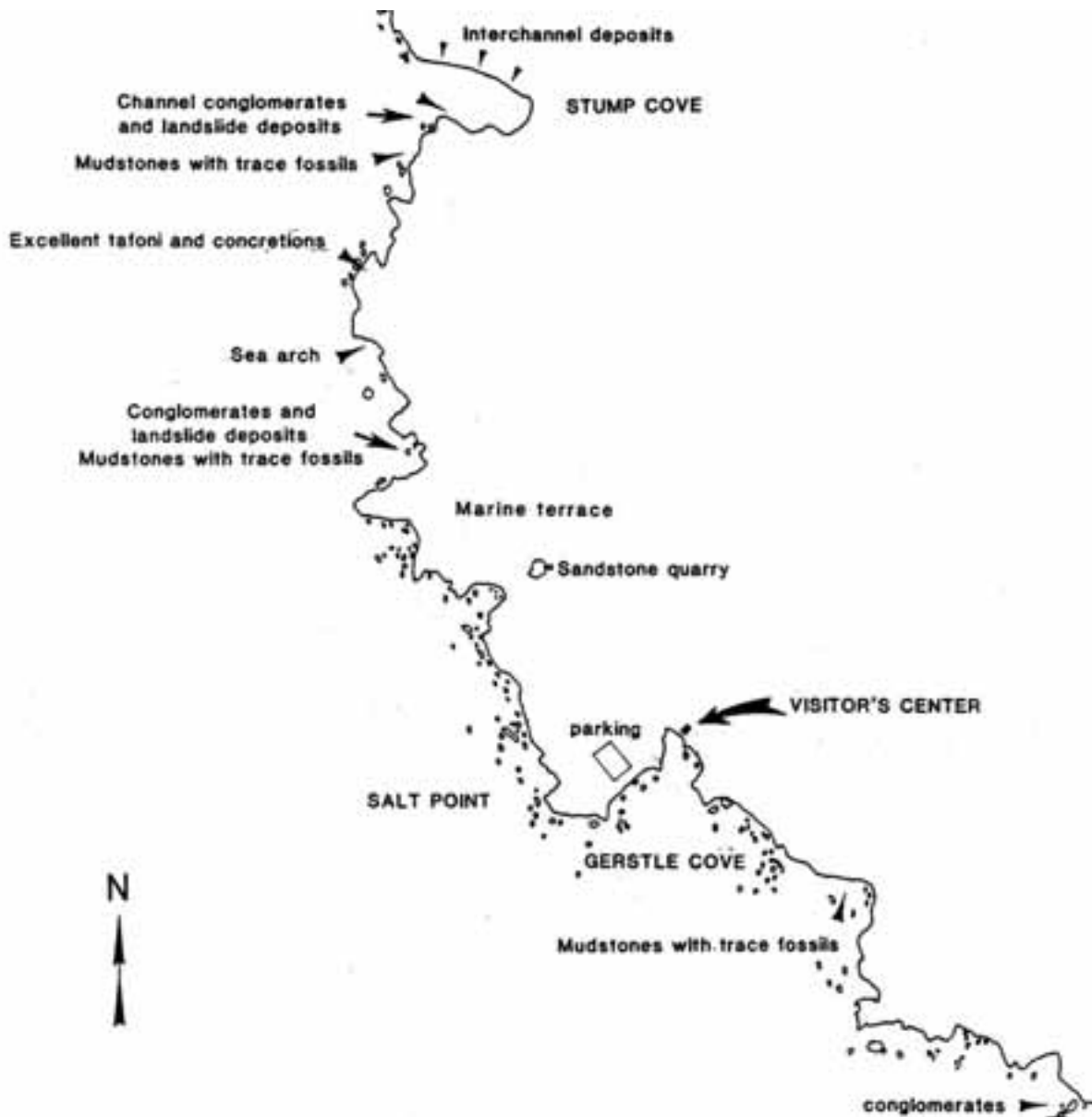
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Geology Of Salt Point State Park

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INTRODUCTION

Salt Point State Park provides spectacular vistas of the ocean, with rugged offshore rocks and steep sea cliffs that take the full impact of the waves. The rocks are sculpted into an infinite variety of forms and shapes. Extending underwater, the rocks offer a range of habitats to a wide variety of marine plants and animals. Divers can enjoy the rich underwater world. Uphill from the coast, the park continues to the top of the coastal ridge. Habitats change from coastal grassland to forests of Bishop pine, madrone, tanoak, and redwoods. A pygmy forest of stunted cypress, pine, and even redwoods, as well as a large open “prairie,” provide unique surprises for the hiker.

What makes Salt Point State Park so special? What has created this unique landscape? There are many more questions than we can easily answer, but we can begin to unravel the mysteries of its origin and formation. We can look beneath the surface at the dramatic geologic processes that create this magnificent landscape.

The terrain of the park has been formed and modified over tens of millions of years. The processes involved in its formation include those processes that move continents and create oceans, build mountains and generate destructive earthquakes.

To fully appreciate the geologic history of Salt Point State Park, it is helpful to understand how the rocks of the park formed and what dynamic processes were involved in the creation of the coastal mountains of California.

ROCKS

There are three types of rocks: **igneous**, **sedimentary**, and **metamorphic**, defined by how they are formed (Figure 1). Igneous rocks were molten at some time in their history. The melt is called **magma** when it is found beneath the earth's surface or **lava** when it is erupted onto the surface. When the melt cools, it forms a rock made of intergrown, interlocking crystals composed of several different minerals. When the melt cools slowly, the crystals have time to grow large, producing an igneous rock such as granite. If the melt cools quickly, the crystals that form are very small, often too small to be seen with the unaided eye. Basalt is an example of an igneous rock which is formed from lava that cooled quickly.

Sedimentary rocks are formed on the earth's surface by the action of surface processes, such as weathering, erosion, deposition, and cementation. When any type of rock (igneous, metamorphic, or sedimentary) is exposed at the earth's surface, it comes in contact with the atmosphere. Oxygen in the atmosphere and weak acids in rainwater react with the rocks. The exposed rocks are chemically altered and mechanically broken apart into smaller and smaller pieces, a process called **weathering**. The rock fragments, known as **sediment**, are then transported by wind, rivers, ocean currents, or glaciers. This transportation process is termed erosion.

Eventually the rock particles are **deposited** in some low place, such as on the bottom of a lake or on the floor of the ocean, and they accumulate layer upon layer. With the passage of time, the weight of the overlying sediment and the precipitation of minerals in between the rock particles **cements** the grains together and transform the loose sediment into solid sedimentary rock.

Sedimentary rocks are classified based on the size of the particles making up the rock. Large, rounded pebbles cemented together form a **conglomerate**. Sand-sized particles form a sandstone, while mud and clay-sized particles form mudstone and shale. Each of these types of sedimentary rock can be seen at Salt Point State Park and will be described in greater detail later in this guide.

If sedimentary rock or crystallized igneous rock is deeply buried and subjected to high temperatures and pressures, it will be altered to a new rock called **metamorphic** rock. Metamorphic rocks are often made of crystals like igneous rock, but the crystals are arranged in layers (called **foliation**), reflecting the modifying heat and pressure. Examples of metamorphic rocks are quartzite, marble, slate, schist, and gneiss (pronounced “nice”).

Igneous and metamorphic rocks, originally formed at depth, can be uplifted by mountain-building processes and become sedimentary rocks. These sedimentary rocks, in turn, may be buried and converted into metamorphic rock or melted to become igneous rock, thus completing the **rock cycle** (Figure 1).

All of the rocks along the coastline in the park are **sedimentary sandstones, conglomerates** and **mudstones**. Metamorphic and igneous rocks can only be found as large, rounded pebbles within the **conglomerates**. Conglomeratic pebbles vary in the color of their crystals. Pebbles composed of large white and black crystals are igneous granite. Volcanic pebbles are usually dark with a scattering of tiny light-colored crystals. All-white pebbles are usually white quartz. These types of igneous rock are fairly abundant. Pebbles made of metamorphic rock are often dark in color and may show alternating dark and light layers of small crystals. Identifying these different rock types may be especially difficult when the pebble has been rounded and polished and the sample is small. Even experts may have difficulty, so don't get discouraged.

THE ROCK CYCLE

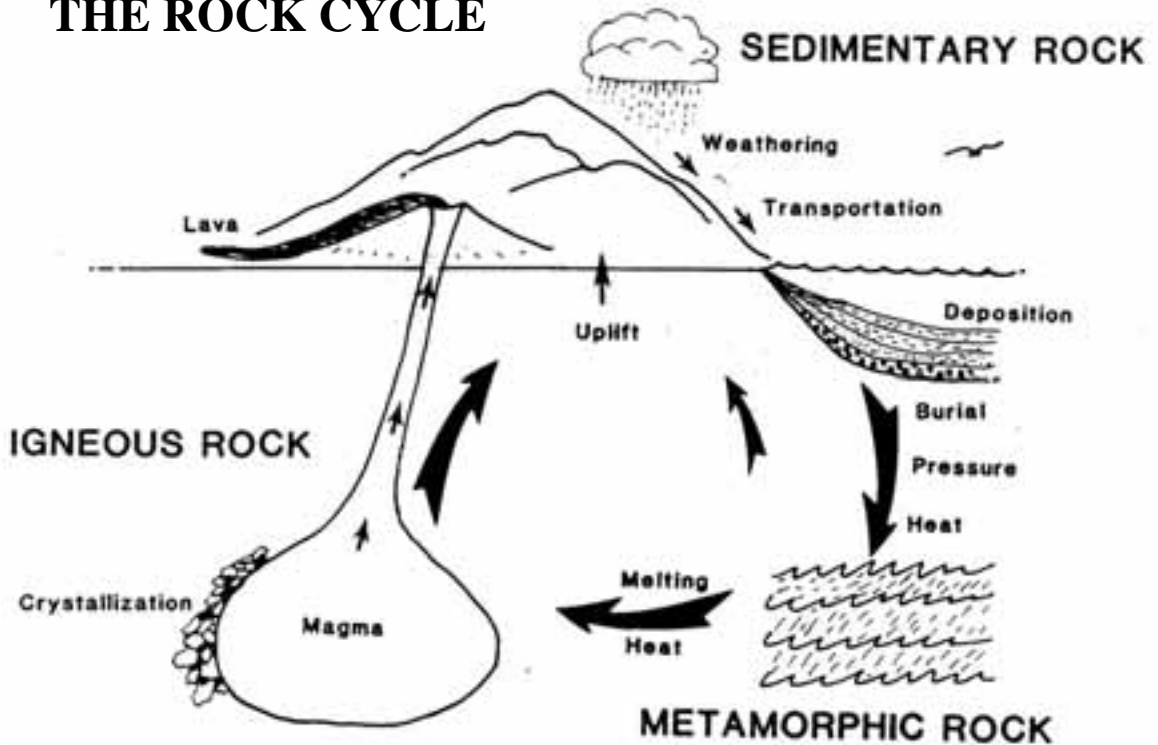


Figure 1. The rock cycle shows the geologic processes operating beneath the earth's surface and at the surface which transform one rock type into another.

READING THE STORY IN THE ROCKS

Rocks contain a record of their geologic history: how, when, and where they formed. Geologists are able to read the story contained within the rocks, and they can interpret and recreate the history of the California coast through geologic time. It doesn't take a professional to do this. With a little background, you can begin to look beneath the surface and take a voyage back through time.

MOVEMENT OF PLATES, BUILDING OF MOUNTAINS

The story begins over 100 million years ago with the formation and movement of large blocks of the earth's crust and upper mantle called **plates**. The outer portion of the earth is divided into about a dozen rigid plates that are "floating" on a plastic-like portion of the upper mantle (the layer of the earth beneath the crust). These plates are in motion; some move apart and some move toward each other. Where plates move apart, molten magma comes to the surface in the rift and cools to form new **oceanic crust**.

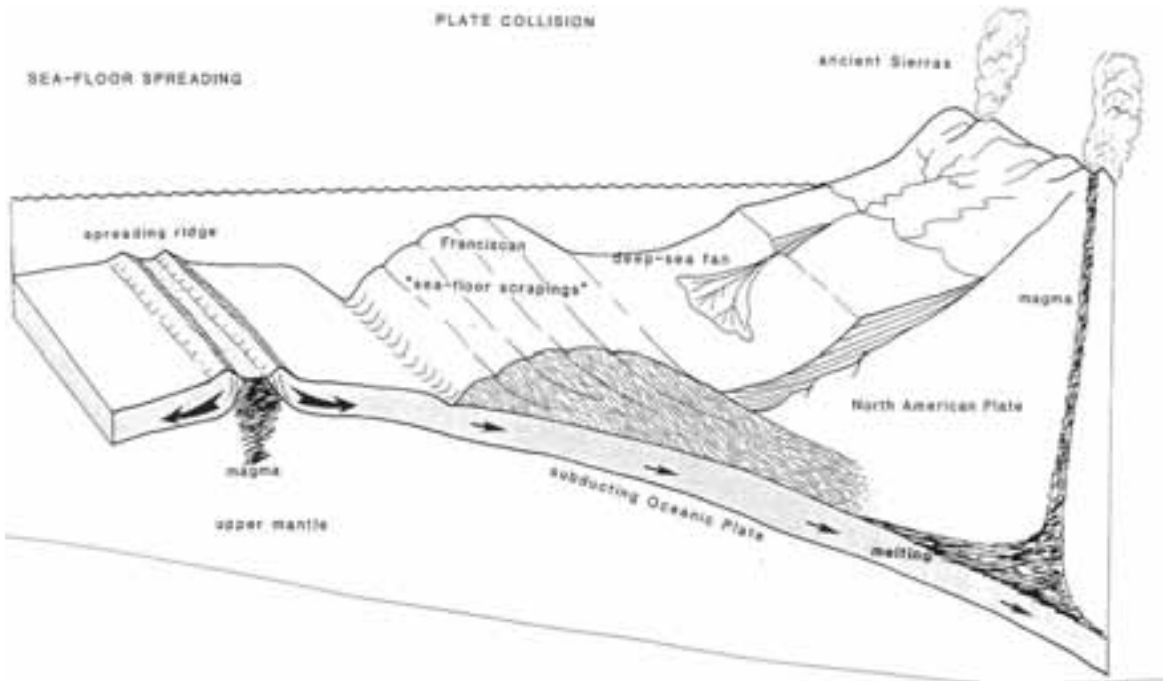


Figure 2. Schematic cross-section of northern California about 100 million years ago. A sea-floor spreading ridge to the west (left) generates the Pacific Ocean plate which is subducted under the North American plate (right). Heat generated where the plates collide causes melting of the crust. The molten magma rises to form volcanoes at the surface. Large bodies of molten rock cool at depth, forming the granite of the ancestral Sierra Nevada mountains. Ocean floor sediments and portions of the oceanic crust are scraped off the subducting plate against the North American plate and pile up, eventually forming the rocks of the Coast Range mountains. These "sea-floor scrapings" are called the Franciscan Assemblage.

When this process occurs under the ocean, the process is called **sea-floor spreading**. As spreading occurs and new crust is formed, the plates move away from each other. As the plates separate, they move toward other plates. Where plates collide, one plate moves down under the other, a process called subduction (Figure 2).

Collision and subduction of plates are the processes that created most of the rocks of California. Millions of years ago, the Pacific Ocean plate moved eastward away from a spreading ridge and collided with the North American plate (Figure 2). As the two plates collided, the North American plate acted like a gigantic snowplow and scraped off a thin portion of the Pacific Ocean plate as it was being consumed. Over millions of years, these “sea floor scrapings” piled up at the margin of the North American plate and today make up much of the rock of the northern coastal mountains.

For hundreds of millions of years, the West Coast of North America had been a collision-type plate margin (Figures 2 and 3A). There was a sea-floor spreading ridge to the west, generating the Pacific Ocean plate. The Pacific Ocean plate, formed at the spreading ridge, moved toward the western margin of the North American plate, collided with it and was subducted beneath the North American plate. Farther to the east, molten rock, generated by the friction developed as the two plates collided, rose to form volcanoes at the surface and, at depth, cooled to form the granite of the ancient Sierra Nevada mountains (Figure 2).

SAN ANDREAS FAULT

About 25 million years ago, the California coastline went through a dramatic change. (Figure 3B). A new type of plate margin formed. Instead of colliding, the Pacific and North American plates move past each other along the San Andreas fault. The cause of this change was the North American plate overtaking and overriding the eastern portion of the Pacific plate and the spreading ridge. More and more of the Pacific plate has been overridden, and the **San Andreas fault** has become longer.

Today the San Andreas fault, the boundary between these two huge plates, traverses the State of California from the head of the Gulf of California in the south to Point Arena in the north (Figure 3C). The San Andreas fault crosses through the eastern part of Salt Point State Park. This segment of the fault ruptured in the great San Francisco earthquake in 1906.

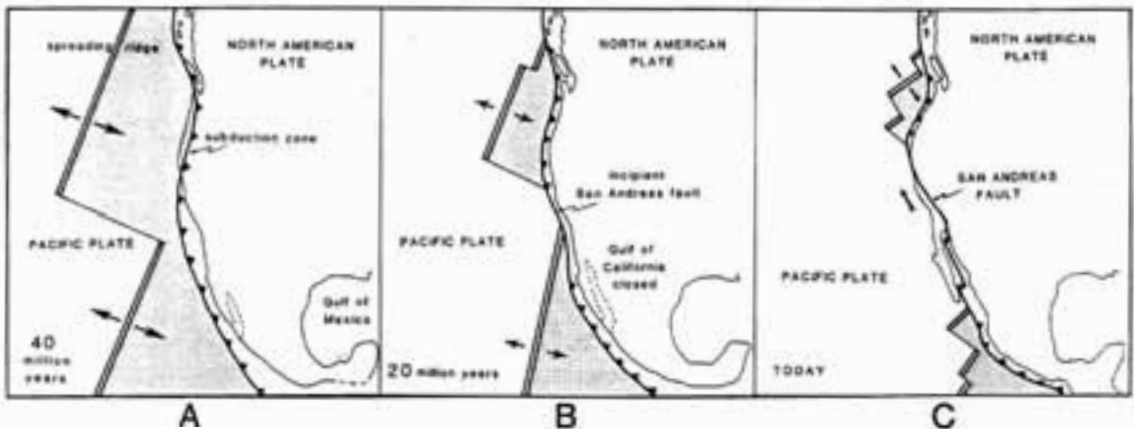


Figure 3. Reconstruction of interactions between the North American plate and the Pacific Ocean plate over the last 40 million years. (A) 40 million years ago, a spreading ridge generated the oceanic plate which was subducted (line with arrows) under the North American plate. (B) 20 million years ago, North America moved westward and overrode a corner of the spreading ridge, the oceanic plate and the subduction zone, thus forming the beginning of the San Andreas fault boundary where the two plates slide past each other. (C) Today, the San Andreas fault has lengthened as more of the Pacific Ocean plate is overridden. Sea-floor spreading and subduction still occur to the north and to the south. The Pacific Ocean plate is now moving northwest along the San Andreas fault.

All of the California continental crust to the west of the San Andreas fault is attached to the Pacific Ocean plate and is moving northwest with the Pacific Ocean plate (Figures 3C and 4). This sliver of continental crust is called the **Salinian block**. The Salinian block has moved hundreds of miles to the north along the San Andreas fault system along with all the younger rocks which formed on top of it, including those at Salt Point State Park (Figure 4B). Because of this northward migration of the Salinian block, the rocks of Salt Point State Park on the east of the San Andreas fault are very different in composition and in age from the rocks on the west side of the fault.



Figure 4. (A) California today. Map of California shows where rocks of the Franciscan Assemblage are presently found and the location of the San Andreas fault and Salinian block. Enlarged area shows the locations of Salt Point and illustrates the San Andreas fault separating the German Rancho Formation rocks on the Salinian block on the west side of the fault from Franciscan Assemblage rocks on the east side.

(B) Reconstruction of California 40-60 million years ago shows where the rocks of the German Rancho Formation originally formed in the deep submarine basin on the Salinian block, 200-260 miles south of the location of Salt Point State Park today.

The rocks in the park to the east of the San Andreas fault are called the **Franciscan Assemblage** and make up much of the Coast Range mountains. Franciscan rocks are made of the deep ocean sediments and portions of oceanic crust scraped off the descending Pacific Ocean plate as it was subducted about 100-150 million years ago (Figures 2 and 4). Franciscan rocks are difficult to see in the park because the portion of the park east of the San Andreas fault is covered with dense forest and soil, and the Franciscan rocks are poorly exposed. However, excellent examples of Franciscan rocks can be seen in road cuts along the coast south of the park between Fort Ross and Bodega Bay.

As a result of the mountain building processes that have raised portions of the California coast and the movement along the San Andreas fault, the rocks of Salt Point State Park have been folded and, in some places, faulted. These folds and faults can be seen in the rocks along the coast.

ROCKS ALONG THE COAST AT SALT POINT

GERMAN RANCHO FORMATION

The rocks along the beautifully rugged coastline are tilted sedimentary rocks, mostly sandstones with interbeds of conglomerates and mudstones, part of the **German Rancho Formation**. A formation is a group of rocks having similar composition. This one is named for a local geographic landmark. In 1846, Rancho German was a large land grant that extended north from Fort Ross. Rocks of the German Rancho Formation can be found from Fort Ross to Point Arena. North of Fort Ross the sequence is thought to be as much as 18,000 feet thick!

The sedimentary rocks of the German Rancho Formation were formed in a submarine basin on the then submerged Salinian block 40-60 million years ago (during the Paleocene to Eocene epochs of the geologic time scale). The marine basin and Salinian block were at that time situated 200-260 or more miles to the south of where Salt Point State Park is located today (Figure 4B). These rocks have been moved that distance along the San Andreas fault in the last 20 million years! Geologists use the composition of the pebbles and sand to locate

the original mountainous source area for the sediments now distantly separated along the fault. In this way they are able to reconstruct the past geography and environment at the time these rocks were forming.

TURBIDITY CURRENTS, TURBIDITES & DEEP-SEA FANS

The thick layers of sandstone alternating with layers of conglomerate and mudstone which make up the German Rancho Formation are interpreted to have been deposited by flows of dense, turbulent, sediment-laden water flowing down a submarine canyon. These high density flows are called **turbidity currents**. The rocks formed from the deposition of sediments from turbidity currents are termed **turbidites**. Rapid sedimentation on slopes of the submarine basin may result in instability. Intense storm activity or an earthquake may trigger a submarine slide that starts the turbidity current moving. The flow moves downslope, down a submarine canyon and then out onto the ocean floor where the sediment is deposited on a **deep-sea fan** (Figure 2).

A modern example of these processes and deposits can be found at Monterey Bay. Today, rocks in the high Sierra Nevada mountain range are weathered, and the sediment is carried by streams and rivers into the Sacramento and San Joaquin rivers, through the Delta to San Francisco Bay and out the Golden Gate to the ocean. There, longshore currents (currents flowing parallel to the coast), driven by prevailing winds, carry the sediments southward along the coast forming the beaches from San Francisco to Monterey.

In Monterey Bay, the sediments are funneled down the Monterey submarine canyon where they flow in underwater channels and finally come to rest on the Monterey deep-sea fan. The fan has numerous channels at the top which carry the coarsest sediment, such as conglomerates. The sediment gets finer farther down the fan and between the channels where the sediment may have overflowed the banks of the channels.

GENERALIZED DEEP SEA FAN DEPOSITS

Channel Deposits

Interchannel Deposits

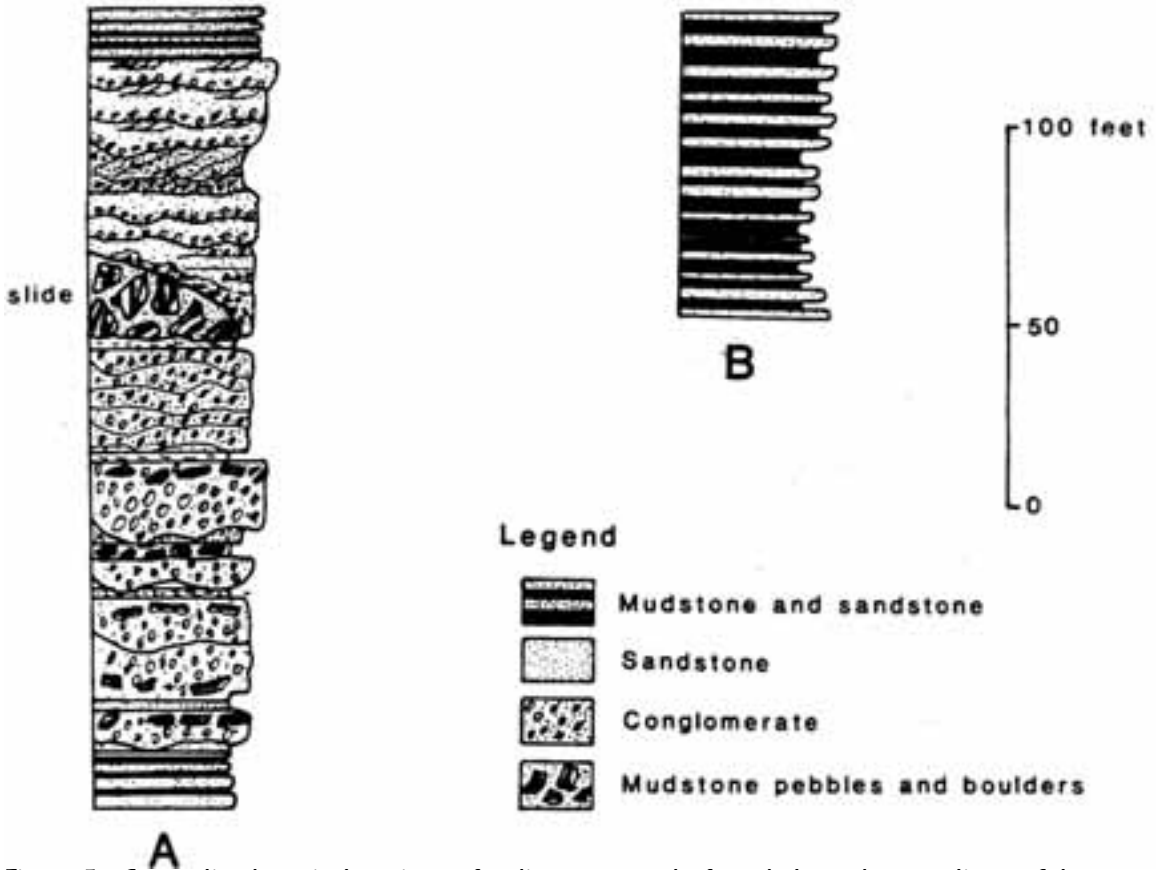


Figure 5. Generalized vertical sections of sedimentary rocks found along the coastline at Salt Point State Park. These rocks are thought to represent sediments transported by dense turbulent mixtures of sand, mud, and pebbles (turbidity currents) flowing down a submarine canyon and deposited (as turbidites) on a deep sea fan. (A) Sequence representing channel deposits of coarse conglomerates, sand and large chaotic blocks from submarine landslides (slide). (B) Interchannel deposits composed of alternating layers of sandstone and mudstone. Redrawn after J. D. Farmer and M. F. Miller, 1981.

The sandstones and conglomerates at Salt Point are thought to have formed in the channels, and the thinner beds of sandstone and mudstone are thought to have formed between the channels on a large, submarine deep-sea fan millions of years ago. These channel and interchannel deposits can be seen in many places along the sea cliffs (Figure 5).

How did these sedimentary rocks from a deep-sea fan, deposited thousands of feet beneath the ocean, get raised to their present position above sea level? These same processes that created the Coast Range mountains can be seen in action today.

On October 17, 1989, a 7.1 magnitude earthquake rocked the San Francisco Bay region. The epicenter was in the Santa Cruz mountains. The San Andreas fault ruptured along 25 miles, at a depth of between 2 and 11 miles beneath the surface. The fault did not break the surface as it did in 1906. After the earthquake, surveys of the surrounding peaks indicated that the Santa Cruz mountains had moved about 4 feet upward and 6 feet to the north. There is evidence at Salt Point State Park of similar kinds of uplift and northward migration.

The sandstones, shales, and conglomerates of the German Rancho Formation were originally deposited in horizontal layers, like the layers of a cake. The layers are now tilted, or tipped, along the entire coastline of Salt Point State Park. This tilting exposes rocks of different ages. In a sequence of sedimentary rocks, the strata at the bottom is the oldest (first deposited) and the strata at the top is the youngest (last deposited). If the sequence of strata remains horizontal and flat, the only way to see what is below the surface is to cut a slice into it, as has occurred where the Colorado River has cut the Grand Canyon through a mile of rock, exposing older and older rock as you descend to the bottom of the gorge. Alternatively, when rock is tilted, and erosion carves away the edges, older and older rock is exposed at the surface. At Salt Point State Park, the oldest rocks are at the southern park boundary, and you come upon younger and younger rock layers as you walk northward up the coast. About a third of a mile south of Horseshoe Point, the rocks are tilted in the opposite direction, and the layers get progressively older to the north. This change in tilt is because the rocks are folded into a huge downfold called the **Horseshoe Point syncline**. The youngest layers are at the center of the syncline, while the layers get progressively older away from the center.

The tilting not only exposes rocks of different ages, it exposes rocks of different hardness and different resistance to weathering and erosion. The waves wear away the weaker rock layers from the harder ones, forming coves among the more resistant points and headlands.

MARINE TERRACES

As you drive or walk from Highway 1 to the coastal edge at Salt Point State Park, you will notice the broad, flat surface above present sea level where the waves break along the cliffs. These flat surfaces are called **marine terraces**, and they are old, uplifted ocean floor. To visualize how these terraces formed, imagine what would happen if the water were suddenly drained from the ocean. You would find a gently sloping surface running from the beach offshore to the west.

Imagine what would happen if the land were suddenly raised 20 feet (and the ocean returned to its previous level). You would have a broad gently sloping surface like the one you drive across to reach the coast. In fact, the rocks that rise above the terrace level are ancient **sea stacks**, similar to the resistant rocks off the coast today that take the initial impact of the waves before they reach the sea cliff.

WATER, WIND AND SALT

The sandstone sea cliffs look as if a sculptor shaped and carved the rocks into all manner of imaginative forms. In fact, the sculptor is the wind, waves, and sea spray. Look beyond their amazing shapes and forms into their origin and history. If you look carefully at the sandstones along the coast, you can see the layering in the sandstone and also see that the layers are tilted at an angle, exposing them to the elements. Some of the sandstones are harder because they are better cemented than adjacent sandstone layers. Layers that contain more clay may be softer. The waves and wind are able to etch and remove the softer, exposed layers, leaving the harder layers standing as ridges and ribs. The massive sandstones and conglomerates form the points and headlands; the coves form where the rocks contain more mudstone or the rock has been fractured.

FRACTURES AND FAULTS

The extent to which rocks are broken is another important factor in how easily rocks are eroded. A fault is a break along which movement occurs; a fracture or joint is just a crack in the rock. The close proximity of the San Andreas fault and the tilting of the rocks indicate that the rocks have been subjected to stress. In some cases, the rocks respond by simply cracking; in other cases, the rocks on the two sides of the break move, one side relative to the other. As you walk along the headlands, notice that the massive sandstones are highly fractured. Differences in color of the rocks due to weathering often accentuate the fractures.

Faults also break up the rock. The fault plane where rocks have been broken can be recognized by polished surfaces called **slickensides**. These can be seen along the road down to Gerstle Cove.

Faults can also be recognized by seeing the strata on one side of the fault displaced from the strata on the other side, or by seeing rocks juxtaposed which may be entirely different in composition. Faults are also recognized where layers of rock are tilted at a different angle from the rocks across the fault. These fault features are very apparent at Gerstle Cove and in the cove to the north of Salt Point. Gerstle Cove is a cove because the shattered rocks in the fault zone have been more easily removed by the waves.

WEATHERING

One of the most unusual and beautiful features of the sandstone along the sea cliffs is the development of a honeycomb-like network called **tafoni**. The exact process of formation of tafoni is not entirely understood. The waves and salt spray leave salt crystals on the sandstones. Salt and water interact with the cement between the sand grains and within minute fractures in the rock. Alternately, some portions are hardened while others are loosened. This creates the lacy, box-like pattern.

Large, rounded rocks, some even standing on pedestals, are found on some of the points of rock along the coast. These rounded rocks are called concretions. The concretions represent areas within the sandstone layers where the sandstone is better cemented than in the surrounding sandstone and, therefore, are more resistant to weathering and erosion.

WAVE EROSION

One of the most awesome sights is a view of winter storm waves battering the coast. Waves strike the rocks with tremendous force. Water is massive material; a cubic yard of water weighs about a ton! Seismographs used to detect earthquakes can actually register the minute tremors caused by the sudden impact of tons of water striking solid rock at the coast. Storm waves are even more destructive than the force of the water alone because waves pick up and hurl sand and boulders against the shoreline. As the waves break, water pressure forces sea water into every tiny crack, enhancing chemical weathering of the rock as the water evaporates.

Much of the wave energy is focused on the headlands that project into the ocean. The waves are bent (refracted) around the headland so the force of the wave is directed against the sides of the headland as well as at the point. This causes erosion along the sides, leading to the formation of **sea arches**. If erosion isolates the point of a headland, **sea stacks** form.

FOSSILS

Fossils are traces or remains of once living organisms now preserved in rock. At Salt Point State Park, fossils can be found in the sandstone and mudstone exposed in the sea cliffs. These are **trace fossils**, or ichnofossils (“ichno” meaning footprint or track), which are the tracks, trails, burrows, or borings made by organisms in the sediment in which they lived. Unlike body fossils, such as shells or bone that are the actual hard-part remains of the organism, trace fossils are indications of

the organism's behavioral activity, such as feeding traces, locomotion tracks, or of its home-dwelling burrow. These fossils may not be obvious at first glance. They appear as a series of straight, curved or branched tubes, about ¼" to 1" in diameter, within the sedimentary layers. In cross-section, they appear as small circles. Traces are produced by a variety of animals, such as crabs, clams, and worms. It is not always possible to identify the organism that produced the track, trail or burrow. However, it has been determined that certain types of trace fossils found together represent a particular depositional environment. Some traces represent shallow water, others near-shore environments, and still others progressively deeper offshore waters. The Salt Point trace fossils are thought to be from a deep-water environment.

GEOLOGIC PROCESSES AT SALT POINT STATE PARK

Salt Point State Park provides an opportunity to view geologic processes in operation today. Take a trip through time and space to explore the millions of years of Earth history recorded in the rocks. See the evidence of great plates colliding and passing. Touch rocks that formed deep on the ocean floors, composed of materials eroded from mountains long since vanished. See these geologic wonders for yourself by following the *Field Guide to Salt Point State Park*.

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