GEOLOGIC TRIPS

SEA RANCH

AND BOWLING BALL BEACH

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GEOLOGIC TRIPS, SEA RANCH
AND BOWLING BALL BEACH

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GEOLOGIC TIME SCALE				
Era	Period	Epoch	MYA*	Event
Cenozoic	Quaternary	Holocene	0.01	Bluff formed
		Pleistocene	2	Meadow terrace cut Hillside terraces cut Uplift of old land surface
	Tertiary	Pliocene	5	Old land surface eroded
		Miocene	22	Uplift and erosion Black Point anticline formed Point Arena Formation deposited Galloway Formation deposited
		Oligocene	37	San Andreas fault begins (25 MYA) Iverson Basalt deposited
		Eocene	58	German Rancho Formation deposited
		Paleocene	65	
Mesozoic	Cretaceous	Upper	100	Last dinosaurs (65 MYA) Gualala Formation deposited Black Point Beach basalt Gualala basin formed
		Lower	145	
	Jurassic		208	
	Triassic		245	First dinosaurs
Paleozoic			570	First amphibians (300 MYA) First jawed fish (340 MYA) First trilobites (570 MYA)
Pre-Cambrian			4600	Bacteria (2100 MYA) Formation of earth (4600 MYA)
* MYA, million years ago, to beginning of interval.				

Most of the rocks in the Sea Ranch area were formed between 50 and 100 million years ago. These are relatively young rocks when compared to the 4.6 billion year age of the earth. If the age of the earth were compared to a human lifespan of 100 years, then these rocks were formed when the earth was over 98 years old.

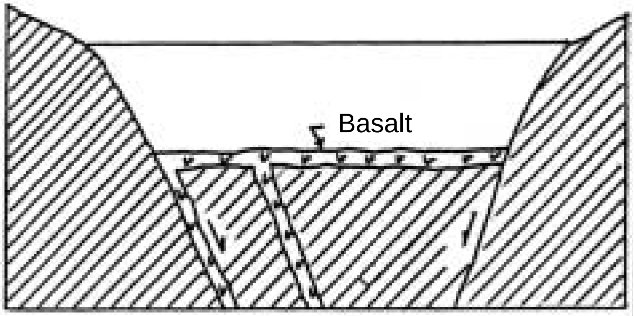
THE ROCKS TELL THEIR STORY

LISTENING TO THE ROCKS

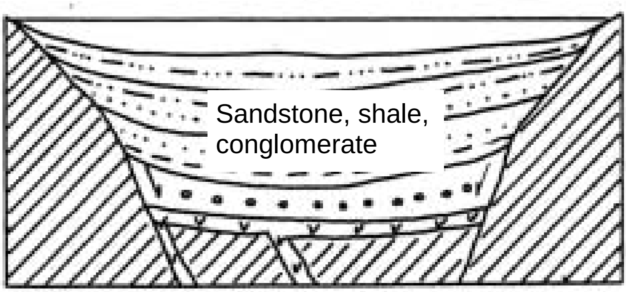
The rocks along the Sea Ranch bluff reveal an unusual and exciting geologic history. Like the north coast inhabitants, the rocks are well traveled, span a good age range, have been battered around a bit, and have been modified by the effects of living near the ocean.

The Sea Ranch rocks were born 90 million years ago in the Monterey area. They spent most of their life in that area, growing to a thickness of 30,000 feet. About 25 million years ago the rocks became restless and hitched a ride north along the San Andreas fault. During this ride they were bashed around, squeezed and folded, and lifted above sea level so that they began to be worn away by rivers and the ocean. By the time the rocks arrived in Sonoma County they were worn down to near sea level. In their old age, about two million years ago, they were uplifted again and subjected to attacks by the rivers and the ocean. The bluff, meadow, and the terraces on the hillside are scars from these attacks.

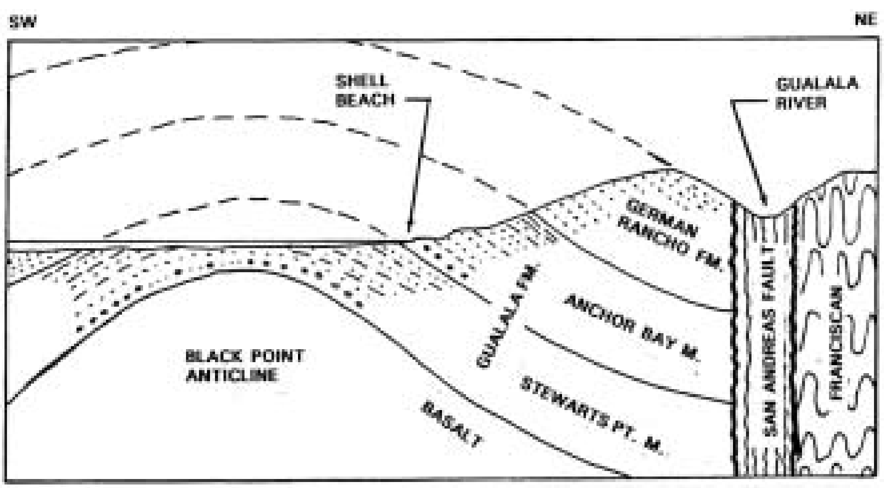
The rocks are coping well in their old age. We plan to take some geologic trips to read the fascinating story they have to tell. To get the most out of the trips you need to learn to think like a geologist. To do this, take one good last look at the bluff, meadow, hillside, ridge and river valleys. Now wipe all of this landscape out of your mind. Although these landforms may look like they have been here forever, they all formed during the last two million years, merely an instant in geologic time relative to the 4.6 billion-year age of the earth. In place of these landforms picture the land as it was millions of years ago when the rocks were being deposited. Listen to the story as told by the rocks.



The Gualala basin formed in late Cretaceous time when a large block of the earths crust subsided along faults. Basalt magma flowed upward along these faults and flowed out onto the sea floor.



The basin continued to subside until Miocene time. As the basin subsided, it was filled with 30,000 feet of conglomerate, sandstone and shale.



In late Miocene time, 10 million years ago, the rocks were folded into the Black Point anticline. As the rocks were folded, the rocks on the top of the anticline were lifted above sea level and removed by erosion.

THE EARLY YEARS

If we had taken a trip to the Monterey area 90 million years ago we would have seen a landscape of low hills separated by broad river valleys. An arm of the Pacific ocean extended into these hills to form an ocean basin, the Gualala basin. This basin formed when the earth's crust was fractured and pulled apart by forces deep within the earth. Basalt magma flowed out onto the floor of the Gualala basin through these fractures. This basalt is the oldest rock at Sea Ranch and can now be seen in the cliffs at Black Point Beach.

As the Gualala basin subsided, the nearby hills were uplifted. The hills consisted of granite, gabbro, volcanic rocks, sedimentary rocks and metamorphic rocks. The river valleys were filled with cobbles and boulders of these rocks. As the hills were uplifted, the rivers carried these sediments to the Gualala basin. At the *margi*n of the basin the sediments were mixed with sea water and then carried to the floor of the basin by underwater avalanches called turbidity currents. The water was several thousand feet deep in the central part of the basin. The floor of the basin continued to subside as fast as the sediments were deposited, so that the floor remained in deep water. Over 30,000 feet of sedimentary rocks accumulated in this manner over the next 80 million years, an average rate of one half inch every 100 years. The layers of sediments were stacked in the basin like pancakes on a large platter, the oldest on the bottom and the youngest on top. These sediments, with time and pressure due to the deep burial, became the hard sedimentary rocks that are now exposed at Black Point and along the bluff from Pebble Beach to the north end of Sea Ranch.

THE MID-LIFE CRISIS

The San Andreas fault became active 25 million years ago and began to move the Gualala basin to the north. At first, deposition of the sediments continued. Then about 10 million years ago deposition stopped and the sediments began to be folded as they continued to move north. The rocks at Sea Ranch were bent into a large anticline, an upward fold, as if the stack of pancakes were squeezed so that the center was bent upward. The center of this anticline is at Black Point Beach, and the fold is called the Black Point anticline.

As the rocks were folded, they were lifted above sea level and began to be eroded. As much as 30,000 feet of sedimentary rocks have been removed by erosion from the top of the Black Point anticline. It's as if someone had cut through the folded stack of pancakes horizontally with a knife and thrown away the upper part of the stack. If you looked down on the remaining pancakes you would see the oldest pancakes bowed up and exposed in the center of the platter. Only the rims of the upper pancakes would be preserved at the edges of the platter. In the same manner, the top of the Black Point anticline has been removed by erosion. The oldest rocks are bowed up and exposed in the center of the anticline at Black Point Beach. The younger sedimentary rocks are tilted away from the center of the anticline, and are now exposed along the Sea Ranch bluff, like books tilted on a bookshelf. When the Black Point anticline was uplifted, the younger rocks that overlay the German Rancho Formation were stripped from the Sea Ranch area by erosion of the top of the anticline. These younger rocks are preserved north of Sea Ranch, and include the Iverson basalt of Oligocene age and the Galloway and Point Arena Formations of Miocene age.

THE LATE YEARS

By late Pliocene time, three million years ago, the coastal area around Sea Ranch had been eroded nearly to sea level. If you had visited the Sea Ranch, you would not have recognized anything. There was no bluff, no meadow, no hillside and no ridge. A shallow sea covered the coastal area from Fort Ross to Point Arena and in places extended eastward into the Coast Ranges. The Coast Ranges had been eroded to low rolling hills. The Gualala River flowed west across this landscape and emptied into the Pacific Ocean. The flat tops of Miller ridge and the Gualala ridge are remnants of this old topographic surface.

At the beginning of the Pleistocene, about two million years ago, the coastal area began to be uplifted again. While the land was being uplifted sea level fell and rose as the glaciers formed and melted during glacial and interglacial episodes. When sea level was high during interglacial episodes, the ocean attacked the rocks along the coast cutting terraces into the hillside. The terraces were preserved as the land continued to be uplifted. The oldest terraces are the highest on the hillside. The meadow is the youngest terrace.

Ten thousand years ago, at the end of the Wisconsin glacial episode, sea level was low and the shoreline was several miles west of its present position. The meadow extended to this shoreline. As the Wisconsin glaciers began to melt, sea level began to rise and a sea cliff began to be cut into the meadow. As sea level continued to rise, the sea cliff continued to be cut landward and has evolved into our present bluff.

The bluff at Sea Ranch is irregular. As you walk along the Blufftop Trail you are constantly swinging out toward a point or turning inland to go around a cove. The sea is constantly sculpturing the rocks along the bluff emphasizing the different rock types just as weathering emphasizes knots and growth rings in driftwood. Conglomerates and thick sandstones resist erosion, and form points or headlands. Examples are Black Point, Bihler Point, the point between Shell Beach and Tide Pool Beach, Del Mar Point, Gualala Point and Whale Watch Point. Shale is easily eroded and forms recesses in the bluff where sand accumulates. Pebble Beach, North Rec. Beach, Stengel Beach, Shell Beach, Tide Pool Beach, and Walk-On Beach were all formed in this manner. Many on the smaller coves along the bluff formed where the rocks have been broken by faulting and fracturing.

The sand that forms the beaches along the Sea Ranch has mainly come from the Gualala River and has been transported south to the beaches by longshore currents. The sand accumulated in the protected coves and reentrants. The beach sand is constantly being moved from one place to another and back again by wave action. Large winter waves carry the sand offshore to form offshore bars. In summer, the sand is carried back to the beach by gentle waves and the beach is restored. Much wave energy is expended in this constant movement of sand from one place to another.

We should now be prepared to go on the geologic trips to the Sea Ranch bluff and the Sea Ranch meadow and hillside. We'll also take bonus trips to Gualala Point Regional Park and Bowling Ball Beach, which have some unusual and interesting geologic features. For the trips you should have a map showing locations of the bluff trail, beaches, and roads in the Sea Ranch area. Since the Sea Ranch is private property, proper permission should be obtained before visiting any of the locations that are not on public access paths.

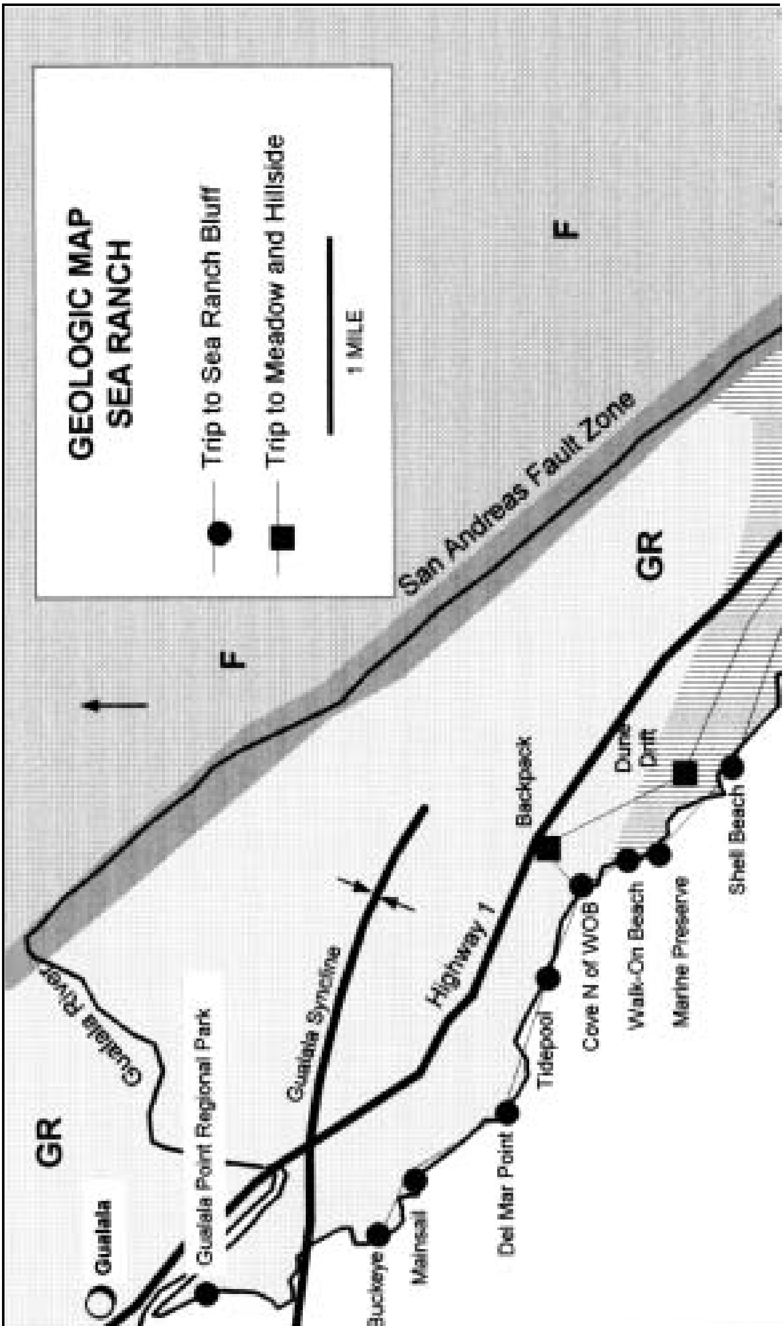
The bluff at Walk-On Beach consists of shale which is soft and was easily eroded to form a broad reentrant of the coastline. Sand accumulated in this protected reentrant giving sandpipers a good place to stop for lunch.

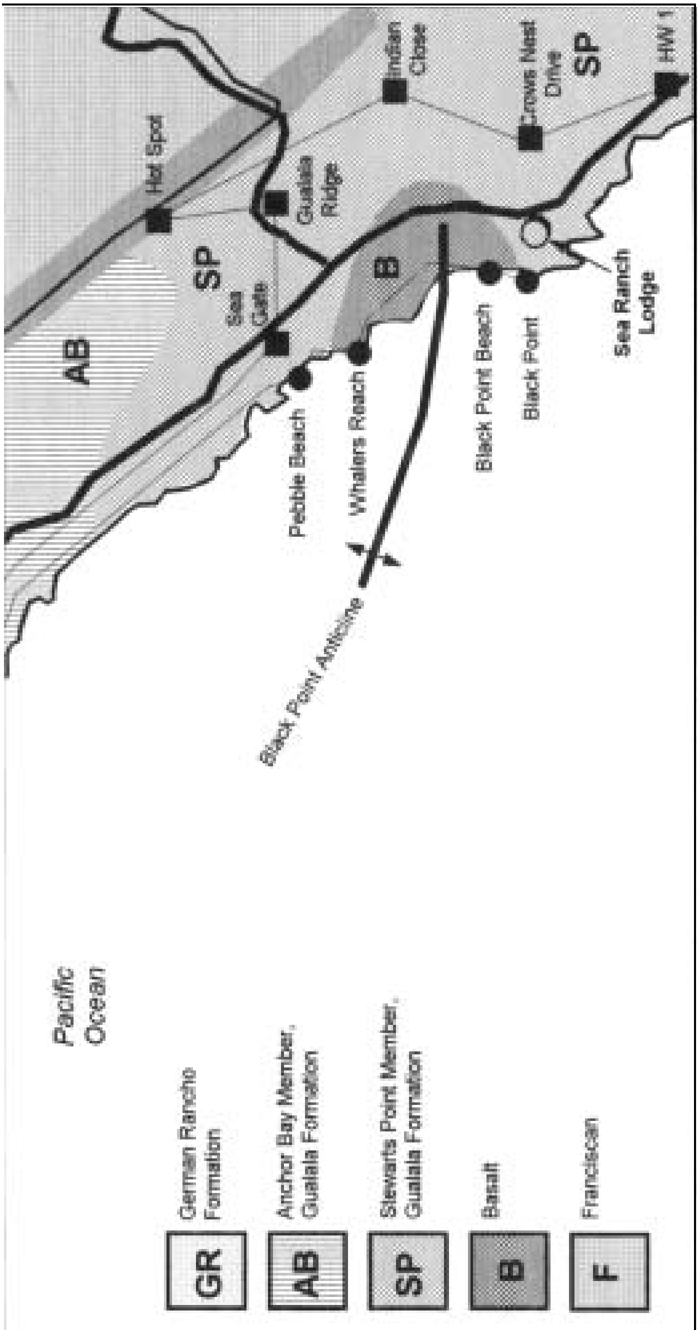
TYPES OF ROCKS AT SEA RANCH
SANDSTONE: Most of the rocks on the bluff are sandstone, sand that has been cemented to form a rock. The sandstone occurs in "beds" that are a few inches to over 10 feet thick. The sandstone is light gray where fresh, and yellow where weathered. The sand grains may be fine, medium or coarse, and the rock feels like sandpaper when rubbed. Sandstone is resistant to weathering and tends to form headlands and points along the bluff, especially north of Walk-On Beach. Del Mar Point, Gualala Point, and Whale Watch Point all have excellent exposures of thick sandstone beds.
SHALE: Shale is mud that has been altered by time and pressure from the overlying rocks. Shale is dark gray and very smooth on fresh surfaces. Where weathered, the shale easily breaks apart by hand. Shale erodes easily and tends to form recesses between the harder sandstone beds. Most Sea Ranch beaches have formed where shale has eroded forming a recess in the bluff: Pebble Beach, North Rec. Beach, Stengel Beach, Shell Beach, Tide Pool Beach, and Walk-On Beach.
CONGLOMERATE: Conglomerate is like sandstone, but contains large round cobbles about the size of oranges. The cobbles are of many different types of rocks. The conglomerate is very resistant to weathering and forms points along the bluff and islands. The conglomerates at Sea Ranch are all south of Walk-On Beach. The best exposures are at Bihler Point, Black Point and Shell Beach.
BASALT: Basalt is dark green and fine grained where exposures are fresh, and yellow where weathered. Most of the basalt weathers easily, but some parts are highly resistant to weathering, forming sea stacks and arches offshore from Black Point Beach to Pebble Beach. The basalt only occurs in the south part of Sea Ranch, from Black Point Beach to the cove south of Pebble Beach.

There are four types of rocks exposed in the bluff along Sea Ranch, sandstone, shale, conglomerate and basalt. The basalt is an igneous rock, which solidified from a molten magma that was extruded onto the floor of the Gualala basin when the basin was formed. The sandstone, shale and conglomerate are sedimentary rocks and were deposited as layers of sediment in deep water at the bottom of the Gualala basin.

FORMATIONS DEPOSITED IN THE GUALALA BASIN	
POINT ARENA FM. Sandstone and shale. Exposures at Arena Cove and at Pt. Arena lighthouse.	**MIOCENE**
GALLOWAY FM. Sandstone and shale. Exposures at Bowling Ball Beach.	
IVERSON BASALT. Basalt. Exposures in Highway 1 road cuts 1.0 mile north of Iverson Road.	**OLIGOCENE**
GERMAN RANCHO FM. Sandstone and shale. Sandstone light gray or yellow and thick bedded. Exposed from north of Walk-On Beach to Gualala Point Regional Park.	**EOCENE** **PALEOCENE**
GUALALA FORMATION, ANCHOR BAY MEMBER Sandstone, shale and conglomerate. Conglomerate has dark cobbles. Exposures from Stengel Beach to Walk-0n Beach.	
GUALALA FORMATION, STEWART'S BAY MEMBER Sandstone, shale and conglomerate. Conglomerate has light-colored “granitic"cobbles. Exposures at Black Point and from Pebble Beach to North Rec. Beach.	**LATE CRETACEOUS**
BLACK POINT BEACH BASALT. Basalt and pillow basalt. Dark green and fine grained. Exposures at Black Point Beach.	

Geologists name rocks for the same reasons that parents name children, so they can identify them and talk about them. Rocks of a similar age and type are called a formation, and the formation is named for the locality where it was first described. Formations can be further subdivided into members. This table summarizes the names ages and characteristics of the formations that were deposited in the Gualala basin.


GEOLOGIC MAP
SEA RANCH
Trip to Sea Ranch Bluff
Trip to Meadow and Hillside
1 MILE
F
F
GR
GR
San Andreas Fault Zone
Gualala River
Gualala
Gualala Point Regional Park
Gualala Syncline
Highway 1
Buckeye
Mainsail
Del Mar Point
Tidepool
Cove N of WOB
Walk-On Beach
Marine Preserve
Backpack
Dune
Drift
Shell Beach


AB
Hot Spot
SP
Sea Gate
Gualala Ridge
Indian Close
Crows Nest Drive
SP
HW 1
B
Pebble Beach
Whalers Reach
Black Point Beach
Black Point
Sea Ranch Lodge
Black Point Anticline
Pacific Ocean
GR German Rancho Formation
AB Anchor Bay Member, Gualala Formation
SP Stewarts Point Member, Gualala Formation
B Basalt
F Franciscan

A TRIP TO
THE SEA RANCH BLUFF

The geologic trip along the bluff starts at the Sea Ranch Lodge and goes north along the Blufftop Trail to Gualala Point Regional Park. The bluff and beaches are the best places to see the geology of Sea Ranch. The rocks are fresh, well exposed and easily accessible from the trail. The visits to the beaches should be made at low tide if possible, or you may not be able to reach some of the localities. The distance is eight miles one way, but the trip can be broken into as many segments on as many days as one desires.

Stop 1. Black Point, Conglomerate Makes a Point

Follow the trail from the Sea Ranch Lodge to the end of Black Point and find an area where the rocks that make up Black Point look clean and fresh. Black Point is formed from conglomerate. The conglomerate is extremely resistant to erosion. Without the conglomerate there would be no Black Point. Black Point juts out into the Pacific where it attracts large ocean waves like a lightning rod attracts lightning.

The photograph shows the rounded cobbles that form the conglomerate exposed on Black Point and Bihler Point. The cobbles were derived from the many different types of rocks that formed the hills in the vicinity of the Gualala basin 80 million years ago. The cobbles were transported to the Gualala basin by streams, and then carried to the floor of the basin by a dense mixture of sediment and water called a turbidity current..

The conglomerate consists of round cobbles, about the size of oranges, with sand filling the spaces between the cobbles. The cobbles are of many types of rocks, including granite, marble, gneiss, schist, amphibolite, quartzite, volcanic rocks, shale, and sandstone. They represent a sampling of the different rocks that formed the hills in the vicinity of the Gualala basin.

When the Gualala basin formed, the nearby hills that were formed from these rocks were uplifted. Angular pieces of rock that had broken from outcrops on the hillsides were carried downslope to stream valleys and then had their rough edges worn off during their trip downstream. The cobbles and sand in the stream valleys were carried to the shore of the basin where they accumulated in shallow water. The flanks of the ocean basin were steep, so that periodically the sediments became unstable, probably during storms or earthquakes. When the sediments became unstable, they mixed with sea water and formed a dense turbidity flow that moved down the flank of the basin like an underwater avalanche.The sediments were then deposited on the ocean floor when the current slackened. The conglomerates at Black Point are made up of numerous turbidite flows of this type, each perhaps twenty feet thick, piled one on top of the other. It is difficult to distinguish individual beds of conglomerate since there are no sandstone or shale beds between the conglomerates. The conglomerates look like they had been poured from a cement truck. Look for large boulders in the conglomerate. Some are over a foot in diameter. It took an impressive current to move rocks of this size. Also look for slabs of sandstone from a few inches to over ten feet long that are incorporated in the conglomerate. These appear to be parts of the sea floor that were torn up by the turbidity current and then deposited with the conglomerate when the flow stopped.

Bihler Point has exposures of the same conglomerates as Black Point. The conglomerates at Black Point and Bihler Point belong to the Stewarts Point Member of the Gualala Formation. Other conglomerates of the Gualala Formation occur at several places between Pebble Beach and Tide Pool Beach, but in thinner beds, and interbedded with much more sandstone and shale.

Stop 2. Black Point Beach, The Floor of the Gualala Basin

Go back to the Blufftop Trail and follow the trail north to the public access steps to Black Point Beach. At Black Point Beach you can see the basalt that formed the floor of the Gualala basin in Late Cretaceous time 90 million years ago. These are the oldest rocks at Sea Ranch. To get a good look at the basalt, go down the public access steps to Black Point Beach. The rock that you are looking at on the way down the steps is basalt. The basalt is dark green and fine grained. It is difficult to see the rock crystals even with a hand lens. The basalt looks hard, but if you hit it with a hammer it shatters into small sharp fragments.

We know that this basalt formed under the ocean rather than on land because there are pillows in the basalt and pillows form where basalt flows are extruded under water. Although the basalt has pillow structure, it is difficult to see the pillows at Black Point Beach because the basalt is so highly fractured and faulted. Good pillows can be seen at Stop 3 near Whaler's Reach where weathering has etched the shapes of the individual pillows.

Basalt is a very common rock on the earth's surface. It forms when the dark heavy ultramafic rocks of the earth's mantle, deep within the earth, rise to near the surface of the earth. The ultramafic rocks are still hot, but because they are at a lower pressure near the surface they begin to melt. The molten rock, or magma, flows out onto the earths surface through fractures. The magma solidifies rapidly, forming layers of basalt. Most of the world's ocean basins are underlain by basalt. There are also extensive layers of basalt in many continental areas. When extruded on land, the basalt tends to have many small holes caused by gas escaping from the magma when it solidifies. When the basalt magma is extruded under water the water pressure tends to keep the gas in the rock, so the small holes, or vesicles, do not form.

The south end of the beach ends abruptly at a cliff. This cliff is formed from the same conglomerate that we saw at Black Point. The conglomerate is resistant, and that's why the beach stops here. At the southernmost end of the beach you can see a vertical zone in the bluff that forms the contact between the conglomerate and the basalt. It appears that the conglomerate was deposited on top of the basalt, but minor faulting occurred along the contact.

During the late 1800's there was a chute at Bihler Point for loading lumber on schooners, and the area between Bihler Point and Black Point had a hotel, postoffice, livery, and blacksmith shop. During the summer, about five schooner's a month would be loaded with tan bark, oak, and redwood lumber using this chute.

Stop 3. Whaler's Reach, Pillow Basalt

From the steps at Black Point Beach, follow the Blufftop Trail one mile north to the hedgerow at Whaler's Reach. Follow the path in the hedgerow to the edge of the bluff. The bluff is formed of steeply dipping beds of pillow basalt. Pillow basalts form when basalt is extruded into water. As the basalt magma flows out onto the sea floor the water chills the outer part of the magma forming a crust in the shape of a pillow. The magma inside the pillow continues to flow, and breaks through the crust to form another pillow, and so on. They form piles that look like hard black pillows that have been stacked together.

The pillows here have been etched by weathering. The central parts of the pillows are largely missing, but the outer margins remain. The green mineral in the fractures and holes in the pillows is epidote. The epidote was deposited long after the pillows were formed.

The knife points to the edge of a pillow in pillow basalt exposed on the bluff near Whaler's Reach. The pillow was formed when basalt magma was chilled by sea water when it was extruded onto the floor of the Gualala basin in late Cretaceous time.

Stop 4. Pebble Beach, Sandstone and Shale

Continue along the Blufftop Trail north to the public access steps to Pebble Beach and go down the steps to the beach. Now go to the cliff at the north end of Pebble Beach. This cliff is formed from conglomerate that is similar to the conglomerate at Black Point. However, the conglomerate at Black Point is hundreds of feet thick, whereas this bed is less than 20 feet thick and is interbedded with sandstone and shale.

Go to the rocks that form the cliffs at the south end of the beach. These rocks are thick sandstone beds. If you look at the rock closely you will see that it is made up of sand grains similar to the beach sand. If you stand back a few feet and look at the rocks you will see that the rocks form distinct tabular layers several feet thick that are tilted like books on a bookshelf. Each of these tabular layers is a "bed" of sandstone. The sandstone beds are separated by thinner beds of dark gray fine grained shale. The shale is mud that has been hardened by deep burial. It is fine grained, dark gray, and easily eroded.

To picture how the sandstone and shale beds were deposited, pick one of the shale beds and pretend you are standing on the sea floor 75 million years ago when the mud was deposited. The water was about 3000 feet deep over your head. As you are standing there, a thick mixture of sand, mud and sea water approaches you like a snow avalanche. As you are caught up in the turbidity current, you are a little lighter than the mixture of mud, sand and water, so you end up riding along in the top of the flow. As the velocity of the turbidite flow decreases, the sand begins to settle out to form a sandstone bed. The mud then settles out on top of the sandstone bed and forms a new mud sea floor. You can now stand on this new sea floor and await the next turbidite flow. Most of the rocks that we'll see along the Sea Ranch bluff are sandstones and shales similar to these and deposited in a similar manner, one on top of the other, for millions of years.

At low tide you can make your way around the rocks at the south end of the beach and enter a small cove that has a waterfall. Immediately to the right of the waterfall you can see the contact between the Black Point Beach basalt and the sandstone and shale at Pebble Beach. We saw a similar contact at the south end of Black Point Beach between the basalt and the conglomerate at Black Point. The conglomerate at Black Point and the sandstone and shale at Pebble Beach both directly overlie the basalt and were therefore deposited at about the same time. If they were deposited at the same time why are there so few conglomerate beds at Pebble Beach? Possibly Black Point was in a deeper part of the basin during deposition of the sedimentary rocks, and the conglomerates were therefore concentrated at Black Point.

Now return to the center of Pebble Beach. The bluff along the central part of the beach is mainly shale and thinly bedded sandstone. These rocks are softer and less competent than the conglomerate at the north end of the beach and the thick beds of sandstone at the south end. The thin bedded sandstone and shale have been easily contorted and squeezed into small anticlines, where the beds are bent upwards, and synclines, where the beds are bent downward. These soft rocks were also easily eroded to form a cove between the hard conglomerate at the north end of the beach and the thick and competent sandstone beds at the south end of the beach. Sand accumulated in the protected cove, resulting in Pebble Beach.

The rocks at Smuggler's Cove, North Rec. Beach and Stengel Beach are similar to those at Pebble Beach, mainly sandstone and shale, with an occasional conglomerate bed. All of these beaches have a thick conglomerate bed at the north end and thick beds of sandstone at the south end of the beach. The beach itself in each case was eroded from the softer shale and thin bedded sandstone. Sand accumulated in the protected coves resulting in these beaches.

Stop 5. Shell Beach, The Sediments Dip North

Continue north on the Blufftop Trail to Shell Beach and go down the public access path to the beach. Shell Beach has excellent exposures of conglomerate. The conglomerate forms the point of land that separates Shell Beach from Tide Pool Beach. The rocks in the surf zone and the cliffs at the south end of the beach are conglomerate. The conglomerate is also exposed along the bluff for half mile south of Shell Beach.

The conglomerate at Shell Beach differs from the conglomerate at Black Point in that the conglomerate at Shell Beach occurs in distinct beds and is interbedded with sandstone and shale. Each of the conglomerate beds and sandstone beds represents a different turbidite flow. The conglomerates are overlain by shale. This shale forms the recessed part of the bluff with the access steps to the beach. It is this soft shale that has been eroded to form Shell Beach.

The rocks at Shell Beach are tilted, or dip, to the north. Indeed, most all of the rocks on the Sea Ranch bluff from Pebble Beach to the north boundary of Sea Ranch dip north. They dip north because they are on the north flank of the Black Point anticline. The top of the anticline has been removed by erosion. The dipping beds all along the bluff are truncated by this erosion. The center, or axis, of the anticline is offshore from Shell Beach and trends south to intersect the coast at Black Point Beach. The oldest rocks are exposed at the center of the anticline and the rocks become younger away from the center. Thus the rocks at south end of Sea Ranch are older and the rocks to the north are younger.

Although the conglomerate is highly resistant to marine erosion and therefore forms points along the bluff, it is readily decomposed by surface weathering. Because of its susceptibility to weathering, it is difficult to find good outcrops of conglomerate on the hillside. To see this weathering, go to the point of land that separates Shell Beach from Tide Pool Beach. The conglomerate at the base of the bluff is hard. At the top of the bluff the conglomerate is yellow and you can dig into the conglomerate with your fingers. This yellow weathered zone extends from the surface of the meadow down into the rocks for about 10 feet. In this zone the rocks are constantly exposed to water, which accelerates the breakdown of the minerals in the rocks.

Stop 6. Marine Preserve, A Wave Cut Platform

Continue north on the Blufftop Trail to the headlands at the marine preserve south of Walk-On Beach. At low tide you can take one of the paths down the bluff and walk out onto the rocks that form the sea floor at the marine preserve. The sea floor consists of dark gray shale and thin beds of fine grained sandstone. The beds have been tilted and have been truncated by the grinding action of the rocks in the surf zone so that they now form narrow ridges on the sea floor. Rocks moving back and forth in the surf zone work like a giant horizontal chain saw abrading the sea floor to produce this nearly flat surface. During periods of high swells, the chain saw is on high power. If you have any doubts about the efficiency of this cutting mechanism, stand on the bluff when large swells are coming into the coast and listen to the chain saw in action.

This flat sea floor surface is called a wave cut platform, and may well become a marine terrace in the future. With a drop in sea level several things would happen. The shoreline would move west, the wave cut platform would be preserved as a terrace, sediments would be left behind to cover the wave cut platform, the bluff would be preserved as an old sea cliff, and the sea would begin to cut a new wave cut platform and bluff along the new shoreline.

The sea floor at the marine preserve south of Walk-On Beach is formed of steeply dipping beds of sandstone and shale of the Anchor Bay Member of the Gualala Formation. The tilted layers of rocks were carved to the present horizontal surface by wave action.

Stop 7. Walk-On Beach, A Walk from Dinosaurs to Mammals

Continue north on the Blufftop Trail to the access path at the south end of Walk-On Beach and go down to the beach. This path is on sand and goes down the face of a sand dune. Now go south on the beach to the rocks that form the south end of the beach. These rocks are sandstone. Many of the sandstone beds show graded bedding, which is characteristic of deposition by turbidity currents. To see the graded bedding, look for a sandstone bed where the sand grains at the base of the bed are coarse and the sand grains at the top of the bed are fine. As the velocity of the turbidite flow decreased, the coarse grains settled out first, followed by the finer sand grains. The sandstone beds are separated by beds of dark gray shale. Some of this shale was deposited during the final stages of the turbidity flow and some settled out of suspension from the sea water after the flow.

When this white sandstone bed was deposited by a turbidity current it cut a small channel in the sea floor. The sand grains at the base of the bed are coarse and were deposited when the current was strong. The sand grains at the top of the bed are fine, and were deposited when the current was weak. The photo is from the south end of Walk-On Beach.

When some of the sandstone beds were deposited, they cut small channels into the underlying shale that formed the sea floor at that time. The channels have coarse sand in the lowest part of the channel. These channels are generally linear, and can be used to tell the direction of flow of the turbidity current. They are also one of the best ways to determine the base and top of the bed. If the channel is upside down, the bed is overturned.

Many of the sandstone beds have small fragments of shells mixed in the sand grains. The shell fragments are about the size of a finger nail clipping. The shell fragments indicated that the sand was derived from a marine environment, probably a beach. The shell fragments were mixed with the sand and carried to the floor of the Gualala basin by turbidity currents.

Proceed north along Walk-On Beach toward the public access steps. The low cliffs along the main part of the beach are mainly shale. Some of the shale beds at the north end of the beach have good examples of organic borings, the fossilized remains of paths bored in the mud by various animals. To see the organic borings go to the low rocks that are exposed on the beach near the access steps. These rocks are thin beds of sandstone and shale. The shale beds are dark gray and fine grained. If you examine the shale in detail you will see linear sandy tubes in the shale, about the size of straws, somewhat lighter gray than the surrounding shale. These are the organic borings. Some borings extend to the top of the shale bed, indicating the bore hole entrance on the sea floor. Organic borings are common in shale, but are often hard to see because the shale weathers easily, destroying traces of the borings. There are excellent examples of organic borings at Bowling Ball Beach.

The sandstone and shale in the south and central parts of Walk-On Beach belong to the Anchor Bay Member of the Gualala Formation and were deposited in Cretaceous time, while dinosaurs roamed the North American continent. The sandstone beds at the access steps at the north part of Walk-On Beach belong to the German Rancho Formation, and were deposited in Paleocene time, after all the dinosaurs had died out. As you walk up the steps at the north end of the beach you are leaving Cretaceous time and no longer have to be concerned about running into Tyrannosaurus Rex. You are entering the age of mammals as you continue your walk along the bluff to the north.

Stop 8. Cove North of Walk-On Beach, Reading the Rocks

Continue north on the Blufftop Trail to the small cove 200 feet north of the hedgerow north of Walk-On Beach. The rocks in this cove provide a good summary of the geologic history of Sea Ranch. If you look from the Blufftop Trail to the north wall of the cove you will see the tilted sandstone beds overlain by horizontal terrace deposits. Six distinct geologic events are recorded in these rocks:

1. The sandstone beds at the lower part of the cliff belong to the German Rancho Formation, and were horizontal when deposited.
2. The sandstone beds were tilted to the north when the Black Point anticline was formed 10 million years ago.
3. The tilted sandstone beds were eroded to a horizontal surface during Sangamon interglacial time 100,000 years ago.
4. The horizontal sediments that underlie the meadow were deposited as sea level dropped at the beginning of the Wisconsin glacial period.
5. The meadow was uplifted about 40 feet above sea level.
6. The bluff has been eroded to form the cove.

The bluff in this small cove shows a well defined "unconformity" between the tilted beds at the lower part of the cliff and the horizontal beds at the uppermost part of the cliff. The tilted beds belong to the German Rancho Formation. The horizontal beds were deposited during the Pleistocene, and underlie most of the Sea Ranch meadow.

The surface that separates the older tilted sandstone beds from the younger horizontal terrace deposits is called an unconformity. An unconformity represents a significant break or gap in the geologic record caused by uplift and erosion, or by lack of deposition. The unconformity and the sediments that were deposited on the unconformity underlie the Sea Ranch meadow. The origin of the meadow is described in more detail during Stop 1 on the trip to the meadow and hillside. Stop 1 on that trip is at this same location.

Stop 9. Tide Pool, Bluff Erosion

Follow the Blufftop Trail to the wood bridge near Tide Pool. Continue on the trail 200 feet beyond the bridge to the small point of land at the edge of the bluff. From this point you can get good views north and south along the bluff, and see good examples of bluff erosion. If you look to the south you will see a thick sandstone bed that is tilted toward the bluff. At low tide you can see that the shale at the base of the sandstone has been cut away, so that the sandstone is undermined and forms a slab that overhangs the sea floor. This slab is getting ready to break from the bluff. If you don't believe that it will break from the bluff, look north along the bluff and you will see a similar massive sandstone that has broken from the bluff. The slab is now being broken into smaller pieces by wave action in the surf zone. This is just one of many types of bluff erosion. Most bluff erosion occurs during a few infrequent but violent storms.

A large block of sandstone has broken from the bluff near Tide Pool and is now in the surf zone being broken into smaller pieces by wave action.

Stop 10. Del Mar Point, Weathering of Sandstone

Follow the Blufftop Trail north to Del Mar Point. The bluff at Del Mar Point is formed from very thick sandstone beds of the German Rancho Formation. The sandstone beds stand out in bold relief as steeply dipping beds, and are separated by thin shale beds that form deep recesses between the sandstone beds. These thick sandstones are very hard, and have put up a fierce resistance to the waves, resulting in Del Mar Point.

Although the sandstone beds are now very hard, they were soft when they were originally deposited. The soft sand became hard sandstone due to deep burial and cementation. The oldest sediments in the Gualala basin were covered by as much as 30,000 feet of younger sediments. Due to this deep burial, some of the sand grains were altered chemically and fused together. As the sediments in the basin were compacted, water was squeezed out of the mud. This water circulated between the sand grains and deposited calcite and silica, cementing the grains together.

Many of the sandstone beds at Del Mar Point have small pits on their surface. The pits, called honeycomb weathering, occur in the sandstone that is exposed in the wave splash zone above high tide level. This part of the sandstone is constantly subjected to wetting and drying of the sea water. The water accumulates in depressions in the sandstone and when it dries the salt crystallizes and pries out the sand grains. Through time, the pits are dug into the sandstone. Some of these pits are vertical and are several inches deep, looking like drill holes.

Some of the sandstone beds at Del Mar Point also have irregular or ball-like shapes that protrude from the weathered surface. These features result from differential weathering of the sandstone which accentuates those parts of the sandstone that are more strongly cemented. The cementation sometimes follows subtle patterns that formed within the sandstone bed when the sand was being deposited, like cross bedding, convolute bedding, and graded bedding. Rounded nodules tend to occur in certain parts of other sandstone beds. These rounded nodules are extremely hard and were formed where quartz or calcite cement was localized in the sandstone bed during weathering of the sandstone.

From 1898 to 1910 there was a lumber mill and a chute for loading the lumber on schooners at At Del Mar Point. A small railroad brought the lumber to the mill. On the nearby Coast Road, now Highway 1, there was a store, saloon and school for the children of the millworkers. The Del Mar School is still standing, and can be seen at the southwest corner of Deer Trail and Leeward.

The upper photo shows steeply tilted sandstone beds of the German Rancho Formation at Del Mar Point. The lower photo shows detail of honeycomb weathering in some of these beds. Honeycomb weathering is found in many of the sandstone beds along the Sea Ranch bluff.

Stop 11. Mainsail, A Small Anticline
Continue north on the Blufftop Trail to the point of land at the end of Main Sail. From here look north to the point of land at the end of Buckeye. There is a small anticline that can be seen in the bluff at the end of the point. An anticline is an arched up fold of rocks. One limb of the anticline dips gently northeast and the other limb dips sharply southwest. There are many similar small anticlines in the sedimentary rocks along the bluff. Minor folding and faulting like this can be expected when 30,000 feet of sediments are squeezed and lifted above sea level.

Stop 12. Buckeye, Gualala Point Island
Continue north on the Blufftop Trail to the point of land at the end of Buckeye. From here look north to Gualala Point Island. The island has a flat top with a thin cap of horizontal sediments. The flat top of the island is part of the Sea Ranch meadow that got left behind as the bluff was eroded eastward. The lower part of the island consist of vertical beds of sandstone and shale of the German Rancho Formation, the same rocks that are exposed along the bluff.

Gualala Point Island was left behind as the bluff and meadow were eroded landward. The flat top of the island is a remnant of the meadow.

A TRIP TO
THE MEADOW AND HILLSIDE

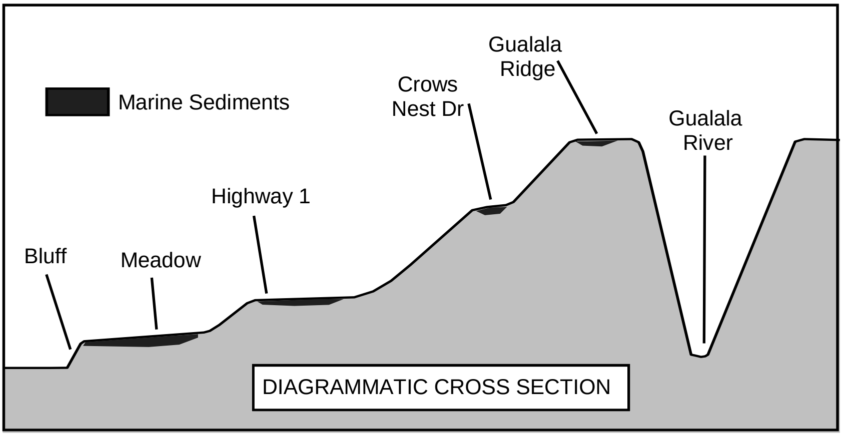
The geologic trip on the meadow and hillside is best done by automobile, with short walks to specific localities. About two hours should be allocated for this trip.

Stop 1. Cove North of Walk-On Beach, The Meadow

At Stop 1 we'll investigate how the meadow was formed. This is the same locality as Stop 8 on the trip to the Sea Ranch bluff. To get to Stop 1 go to the intersection of the Walk-On Beach public access trail and the Blufftop Trail, then go north on the Blufftop Trail 500 feet to the small cove. From the Blufftop Trail you can get a good view of the north wall of the cove.

Near the top of the bluff on the north wall of the cove there is a horizontal erosion surface that truncates the tilted sandstone beds that form the main part of the bluff. Horizontal layered sedimentary rocks lie on top of that erosion surface and extend up to the meadow at the top of bluff. The horizontal erosional surface was cut by the ocean during the Sangamon interglacial period of the Pleistocene when sea level was high. The sedimentary rocks that lie on that surface consist of sandstone, gravel and clay that were deposited as the sea retreated westward at the beginning of Wisconsin glacial time. The erosion surface and the sediments that lie on that surface underlie the entire meadow. The terrace sediments range from 10 to 30 feet in thickness. If you live on the meadow and have a septic system, these are the rocks into which your septic system drains. If these sediments are thick, contain a high proportion of sandstone and gravel, and are above the water table, the system drains well. Where these sediments are thin, have a high proportion of clay, and are in the water table, drainage will be poor.

During the Wisconsin glacial period sea level was low and the meadow extended several miles west of the present shoreline. As the glaciers began to melt at the end of the Wisconsin, about 10,000 years ago, sea level began to rise, and a sea cliff, or bluff, began to be cut along the new shoreline. The sea has continued to erode the bluff landward at an average rate of several inches per year up to the present time. The bluff is still eroding landward. This erosion has exposed the terrace and the terrace sediments at the top of the bluff, and the terrace and the sediments can now be seen at the top of the bluff all along Sea Ranch.



The coastal area from Point Reyes to Cape Mendocino has been uplifted several hundred feet over the last two million years. Old marine erosion surfaces and the marine sediments deposited on those surfaces have been preserved by this uplift. These surfaces are now at elevations of 40 to over 500 feet. The oldest marine erosion surface is the flat top of Gualala Ridge. The terrace at Crow's Nest Drive was cut about 500,000 years ago, the terrace along Highway 1 about 200,000 years ago, and the meadow terrace about 100,000 years ago. As the land was uplifted, the Gualala River maintained its course near sea level. The elevations in this cross section are highly exaggerated and not to scale.

Stop 2. Back Pack, An Old Sea Cliff

Go to the intersection of Leeward Road and Back Pack and drive up the small hill to the cul de sac at the end of Back Pack. Note that the cul de sac is on a flat surface similar to the meadow, but about 40 feet higher than the meadow. This is an older terrace that was cut perhaps 100,000 years before the meadow was cut. This surface was preserved by the general uplift of the coastal area. Much of Highway 1 is on this terrace. The sandstone cliff between Back Pack and Leeward is the old sea cliff that was at the shoreline of the Sangamon sea when the meadow terrace was cut. This old sea cliff has the same relationship to the meadow as the bluff does to the present shoreline. Highway 1 follows along near the edge of the old sea cliff, just as the Blufftop Trail follows near the edge of the bluff. Just as the bluff provides a good perch for houses overlooking the ocean, the old sea cliff provides a good perch for houses overlooking the meadow. One hundred thousand years ago these houses would have been ocean front. Other roads on this old sea cliff include Equinox, Tallgrass, Bosuns and Sea Watch.

The old sea cliff has been wearing down for 100,000 years and is best preserved where it is formed of massive resistant sandstone beds like these at Back Pack.

Stop 3. Dune Drift, A Sand Dune

There are several sand dunes on the meadow. To see one of these dunes go south on Leeward to Dune Drift and park in the cul de sac at the end of Dune Drift. The small hill on the south side of the cul de sac is a sand dune. Although it is now largely covered by vegetation you can still see the dune. Similar dunes can be found at the south end of Walk-On Beach and in the commons at the end of Rock Cod. These dunes all occur at the top of the bluff at the south end of sandy beaches. The sand was carried up over the bluff by the prevailing north wind and deposited near the edge of the bluff.

The hedgerow of Monterey cypress immediately south of the cul de sac at Dune Drift was planted about 1916. At that time this area was a cattle ranch. This is one of several hedgerows that were planted on the ranch to serve as windbreaks.

Opposite page. The houses on Tallgrass, at the top of the hill, are on the edge of an old sea cliff. The houses on Leeward, at the base of the hill, are on the Sea Ranch meadow, which is an old wave cut platform. The old sea cliff has the same relationship to the meadow as the bluff to the present shoreline.

Stop 4. Sea Gate, Old Sea Stacks on the Meadow

To see some old sea stacks, return to Highway 1 and go south to Galleon's Reach at M 51.85. Turn west on Galleon's Reach. Turn right on Sea Gate Road and continue to Whaler's Reach. Immediately east of this intersection there is a small hill of conglomerate. This is the same conglomerate that can be found at Pebble Beach. Next go about 300 feet toward the ocean on Whaler's Reach to the small hill next to the Sea Ranch trail. This hill consists of basalt. This is the same basalt that can be seen in the cliffs along Black Point Beach. Both of these hills were sea stacks in the Sangamon sea when the meadow was being cut. The old bluff that was at the shoreline of the Sangamon sea is between Galleon's Reach and Highway 1.

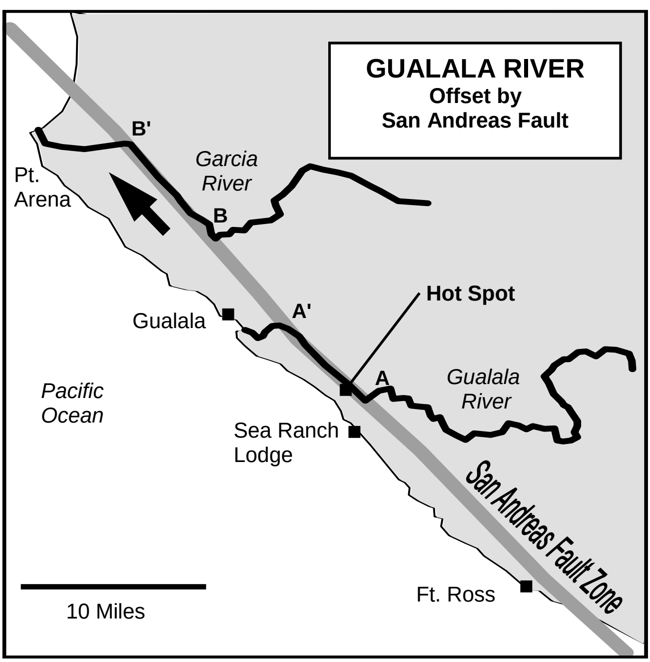
Stop 5. Gualala Ridge, An Old Erosion Surface

The top of Gualala ridge is an old erosion surface. To get to the top of Gualala ridge go up Annapolis Road to the Sea Ranch Airstrip and Business Center and park at the Business Center. You are now on the Gualala ridge. The trip up Annapolis Road to the top of the Gualala ridge was steep, but the land in the vicinity of the airstrip and business center is relatively flat with low rolling hills. This low rolling topography is a remnant of an old erosion surface that was near sea level in late Pliocene time three million years ago. When the coastal area was uplifted at the beginning of the Pleistocene, two million years ago, river valleys cut deeply into this surface, confining the remnants of the old surface to the ridge tops. The next time you drive on the Skaggs Springs Road to Healdsburg notice that many of the mountains and ridges in the Coast Ranges have tops that are nearly flat. These are also remnants of the old erosion surface. Some easily accessible examples are: Old Stage Road from Gualala Arts to Ten Mile Cutoff; Annapolis; Annapolis Road to the County Dump; and Tin Barn Road from the Stewarts Point Rancheria toward Hauser Bridge Road. Most of these remnants are now at elevations of 400 to 1000 feet.

Stop 6. The Hot Spot, On the San Andreas Fault

The Hot Spot is in the San Andreas fault zone, and this is a good place to get near the San Andreas fault. It is also a good place to barbecue a hot dog. To get to the Hot Spot turn north from Annapolis Road onto Timber Ridge Road and then turn right on River Beach Road. Park at the end of the road next to the Gualala River. The fault follows the river through Sea Ranch. The fault zone is at least half a mile wide and the rocks along the fault zone have been ground up and eroded so there are no good exposures of the fault. The Gualala River follows along the fault zone because the rocks were easily eroded. The steep slope down River Beach Road to the Hot Spot is caused by erosion of the pulverized rocks within the San Andreas fault zone.

The fault is still active and moving the rocks on the southwest side of the fault to the northwest at an average rate of about an inch per year. However, this movement comes in jerks, accompanied by earthquakes. There has been no significant movement along this part of the fault since the 1906 San Francisco earthquake. During that earthquake there was about ten feet of movement in this area. If you throw a rock across the Gualala River from the Hot Spot and wait a million years while your hot dog is cooking you will have traveled 16 miles north of the rock, in fits and spurts, courtesy of the San Andreas fault.



Over the last half million years, all of the land on the southwest side of the San Andreas fault has been carried northwest about seven miles by movement along the fault. The Gualala River was offset from A to A’, and the Garcia River was offset from B to B’. The rivers carved out the rocks along the fault zone as they chased their mouths to the north.

Stop 7. Indian Close, A Sag Pond

Sag ponds are often formed along faults. To see a sag pond return to Annapolis Road, turn west past the Business Center, and then turn south on Timber Ridge Road. Go 1.0 mile and park near the intersection of Indian Close and Timber Ridge Road. The sag pond is immediately northwest of the intersection in the commons between Indian Close and Lumberjack. This sag pond formed on the Gualala Ridge fault. Although the main San Andreas fault follows the valley of the Gualala River, there are several nearby faults like the Gualala Ridge fault that run parallel to the main fault and are part of the San Andreas fault system. The Gualala Ridge fault follows the Gualala ridge through Sea Ranch. This fault has formed another sag pond east of the intersection of Schooner Drive and Seabird Road.

Sag ponds occur along the faults because the faulting forms linear ridges and depressions, and these disrupt the established drainage pattern. Many of the depressions, or sags, have no drainage outlet and therefore ponds develop in these depressions. The rocks along the fault zone are pulverized to form a clay like material that retards drainage of the water from the pond into the ground.

Stop 8. Crow's Nest Drive, An Old Hillside Terrace

The hillside has a number of old marine terraces, areas where the hillside flattens out. To see one of there terraces continue south on Timber Ridge Road a short distance to Moonraker and then go west on Moonraker 0.5 miles to Crow’s Nest Drive. Turn left on Crows Nest Drive. Most of Crow's Nest Drive south of Moonraker Road is on a marine terrace. This terrace was formed several hundred thousand years ago in the early stages of the uplift of the coastal area. Many hillside roads and houses are built on these old terraces. Old hillside terraces can be found along Fly Cloud Road, Conifer, Rams Horn Reach, Packet, Wildfern, and Deer Trail.

Most of the hillside terraces were cut from 200,000 to 2,000,000 years ago. The highest terraces are the oldest. These terraces were preserved because of the general uplift of coastal area. If the coastal area had submerged instead, as at San Francisco Bay, the terraces would not have been preserved.

Stop 9. The Rocks along Highway 1

Stop 9 is not really a stop, but rather a drive along Highway 1 through Sea Ranch. The rocks along Highway 1 are the same rocks that are exposed along the bluff. However, on Highway 1 the rocks are weathered and in places covered by terrace deposits. When you do this trip, don't try to drive and look at the road cuts at the same time. Get someone else to drive while you look. To begin the drive go down Moonraker Road to Highway 1. Turn south on Highway 1. Go to Milemarker (M) 49.05, turn around in the pullout area and begin driving north on Highway 1.

M 50.59 + 200 feet: Outcrops of sandstone and conglomerate can be seen in the road cuts on the right side of the road. These are the same conglomerates that occur on Black Point and Bihler Point.

M 51.56 + 500 feet: The large roadcut on the right is basalt. This is the same basalt that is exposed in the cliffs along Black Point Beach. Here the basalt is weathered to a yellow color and fractured so that it breaks into small fragments.

Highway 1 and Annapolis Road: The outcrops on the right side of the road are sandstone and shale of the Gualala Formation, similar to the sandstone and shale at Pebble Beach. The rocks dip steeply.

M 53.34 + 300 feet: The small hill on the right is sandstone of the Gualala Formation, similar to the sandstone seen at Stengel Beach.

M 55.97: The large white boulders on the right side of the road are sandstones of the German Rancho Formation.

M 58.05 + 200 feet: This roadcut has exposures of sediments that were deposited on the terrace that Highway 1 follows.

Roadcut between Golf Course Turnoff and Gualala River: This roadcut consists of sandstones and shales of the German Rancho Formation, similar to the sandstones and shales on the bluff in Gualala Point Regional Park. The axis of the Gualala syncline can be seen in this roadcut. A syncline is a downward fold of the rocks. At the south end of the roadcut the sedimentary beds dip north. At the north end of the roadcut the beds dip south. The axis of the Gualala syncline is near the center of the roadcut in the lowest part of the downward fold. The axis of this syncline is also exposed on the bluff at the boundary between Sea Ranch and the County Park.

A TRIP TO
GUALALA POINT REGIONAL PARK

You can reach the Gualala Point Regional Park by continuing north from Sea Ranch on the Blufftop Trail or by car from Highway 1. Whichever way you arrive, follow the trail in the park to the beach. From the beach you can see the sand bar at the mouth of the Gualala River. The sand in this bar was carried down the river during high water stages and deposited as the current slackened upon reaching the ocean. Most of the sand was derived from erosion of sandstones of the Franciscan that are widespread in the headwaters of the Gualala River on the east side of the San Andreas fault. The Franciscan will be described in more detail later.

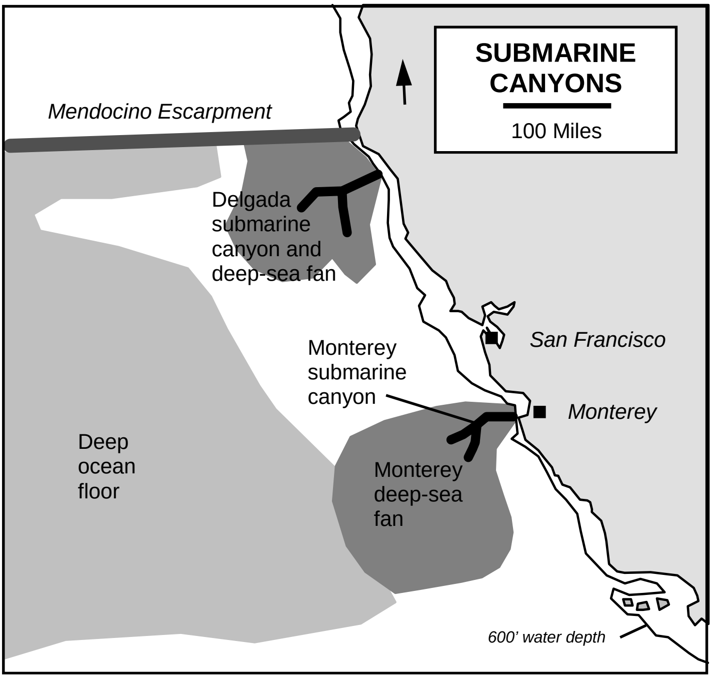
Over the last two million years a huge amount of sand has been carried down the river. Most of the sand did not stay in the bar. Ocean currents carried some of the sand southward to form beaches along Sea Ranch. Some was deposited in sand dunes. Some was carried along the shore until it reached a submarine canyon, and then was carried down the canyon by turbidity currents and deposited on the deep ocean floor. The sand being deposited on the ocean floor is forming new sandstone beds similar to those in the Franciscan from which the sand was derived. The sand is being recycled.

Go south along the beach toward Whale Watch Point. About 100 yards before the beach is terminated by the rocks that form Whale Watch Point there are some excellent exposures of thick turbidite sandstones. One of these beds is tilted so that you can walk on the top of the bed to reach the blufftop. If you look at this sandstone in detail you will see that the sand grains are all about the same size and there is no graded bedding. At the top of the bed there are large pieces of shale that were scoured from the sea floor by the turbidite flow when the sand was being deposited. Since the mud fragments were lighter that the sand, they were carried to the top of the sand during the turbidite flow.

These sandstone and shale beds belong to the German Rancho Formation, and are similar to the rocks along the Sea Ranch bluff north of Walk-On Beach. The rocks are tilted to the southwest and are on the south flank of the Gualala syncline. The axis on the syncline is exposed on the bluff at the boundary between Sea Ranch and Gualala Point Regional Park.

At the far south end of the beach there is a cave in the bluff. The cave formed because the rocks in the bluff are highly fractured and were easily eroded. This fracturing was caused by a small fault. To find the fault, look to the right of cave and locate the resistant three-foot thick sandstone bed. Follow that bed as far as you can toward the cave. It intersects the cave above your head. Now look to the left of the cave and find the same three-foot thick sandstone lower on the cliff. Trace the sandstone toward the cave. It intersects the cave about 10 feet lower than the sand on the right. The fault is the fractured zone in the cliff which offsets this bed. The bed has been faulted downward to the east about ten feet. The roof of the cave is formed by terrace sediments. The fault does not offset the terrace sediments. This means that the fault is older than the terrace. Since the terrace sediments were deposited over 10,000 years ago, the fault has not been active for at least that amount of time.

The thick sandstone bed in the bluff at the right has been offset by a small fault. The same sandstone bed is seen on the left side of the photo about ten feet lower on the bluff, where it has been dropped by the fault. The rocks along the fault have been fractured causing a recessed area in the bluff. The fault is at the south end of the beach at Gualala Point Regional Park. There are many similar small faults along the Sea Ranch bluff.



Turbidity currents are still in action along the California coast. Turbidites periodically flow down the Monterey submarine canyon and the sediments are deposited on the Monterey deep-sea fan and on the deep ocean floor at the base of the fan. Further north, similar processes occur on the Delgada submarine canyon and deep sea fan.

A TRIP TO
BOWLING BALL BEACH

It's best to go to Bowling Ball beach at low tide. To get to Bowling Ball Beach go north on Highway 1 to M 11.41 and park in the designated area for Schooner Gulch State Beach on the west side of the highway facing south. There are two trails from the parking area. Take the trail at the north end of the parking area. Follow this trail 0.1 mile across the meadow and then take the path down to the beach. Continue north along the beach 0.5 miles to the large "bowling balls" in the surf zone.

The sandstones and shales at Bowling Ball Beach belong to the Galloway Formation of Miocene age. These rocks are younger than the rocks at Sea Ranch, but like the rocks at Sea Ranch they were deposited in the Gualala basin by turbidity currents. The rocks dip steeply west and are on the west limb of the Ferguson anticline.

The bowling balls are round, about two to three feet in diameter, and consist of sandstone. The bowling balls were derived from the thick sandstone beds exposed in the cliff a couple hundred yards to the north. You can see the large bowling balls protruding from the beds in the cliff. The bowling balls are concretions and were formed where cement was localized in the sandstone. Concretions result from a tendency of minerals of like composition to precipitate around a common center. As the cliff is worn back by the waves, the hard sandstone concretions will be left behind, forming new bowling balls. Sandstone concretions of this size and shape are unusual.

Many of the sandstones at Bowling Ball Beach have excellent examples of "convolute laminations", complex wavy patterns within the beds. Weathering has emphasized these convolute patterns giving the weathered surface a weird wrinkled appearance. Convolute laminations were formed in the very soft sediments at the final stages of the turbidity flow. The water-sediments were easily contorted in the weak current. If you go back and look closely at the bowling balls you will see that they also have convolute laminations. The sandstone beds that contain the bowling balls also have convolute laminations. The convolute laminations extend across the boundary between the soft sandstone and the hard sandstone that forms the bowling balls. This confirms that the bowling balls are concretions that were formed by differential cementation within the sandstone bed and that they are not separate boulders deposited in the sandstone bed.

The bowling balls at Bowling Ball Beach in the upper photo were derived from the thick sandstone bed seen on the bluff in the center of the photo. The lower photo shows a bowling ball in the process of weathering from the sandstone. The bowling balls formed where the sandstone was locally cemented forming large round concretions.

The highly irregular weathering pattern in this sandstone bed resulted from differential weathering of a turbidite sandstone. The weathering emphasizes the convolute laminations that formed in the sandstone when the bed was deposited.

The pencil-shaped structures represent boreholes that were made by organisms living in the mud on the sea floor. The borings can best be seen on clean fresh surfaces of shale below thick sandstone beds. Similar borings occur in shale of the German Rancho Formation at Sea Ranch.

Go another 0.1 mile north on the beach and you will see some large yellow rocks near the base of the cliff that look like huge toasted muffins. If you look at the muffins in detail you will see that the fresh rock is gray, very fine grained and very hard. The rock is shale that has been cemented by quartz so that it forms large flat concretions that are highly resistant to weathering. Concretions often form around plant or animal fossils, where the chemistry of the rocks around the fossil was altered by the fossil. Concretions may also form where there are no fossils. Most concretions in shale are much smaller than the muffins.

The sea floor in the surf zone under the bowling balls is a wave cut platform. It has low linear ridges that seem to form bowling lanes. The ridges on the sea floor are formed from dipping beds of sandstone and shale that have been truncated by erosion in the surf zone.

Large concretions in shale at the north end of Bowling Ball Beach look like huge yellow toasted muffins. The concretions formed where the shale is locally cemented by quartz. The concretions are extremely hard and were thus preserved as the cliff was eroded by the waves.

THE FRANCISCAN
CLEANING THE OCEAN PLATE

The rocks that we've looked at on the geologic trips are all on the west side of the San Andreas fault. These rocks are completely different from the Franciscan rocks on the east side of the fault. The Franciscan is a complex mixture of sediments and old sea floor that resulted from the collision of two large crustal plates 65 to 200 million years ago.

The Franciscan rocks are named for their exposures in the San Francisco area. They cover much of the coast ranges north of Monterey through Marin, Sonoma, and Mendocino counties. The volume of the rocks in the Franciscan is huge. If the Franciscan were spread out over the contiguous 48 United States, it would cover the States to a depth of 600 feet.

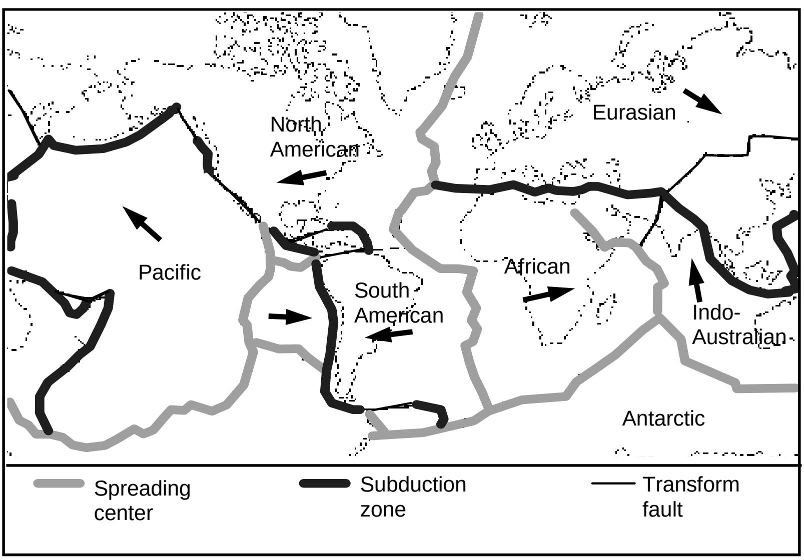
The Franciscan is like stew. It includes red chert that had been deposited on the deep sea floor far from continental areas, sandstone and shale derived from the continent and deposited along the margin of the continent, pillow basalts from the ocean floor itself, and serpentine, which is the altered form of the ultramafic rocks that form the mantle and lower part of the oceanic crust. In many places the Franciscan rocks have been so ground up and mashed by the collision of the plates that they form a clay matrix with boulders and irregular lenses of sandstone and other rocks floating in the matrix. These rocks are very unstable and landslides are very common. Road crews that repair Highway 1 between Jenner and Fort Ross are well aware of the instability of the Franciscan rocks. When you see the road signs "ROUGH ROAD" you are likely driving on Franciscan.

Plate Tectonics
To understand how the Franciscan was formed, and also how California was formed, we need to have an understanding of "plate tectonics". Under the theory of plate tectonics the earth's crust is divided into several large plates, the Pacific, North American, South American, African, Eurasian, Indo-Australian and Antarctic, and about a dozen smaller plates. The plates are relatively rigid and about 60 miles thick. In oceanic areas the uppermost five miles of the plate is basalt. In continental areas the uppermost 30 to 40 miles of the plate is lighter granitic rocks. Below the basalt and granitic rocks the plates consist of heavy dark rocks which are rich in iron and magnesium silicates. At a depth of 60 miles these "ultramafic" rocks become so hot they behave as a viscous fluid, and it is this zone that forms the base of the plates. This zone is called the asthenosphere. The rigid plates float on the asthenosphere. Continents with their lighter granitic rocks float high, like an ice cube in a glass of water, and thus rise above the oceans.

The rocks in the asthenosphere move slowly by convection currents and drag the overlying plates with them. The currents can cause the plates to break apart from one another, to collide, or to slip by one another horizontally. The convection currents move the plates at an average rate of about two inches per year. Where the earth's mantle is especially hot the currents flow upward and then spread apart at the top of the asthenosphere so that the overlying plates pull-apart from each other along "spreading centers". The hot rocks from the mantle rise into these spreading centers and then melt because of the lower pressure, forming basalt magma. The magma flows out onto the sea floor and forms pillow basalt as it cools. As the plates continue to move apart, basalt continues to flow from the spreading center. The Red Sea, Atlantic and Pacific and all of the other world's oceans formed in this manner.

As the convection currents move away from the spreading centers the rocks begin to cool. The cooler rocks are dense and begin to descend into the mantle. Where descending currents meet, the overlying plates collide and one plate is typically dragged, or "subducted", under the other plate. If one plate has continental crust and the other plate has oceanic crust, the dense

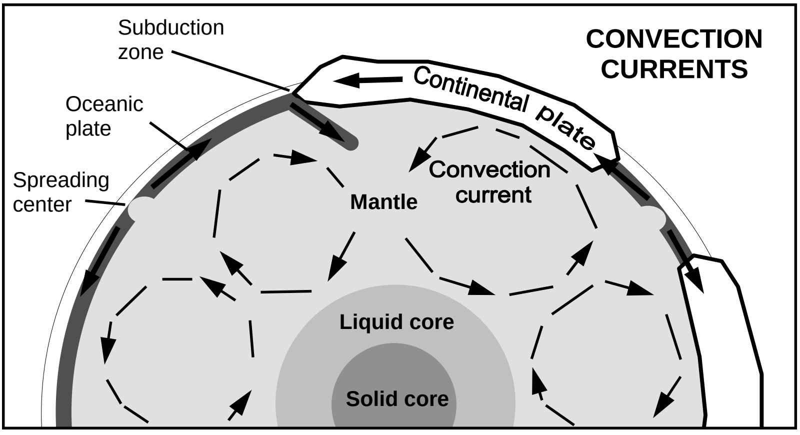
PLATES



The crust of the earth is divided into seven large plates and about a dozen smaller plates. Most of the large plates include both continents and ocean basins. The plates move in different directions, pulling apart, colliding, and slipping by one another laterally.

oceanic plate is dragged under the lighter continental plate. The crust in the collision zone is thick and therefore floats higher in the asthenosphere, forming mountains such as the Cascades. As rocks in the subducted plate descend deeper they become hotter. Some of the rocks in the descending plate melt and form magma rich in sodium, potassium, calcium, aluminum and silicon dioxide, elements obtained from the melting of the wet sediments on the sea floor that were subducted with the oceanic plate. The magma which is rich in these lighter elements rises into the upper plate. Some of the magma reaches the surface as volcanos. The magma that doesn't reach the surface cools slowly at depths of several miles, and crystallizes into granite. The granitic rocks that make up the continents have been slowly built up by this process over hundreds of millions of years.

Where convection currents cause one plate to slip by another plate horizontally, the plate motion is referred to as a transform fault. The San Andreas fault is a transform fault. Although it may seem conceptually difficult to shove around and collide plates that are 60 miles thick, keep in mind the scale of the plates and the earth. If the earth were the size of a basketball, the plates would be the thickness of a penny, and the highest mountains would be 1/10 the thickness of a penny. At this scale, the plates may seem a little easier to manipulate.



Plates are moved by convection currents in the hot and highly viscous rocks that form the earth's mantle. Hot convection currents rise in the mantle and pull apart the overlying plates forming new oceanic crust between the spreading plates. As the crust moves away from the spreading center, the oceanic plate becomes cooler and denser. Where an oceanic plate collides with a continental plate, the dense oceanic plate is subducted beneath the continental plate. Mountains, volcanoes, earthquakes, and granite intrusions commonly occur along these collision zones.

Making of California

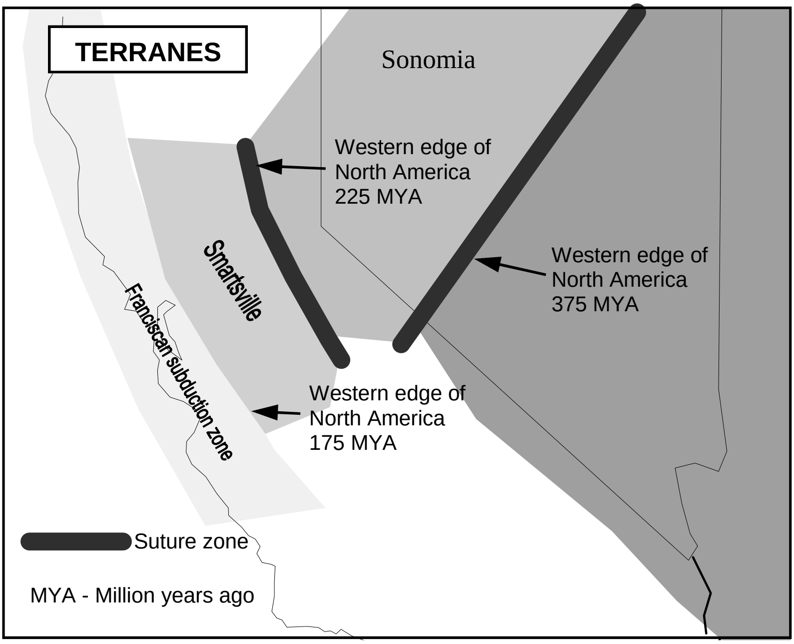
Throughout the earth's history, continents have been pulled apart, slipped by one another and collided with each other, like slag on the surface of a pot of molten iron. Smaller pieces of continental crust that have been added to a continent by these collisions are called exotic terranes. California is made up of several exotic terranes.

Prior to Devonian time, there was no California. The edge of North America was in Utah. To the west there was only ocean, with island arcs and continents that were being carried eastward on an oceanic plate toward the North American plate.

In Devonian time, 375 million years ago, an exotic terrane arrived at the edge of the North American continent, and docked to the continent, extending North America west to central Nevada. At the end of Permian time, 225 million years ago, Sonomia docked, and North America was extended to the Sierra foothills. In mid Jurassic time, 175 million years ago, the Smartsville block docked and extended California to the Coast Ranges.

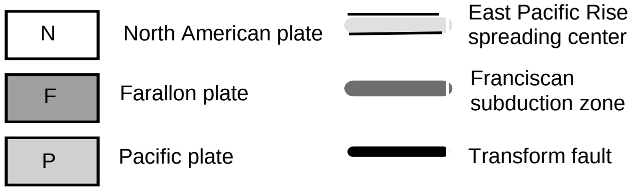
When the Smartsville block docked, it was being carried eastward on a large oceanic plate called the Farallon plate. After docking, Smartsville become part of the North American plate, but the Farallon plate continued to move east and a new plate boundary formed on the west side of Smartsville. The Farallon plate continued to be subducted under the new plate boundary. During this subduction the upper part of the Farallon plate was scraped off and plastered onto the edge of the North American plate. This complex mixture of oceanic crust and oceanic sediments that was plastered onto the North American plate is the Franciscan.

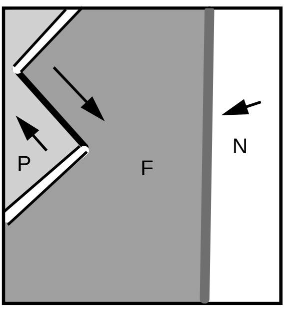
Subduction of the Farallon plate continued from Jurassic time through Cretaceous time and into the early Tertiary. Then 25 million years ago, things got more complicated. The spreading center that separated the Farallon plate from the Pacific plate reached the North American plate and the spreading center itself began to be subducted under the North American plate. Although the Farallon plate was moving east, the Pacific plate, on the west side of the spreading center, was moving northwest. As the spreading center was subducted under the North American plate, it began to tear apart the leading edge of the North American plate. The portion of the North American plate that lay over the Pacific plate attached itself to the Pacific plate and began to move to the northwest with the Pacific plate. The San Andreas fault formed to accommodate this movement, and the Gualala basin began it journey to the northwest.



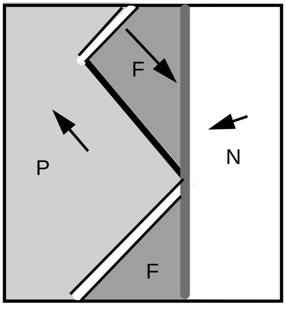
The western margin of North America consists of several large “terranes”, pieces of older continental crust from other parts of the world. These terranes were carried northward and eastward by plate movement and left at the western doorstep of North America like discarded mice. Some large terranes are separated by “suture zones” which contain heavy dark rocks called ophiolites. The ophiolites represent pieces of large oceanic plates that were mashed up and preserved in the collision zone.

ORIGIN OF THE SAN ANDREAS FAULT



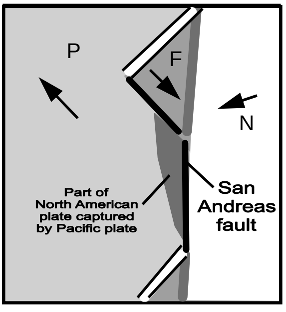


100 MYA - The Farallon plate was moving east into the Franciscan subduction zone and the Franciscan rocks were being formed in the subduction zone. The East Pacific Rise spreading center was also moving east. Although the Pacific plate was moving west relative to the spreading center, it, too, was being carried slowly toward the Franciscan subduction zone.



25 MYA - The East Pacific Rise spreading center finally reached the Franciscan subduction zone. Subduction stopped where the Pacific plate entered the subduction zone because the Pacific plate was moving away from the subduction zone. Part of the Pacific plate was by the North American plate and carried below the leading edge of the plate.

Present



Present - The part of the North American plate that overlay the Pacific plate attached itself to the Pacific plate and began to move to the northwest with the Pacific plate. The San Andreas fault formed to accommodate this movement. The San Andreas fault now forms the boundary between the Pacific plate and the North American plate. The part of the continent west of the fault is moving north with the Pacific plate at about two inches per year relative to the remainder of North American.

SAN ANDREAS FAULT
IT'S OUR FAULT

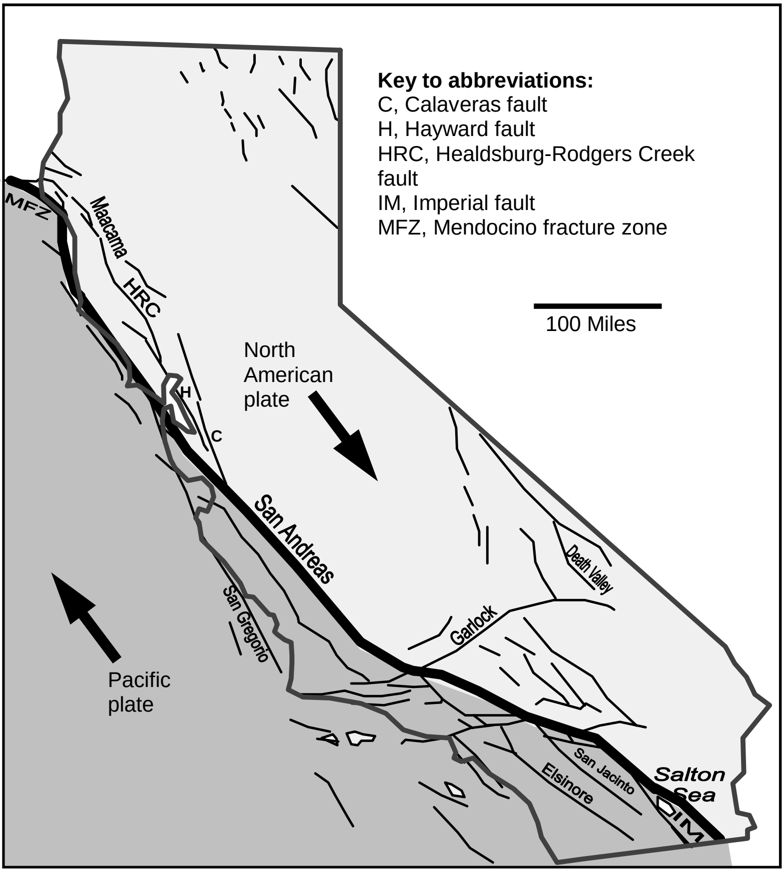
The San Andreas fault is of more than passing interest to those of us that live on the north coast of California. In the first place, if it were not for the San Andreas fault, the north coast would still be in central California. I shall offer no further comment on this point. Secondly, we know that the San Andreas fault has been responsible for major earthquakes. When can we expect a major earthquake? How large will it be? To help answer these questions, we'll look at the San Andreas fault in more detail.

As we learned earlier, the San Andreas fault separates the Pacific plate on the west from the North American plate on the east. These plates are about 60 miles thick, are relatively rigid, and float on the asthenosphere, which is hot and behaves like a highly viscous fluid. Convection currents within the asthenosphere are dragging the Pacific plate northwest at an average rate of about two inches per year relative to the North American plate. The San Andreas fault is the zone along which the plates broke to accommodate this northwest movement.

The break between the plates is not clean and simple. The plates are not homogeneous and the boundary of the convection current is not sharp, so it could hardly be expected that all of the plate movement would be confined to the San Andreas fault. Instead, the plate movement takes place along a number of faults, most of which trend northwest. The San Andreas is the largest and best defined of these faults. The many faults along which the northwest plate movement takes place are referred to as the San Andreas fault system. The system includes many active faults within a hundred miles or so of the main fault. Some plate movement is also occurring on faults as far east as Death Valley and the Great Basin province of Nevada and western Utah.

The San Andreas fault formed about 25 million years ago when the East Pacific Rise spreading ridge was subducted under the North American plate in the Santa Barbara area. There have been many attempts to determine the total amount of movement along the San Andreas fault. Ideally, to determine the total movement one would like to have a unique geologic feature displaced so that one part, like the head of a dinosaur, remained on the east side of the fault and the other part, the tail, traveled north on the west side of the fault. By matching the head with the tail it would be possible to document the exact amount of movement that had taken place along the fault. There have been several matchups of this type using similar rocks found on both sides of the fault rather than pieces of dinosaurs. These matchups indicate horizontal movement of about 200 miles.

SAN ANDREAS FAULT SYSTEM

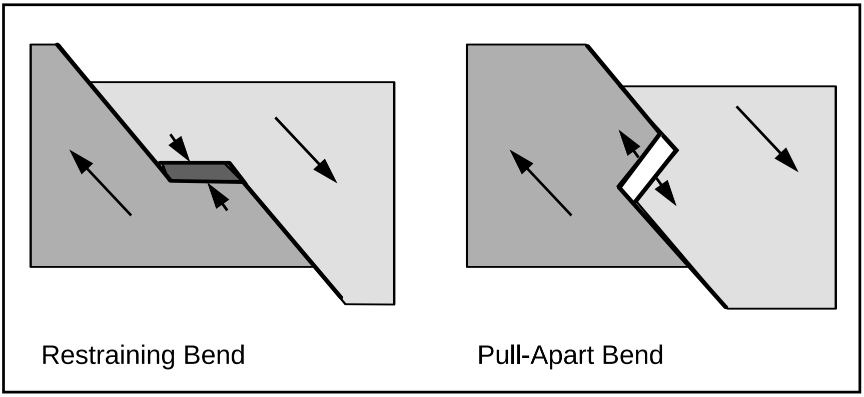


The San Andreas fault is a transform fault that forms the boundary between the North American plate and the Pacific plate. The fault extends from the Gulf of California northwest 750 miles to Cape Mendocino. Rocks on the west side of the fault have been carried north by movement along the fault. Many faults within 100 miles of the San Andreas have similar characteristics to the San Andreas and are considered to be part of the San Andreas fault system.

A fault along which the major movement is horizontal, such as the San Andreas, is referred to as a transform fault, and has certain characteristics. Although transform faults are often fairly straight, they may also converge or diverge with other faults in the same system. Converging faults tend to cause uplifts and diverging faults tend to cause depressions in the area between the faults. Transform faults can also bend. The rocks in the area of a bend can be compressed or pulled apart depending on the direction of movement and the direction of the bend. In a "restraining bend" the compressed rocks in the vicinity of the bend are folded into anticlines and synclines, and thrust faults may also be formed. In a bend where the rocks are pulled apart, the crust is dropped down along faults and a depression or basin is formed. In a transform fault where the west side is moving north, like the San Andreas fault, a bend to the right results in the crust being pulled apart and a bend to the left results in a restraining bend.

The San Andreas fault also affects the topography. The fault zone is typically half a mile wide. Rocks within the fault zone have been ground into clay and are easily eroded, so that the fault zone in some places forms a topographic low and is followed by lakes or rivers. In other areas the rocks along the fault zone may be squeezed upward to form a linear ridge. Common topographic features include offset stream patterns, sag ponds, and hills.

BENDS IN TRANSFORM FAULTS



The San Andreas fault is a transform fault, a fault in which the displacement is mainly horizontal. If there is a bend in a transform fault, lateral movement can cause compression in a restraining bend, or tension in a pull apart bend.

Some of the northward movement along the fault is by slow creep and some is by rapid movement resulting in earthquakes. The creep has been measured in many places, and is usually in the range of one to two centimeters per year. However, the faulting is of more interest since it can result in earthquakes that cause widespread damage. Most earthquakes on the San Andreas fault system occur at a depth of 4 to 12 miles below the earth's surface. The motion and energy from the break is transmitted through the earth by earthquake waves, vibrations of the earth, like hitting a bell with a hammer.

Sizes of earthquakes are usually defined by the Richter Scale (M), which is based on measurements of earthquake waves recorded by seismographs. The scale ranges from 1 to 10 and is logarithmic. For a 1 unit increase in the scale there is a ten fold increase in ground motion. Thus a M7.0 earthquake is ten times more violent that a M6.0 earthquake. The Modified Mercalli Intensity Scale (MMI) is another commonly used method of measuring earthquakes. This scale, which measures earthquakes based on the amount of damage to structures, uses Roman numerals I through XII, and can thus be readily distinguished from the Richter Scale. California's first seismographs were installed in 1887 at U.C. Berkeley and the Lick Observatory so records prior to 1887 are poor, and a large number of earthquakes prior to that date are unrecorded.

Earthquakes occur when stresses build up in the rocks to the point that the rocks can no longer withstand the force being applied, and then the rocks break. Stresses in the rocks can be relieved by creep with no earthquakes, by numerous small dislocations with minor earthquakes, or by a few large dislocations with major earthquakes. The earthquakes may occur on the San Andreas fault itself, on other faults in the San Andreas system, or on thrust faults or pull-apart faults indirectly related the San Andreas fault.

Movement on one fault in the San Andreas system would normally relieve stress along that portion of the fault system, and would likely affect the stress on other nearby faults in the system. Earthquakes of M8.0 are very effective in releasing stress, and it takes a long time for stress to build up again that would be sufficient to cause another M8.0 earthquake.

RICHTER SCALE	
M1.0	Not felt
M2.0	May be felt
M3.0	Slight damage
M4.0	Moderate damage
M5.0	Considerable damage
M6.0	Severe damage
M7.0	“Major”, widespread damage
M8.0	“Great”, tremendous damage

The Richter Scale (M) is based on measurements of earthquake waves as recorded by seismographs. This scale is used in many scientific studies of earthquakes. The scale is logarithmic. For a 1 unit increase in the scale there is a ten fold increase in ground motion and a thirty fold increase in energy released. An M7.0 earthquake is ten times more violent than an M6.0 earthquake.

The Modified Mercalli Intensity Scale (MMI) is based on the affect of earthquakes on buildings and other structures. This scale is used for detailed analysis of earthquake damage. It is also used where good seismograph records are not available. The scale uses Roman numerals and is thus easily distinguished from the Richter scale.

MODIFIED MERCALLI INTENSITY SCALE	
I	Not generally felt
II	Suspended objects may swing
III	Hanging objects swing
IV	Dishes and doors disturbed
V	Small objects upset
VI	Dishes broken
VII	Some chimneys broken
VIII	Numerous chimneys fall
IX	Unreinforced masonry buildings collapse
X	Many frame structures destroyed
XI	Few masonry structures remain standing
XII	Damage total

Number of Earthquakes Worldwide per Year	
Magnitude (Richter Scale)	Average Number
8.0	2
7.0	20
6.0	100
5.0	3,000
4.0	15,000
3.0	over 100,000

Small earthquakes are very common and very large earthquakes are relatively rare.

San Andreas Fault System

The San Andreas fault begins in the Gulf of California as a transform fault associated with the East Pacific Rise spreading center. The spreading center is splitting Baja California away from the west coast of Mexico, and this movement has formed the Gulf of California. Baja California began to move away from the mainland five million years ago. The spreading center is still active and is extending northward toward the Salton Sea. The continental crust under the Salton Sea is now being pulled apart by this spreading and is becoming thinner. As the crust thins, the surface is being depressed along faults. The Salton Sea is now 250 feet below sea level and going down about one inch per year. The Gulf of California would now extend into the Salton Sea except that the ocean is blocked by the delta of the Colorado river, which is 40 feet above sea level. However, a little more time will cure this. The Colorado River delta is subsiding faster than it is being built up. The sediments that would have been deposited on the delta and would have continued to block the ocean are no longer being deposited. These sediments are now filling up Lake Powell instead. With continued spreading, the Gulf of California will in a few million years extend into the Imperial Valley and Salton Sea. Palm Springs will become ocean front property.

The San Andreas fault cuts northwest across California for 650 miles from the Gulf of California to Manchester. From there it continues offshore another 100 miles to the Mendocino fracture zone off Cape Mendocino. The character of the fault and the earthquake activity changes along different sections of the fault. Although it is not possible to make specific predictions of earthquake activity, by studying the different sections of the fault we can learn a little about what might be expected in the future.

Salton Sea: This section of the San Andreas fault system from the Gulf of California to Palm Springs is very active. Major faults are the Imperial, San Jacinto, Banning and Elsinore. Since 1800 there have been 32 earthquakes greater than M5.0 on these and other faults along this part of the San Andreas system. Five of these earthquakes occurred in the last decade. The largest earthquakes were at San Jacinto in 1918 (M7.2), Cerro Prieto in 1915 (M7.1), Mexicali Valley in 1934 (M7.1), El Centro in 1940 (M7.1), San Juan Capistrano in 1812 (M7.0), Imperial Valley in 1875 (M7.0), Laguna Salada in 1891 (M7.0), and the Colorado River delta in 1903 (M7.0). The 1940 earthquake at El Centro was accompanied by ground displacement of 21 feet and managed to offset the international border at Calexico. Not only the Mexicans are headed north, but Mexico itself is crossing the border.

Transverse Ranges: From Palm Springs north to Maricopa, 25 miles southwest of Bakersfield, there is a major westward bend in the San Andreas fault. This is a large restraining bend. The Pacific plate is trying to move north, but has collided with a westward bulge in the North American plate. The rocks in this collision zone have been compressed and squeezed to form the Transverse Ranges. The Transverse Ranges include a complex knot of faults and folds. Major active faults are the San Andreas, Garlock, San Gabriel and Big Pine. These faults all converge at Frazier Mountain near Gorman on I-5. Frazier Mountain has been squeezed southward on a thrust fault due to the compression of the crust where these faults join.

There have been 21 earthquakes larger than M5.0 on this section of the San Andreas fault system since 1800, including three of the four largest earthquakes on the entire San Andreas system: the 1857 (M8.3) Fort Tejon earthquake; the 1952 (M7.7) Tehachapi earthquake; and the 1992 (M7.5) Landers earthquake. Other notable earthquakes include the 1971 San Fernando (M6.6) and 1994 Northridge (M6.7) earthquakes that were on thrust faults at the south boundary of the Transverse Ranges.

Seven of the 21 large earthquakes on this section of the fault system have occurred in the last decade. It appears things are heating up, and the "big one" could be expected anytime.

Central: The San Andreas fault is remarkably straight and relatively uncomplicated from the Transverse Ranges north to San Juan Bautista near Santa Cruz. There is a lot of earthquake activity on this section of the fault but the quakes are generally smaller than M5.0. Only five earthquakes greater than M5.0 are recorded since 1800, and none in the last decade. Stress along this section of the San Andreas fault seems to be handled mainly by creep and numerous small and moderate earthquakes.

Bay Area: From San Juan Bautista to the Bay Area the fault system gets complicated again. The Calaveras fault splits from the San Andreas near Hollister and then the Hayward fault splits from the Calaveras near Hayward. San Francisco Bay lies in a depression that was formed between the Hayward and San Andreas faults.

This section of the fault system has had 26 large earthquakes since 1800. The largest was the 1906 San Francisco earthquake (M8.3), which ruptured the earth over a distance of 270 miles. Maximum surface displacement was 21 feet, recorded near Olema. Near San Francisco, the causeway that crosses the Crystal Springs Reservoir was offset seven feet, the west side moving north. It appears that the 1906 earthquake relieved stresses along this section of the fault for several decades. However, the stresses are beginning to build up. There have been two major earthquakes in the last decade, Morgan Hill in 1984 (M6.2) and Loma Prieta (M7.1) in 1989. The Loma Prieta fault was on a thrust fault related to and nearby to the San Andreas. Measurements between Mt. Diablo and the Farallon Islands indicate the Farallon Islands have moved north five feet since the 1906 earthquake, averaging nearly one-half inch per year. It appears that this section of the San Andreas fault is heating up somewhat.

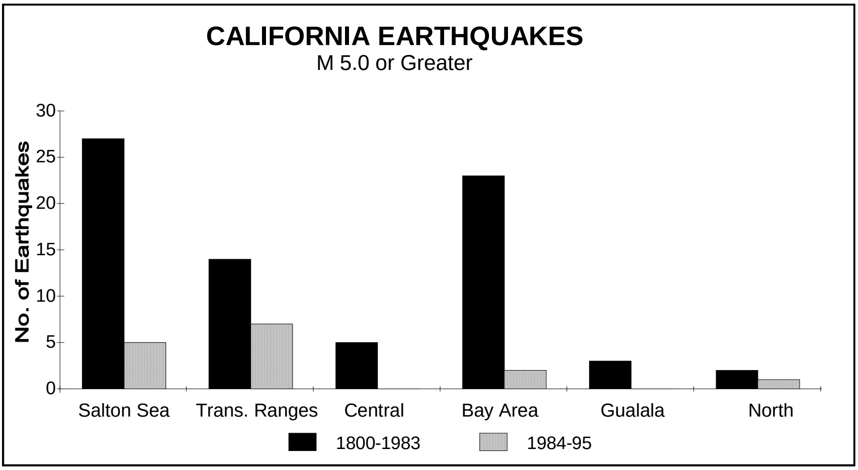
Gualala: From San Francisco northwest to Manchester the San Andreas fault plays tag with the coastline. After the fault leaves San Francisco at Daly City it comes onshore again at Stinson Beach and then continues through Olema into Tomales Bay, separating Point Reyes from the mainland. The fault comes onshore again between Bodega Head and the town of Bodega Bay, separating Bodega Head from the mainland. From Bodega Bay the fault continues offshore for 12 miles then comes onshore again near Timber Gulch, two miles south of Fort Ross. From Fort Ross the fault continues northwest along the South Fork of the Gualala River past the Sea Ranch. After passing Sea Ranch the fault continues along the Garcia River and then goes into the Pacific Ocean for the last time at Alder Creek just north of Manchester.

There are a number of faults in the Coast Ranges that are part of the San Andreas fault system. The largest are the Rogers Creek-Healdsburg fault that goes from San Pablo through Santa Rosa and Healdsburg and the Maacama fault that goes through Ukiah and Laytonville.

This section of the San Andreas fault system has had only two large earthquakes since 1800, and none in the last decade. The 1906 San Francisco earthquake affected this area although the epicenter was near San Francisco. Displacement in the Sea Ranch area was about 10 feet. There has been very little earthquake activity on this part of the San Andreas fault since the 1906 earthquake. It appears that the 1906 earthquake relieved stresses along this section of the fault for several decades.

Although the San Andreas fault has been very quiet over the last several decades, there have been a number of smaller earthquakes on other faults in the system, especially the Rodgers Creek- Healdsburg and Maacama faults. Seismologists indicate that the Rodgers Creek-Healdsburg fault is currently building up stress and is capable of a M7.0 earthquake in the next few decades. If that occurs, it may relieve stress on the San Andreas and further delay a large earthquake. Our ability to predict earthquakes is poor, and we should be prepared for a severe earthquake anytime.

North: From Manchester the San Andreas fault continues north offshore for 100 miles where it intersects the Mendocino fracture zone off Cape Mendocino. It ends its journey in a blaze of glory at what in plate tectonics is called a triple junction, a point at which three plates intersect, the North American, Pacific and Juan de Fuca (Gorda) plates. This triple junction has had four large earthquakes since 1800. One of these was in the last decade, the 1992 earthquake near Ferndale (M7.1). The triple junction offshore from Cape Mendocino is geologically complex. Severe earthquakes can be expected anytime.

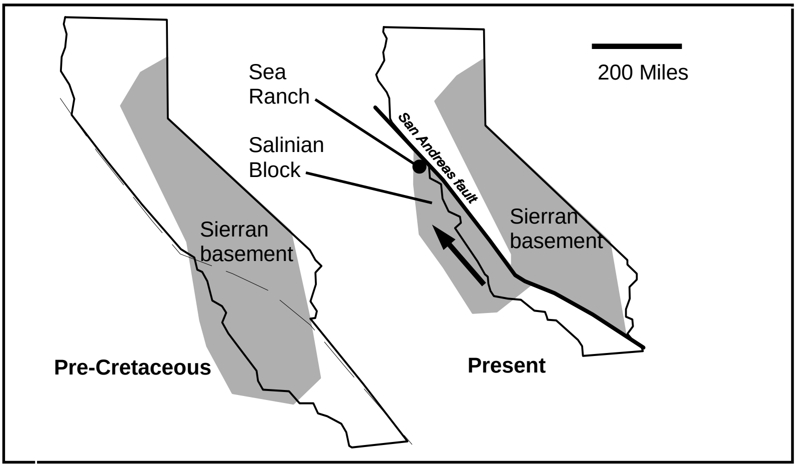


Since 1800 there have been 93 earthquakes of M 5.0 or greater on faults in the San Andreas fault system. Most of these earthquakes have been in Southern California and the San Francisco Bay area. Southern California has been particularly active in the last decade.

MOVING NORTH

Since we began our story of the Sea Ranch rocks at their birthplace near Monterey, it is only fitting that we end our story with some thoughts about where the rocks are headed. Assuming an average movement of one inch per year along the San Andreas fault, the Sea Ranch and the coastal area from Fort Ross to Manchester will in six million years be an island ten miles off the coast from Mendocino. The Hot Spot will be on the east shore of this island looking toward Mendocino. The next stop is Alaska. Los Angeles and Baja California will be stringing along behind, forming an island somewhat like New Zealand. California will have finally achieved its dream of dividing, albeit not in the manner envisioned by most politicians. Best wishes for a good voyage.

SALINIAN BLOCK



Granite occurs unexpectedly at several places in northern California on the west side of the San Andreas fault, including the Farallon Islands and Bodega Head. This granite was probably removed from the southern Sierras by the San Andreas fault and carried northward by the fault several hundred miles to its present position. This well-traveled block of granitic rocks, referred to as the Salinian Block, is still being carried north by the San Andreas fault.

GLOSSARY

A

anticline: an arched-up fold of rock. In most anticlines the oldest rocks are in the center and the beds dip away from the crest.

B

basalt: dark grey or greenish gray fine-grained volcanic rock rich in iron and magnesium silicates. Basalt forms the earth's crust under most of the world's oceans.
basin: a low area in the earth's crust where sediments accumulate.
bed: smallest layer of sedimentary rock, usually a layer from one depositional event.

C

concretion: a hard ball-shaped mass formed in a sedimentary bed by localized precipitation of cement. Concretions result from a tendency of minerals of like composition to precipitate around a common center.
conglomerate: a sedimentary rock consisting of boulders, cobbles and pebbles in a sand matrix.
crust: the outer layer of the earth. Oceanic crust is mainly basalt and about five miles thick. Continental crust is typically granitic, and about 25 miles thick.

E

earthquake: shaking of the earth due to sudden movement along a fault.
erosion: the wearing away of the earth's landscape by natural forces of water, waves, ice, or wind.

F

fault: a fracture in the earth's crust along which the opposite sides have been offset.
feldspar: a common group of rock forming minerals found in many igneous and metamorphic rocks. Feldspars are colorless, white or pink, and consist of aluminum silicates with various quantities of potassium, sodium or calcium. Feldspars are fairly resistant to weathering and are common in beach sand and sandstone.
formation: a distinct mappable body of rock, usually named for the geographic locality where it was described.
fossil: organic remains, shells, skeletons, or prints, buried by natural processes and preserved in the rocks.

G

glacial, interglacial: a glacial period is a climatic episode in which very large glaciers develop. The glaciers recede during interglacial periods. There have been at least four major glacial periods during the last three million years. The last major interglacial period was the Sangamon and the last major glacial period was the Wisconsin.

granite: a coarse grained light colored igneous rock rich in quartz and feldspar, and with black specks of

biotite or hornblende.
Continental crust is characterized by granitic rocks.

I

igneous rock: includes volcanic and plutonic rocks. Volcanic rocks solidified from molten rock before large crystals had time to form. Plutonic rocks formed deep in the crust. They cooled slowly and large crystals have had time to form.

M

magma: molten rock.
mantle: the part of the earth between the base of the crust and the earth's core at a depth of 2900 km. The mantle is composed of ultramafic rocks rich in iron and magnesium silicates.
member: a subdivision of a formation.
metamorphic rock: a rock that has been formed from the action of heat, pressure or hot water solutions on other rocks deep within the earth's crust.

P

pillow basalt: a basalt that has formed under water and is characterized by the formation of pillows.
plate: a discrete segment of the earth's crust that moves as a unit as if it were rigid.
plate tectonics: a geological theory that explains the origin of many of the major geological features of the earth's surface. According to plate tectonic theory, the outer part of the earth is composed of a number of plates that move horizontally over geologic time. The plates are moved by convection currents in the earth's mantle. Major geologic features of the earth's crust form along the margins of these plates: ocean basins where plates pull apart; ocean trenches, mountains, volcanoes, and earthquakes where plates collide; and transform faults where plates slip by each other horizontally.

Q

quartz: a very common mineral composed of silicon dioxide. Quartz occurs in igneous, sedimentary and metamorphic rocks, as well as in veins. Quartz is typically translucent, transparent or glassy. It is extremely hard and resistant to weathering. It is a major component of beach sand and sandstone.

S

sag pond: a body of water occupying a depression created by movement of the earths surface along a fault zone.
sandstone: a sedimentary rocks composed of sand-sized particles.
sedimentary rock: a rock composed of fragments of other rocks. Includes conglomerate, sandstone, siltstone and shale. May also include rocks precipitated from solutions, like salt, and rocks composed of

organic remains, like limestone.
serpentine: a dense, dark green rock formed by the alteration of rocks in the earth's mantle by hot water solutions. Serpentine is typically marks zones where plates have collided, and are used as a marker to identify old plate boundaries.
shale: a sedimentary rock consisting largely of clay minerals.
silt, siltstone: sediment or sedimentary rock composed of grains smaller than sand and bigger than clay.
spilite: a basalt with a high content of sodium, typical of ocean floor basalts.
spreading center: the zone along which plates are pulled apart by upwelling convection currents in the earths mantle.
subduction: a term used in plate tectonics that refers to the descent of an oceanic plate into the earth's mantle.
syncline: a downward fold of rocks. Typically the youngest rocks are in the center, and the rocks on the flanks dip toward the center.

T
terrace: a flat or gently sloping bench that is the remnant of an old coastline.
terrace deposits: sedimentary rocks deposited on a terrace.
transform fault: a fault in which the opposite sides move past each other horizontally.
turbidite: sediments that were deposited by a turbidity current.
turbidity current: a current of dense water and sediment that flows rapidly down the slope of a basin.

U
ultramafic: a rock that contains a superabundance of heavy dark minerals, mainly olivine and pyroxene and little or no feldspar. The earth's mantle consists of ultramafic rocks.
unconformity: a significant break or gap in the geologic record caused by uplift and erosion or lack of deposition.

W
weathering: the alteration of a rock as a result of conditions at the earth's surface, usually involving reaction with water, atmospheric gasses, and organic products. In humid areas weathering normally results in the formation of soil.

SELECTED REFERENCES

Alt, D.D. and Hyndman D.W., 1975, Roadside geology of northern California, Mountain Press Publishing Co., 244 p.

Bailey, E.H., editor, 1966, Geology of northern California: California Division of Mines and Geology Bulletin 190, 507 p.

Borg, I., 1992, The San Andreas fault at Sea Ranch, The Sea Ranch Soundings, Fall 1992, p. 6.

Bullard, E., 1972, The origin of the oceans, in Continents Adrift, Readings from Scientific American, W.H. Freeman and Company, S.F., p. 88-97.

Howard, A. D., 1979, Geologic history of California, University of California Press, Berkeley.

Huffman, M.E. and Armstrong, C.F., 1980, Geology for planning in Sonoma County, California Division of Mines and Geology Special Report 120, 31 p.

James, E.W., Kimbrough, D.L., and Mattinson, J.M., 1993, Evaluation of displacements of pre-Tertiary rocks on the northern San Andreas fault using U-Pb zircon dating, initial Sr, and common Pb isotope ratios, in The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution, Geological Survey of America Memoir 178, Powell, R.E., Weldon, II, R.J., and Matti, J.C., editors, p. 257-271.

Koenig, J.B., 1963, Geologic map of California, Olaf P. Jenkins edition, Santa Rosa Sheet: California Division of Mines and Geology, scale 1:250,000.

McPhee, John, 1993, Assembling California, Farrar, Straus and Giroux, NY.

Norris, R.M. and Webb, R.W., 1990, Geology of California, John Wiley & Sons, Inc., N.Y.

Peters, J., 1985, Evolution of the Sea Ranch landscape, the Sea Ranch Soundings, Fall 1985, p. 9.

Wallace, R. E., editor, 1990, The San Andreas Fault system, California, U. S. Geological Survey Professional Paper 1515, 283 p.

Weaver, C.E., 1943, Point Arena-Fort Ross region [California]: California Division of Mines Bulletin 118, p. 628-632.

Weaver, C.E., 1944, Geology of the Cretaceous (Gualala Group) and Tertiary formations along the Pacific coast between Point Arena and Fort Ross, California: Washington (State) University Publication in Geology, v. 6, no. 1, 29 p.

Wentworth Jr., C.M., 1967, The upper Cretaceous and lower Tertiary rocks of the Gualala area, northern Coast Ranges, California, Ph.D. thesis, Stanford University, 197 p.

NOTES

Geologic Trips, Sea Ranch

Along the bluff from Fort Ross to Point Arena there are spectacular exposures of an unusual suite of rocks whose origin is somewhat mysterious. The rocks were originally formed several hundred miles to the south, probably in the area around Monterey, then carried north by the San Andreas fault, as if on a moving sidewalk.

You can see these rocks during several short geologic trips. You don't need a geologic background to go the trips. With this book as a guide, you are well on your way toward a new understanding and appreciation of these rocks that have provided some of the best coastal scenery in the world. The trips include visits to:

Sea Ranch bluff and beaches
Sea Ranch meadow and hillside
Gualala Point Regional Park
Bowling Ball beach

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