

Excerpt from

Geologic Trips
San Francisco and the Bay Area

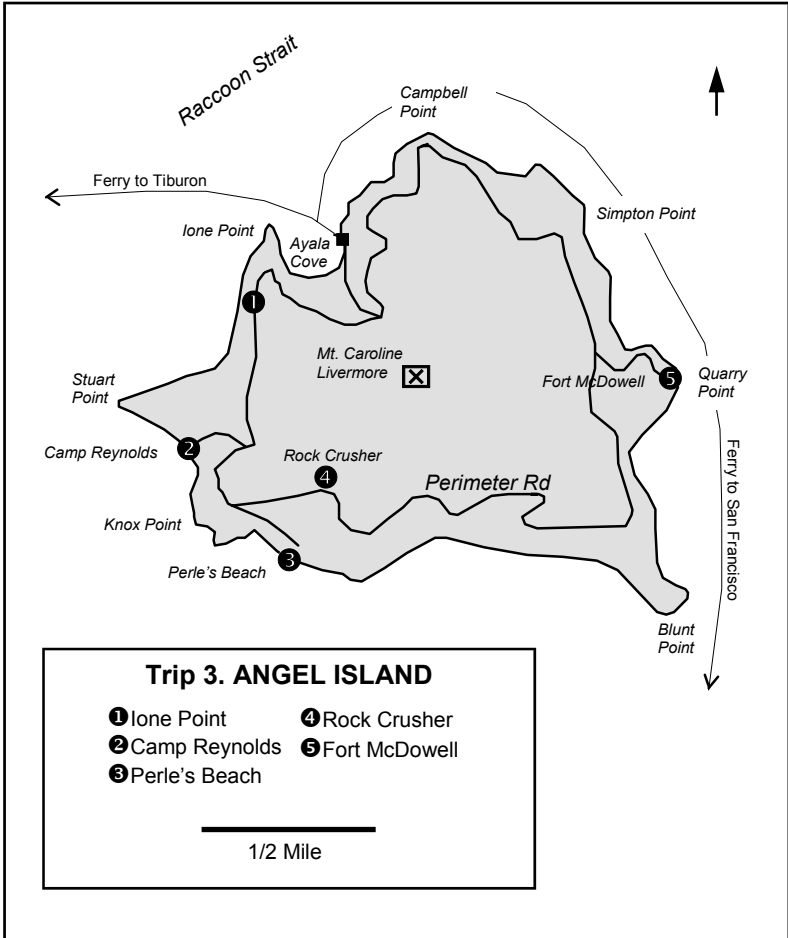
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Angel Island consists mainly of rocks of the Angel Island terrane of the Franciscan. These rocks differ from much of the Franciscan in that they are metamorphosed to the blueschist facies. Blueschists form only under the unusual conditions of extremely high pressures and relatively low temperatures that are characteristic of subduction zones.

Trip 3.

ANGEL ISLAND

Metamorphism and Blue Schists

Most Franciscan rocks have not been metamorphosed; that is, the pressures and temperatures in the subduction zone were not high enough to alter the rocks significantly. However, the Franciscan rocks that make up Angel Island are metamorphosed. They have been altered by extreme high pressure in the subduction zone. These rocks must have been carried to greater depths in the subduction zone than most Franciscan rocks.

The metamorphic rocks on Angel Island are called the *Angel Island terrane*. These rocks were originally sandstone, pillow basalt and serpentine, but were altered to schistose sandstone, schists, blueschists, metamorphosed pillow basalt, and metamorphosed serpentine. The blueschists are of special interest because they form only in subduction zones, and are thus considered as an indicator of subduction zones. After the rocks of the Angel Island terrane were metamorphosed, they were thrust over unmetamorphosed sandstones of the Alcatraz terrane. This must have occurred later when the subduction zone had become cooler.

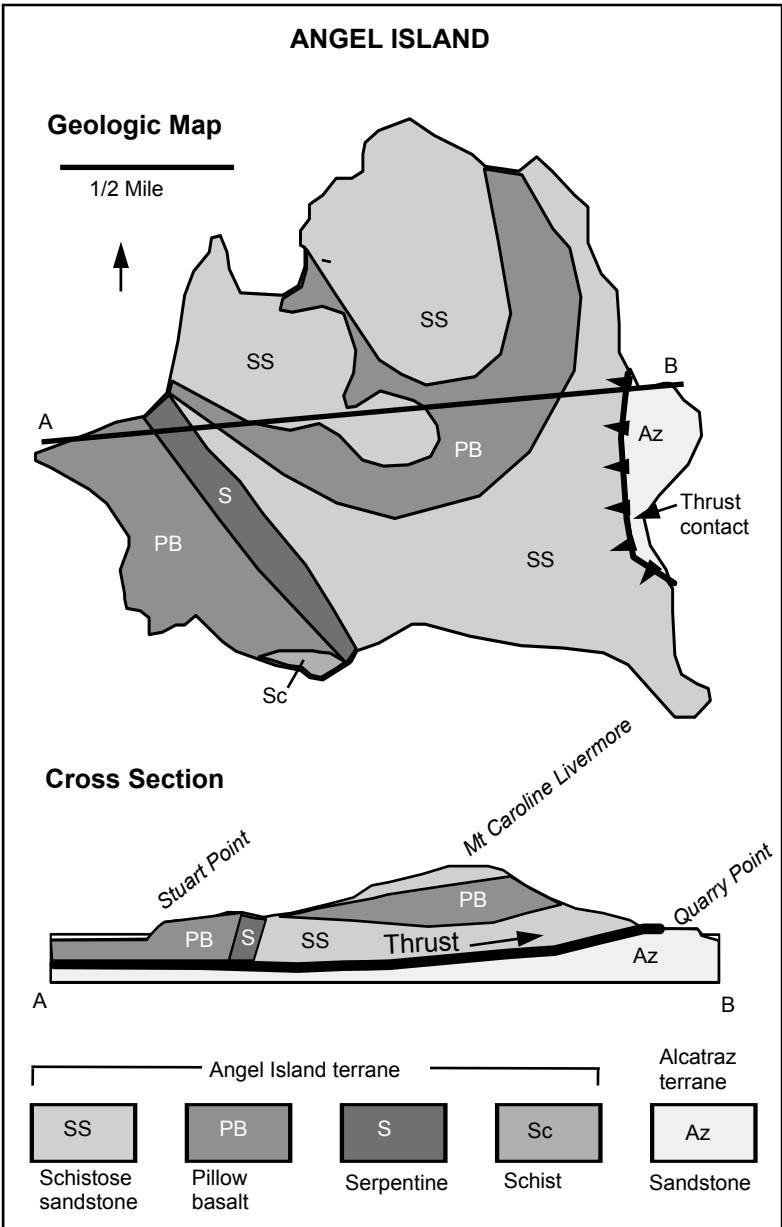
You will see examples of all of the metamorphic rocks of the Angel Island terrane during the trip to Angel Island: schistose sandstone at Lone Point, blueschists at Camp Reynolds, schists and metamorphosed pillow basalt at Perle's Beach, and metamorphosed serpentine at the Rock Crusher. At Camp Reynolds, you will see the unmetamorphosed rocks of the Alcatraz terrane as well as the thrust fault that separates these rocks from the overlying rocks of the Angel Island terrane.

Allow one day for the trip. All of the geologic localities are on or near the Perimeter Road, which makes a five-mile circuit of the island. If possible, try to get to the island during low tide to see the rocks along the shoreline. Angel Island is a State Park with hiking trails, a museum, and a cafe at the ferry dock. The island is accessible by ferry from Fisherman's Wharf, Tiburon, or Vallejo. For information on logistics contact the Angel Island Company (415-897-0715).

Most of the rocks of the Angel Island terrane had only minor changes during metamorphism and the original rock types are still apparent. The schistose sandstone looks like a sandstone that has been squeezed, and the pillow basalt and serpentine appear almost unchanged. However, the schists and blueschists have been so highly metamorphosed that all traces of the original rocks were obliterated. Moreover, the blueschists contain unusual blue metamorphic minerals that form only under conditions of abnormally high pressure and relatively low temperature. Since these abnormal pressure and temperature conditions occur only in subduction zones, the blueschists are considered as indicators of subduction zones.

Rocks of the Angel Island terrane occur along the southern shoreline of the Tiburon Peninsula and in the Berkeley Hills as well as at Angel Island. Metamorphism of a widespread rock unit like the Angel Island terrane is rare in the Franciscan. Metamorphosed Franciscan rocks usually occur as individual boulders in melanges or as small isolated areas of moderate- to high-grade metamorphism.

ROCK TYPES Angel Island Terrane		
Locality	Rock Unit	Description
lone Point (Perimeter Road)	Schistose sandstone	Sandstone with well developed schistosity; appears platy; sand grains still recognizable; some flattened pebbles.
Perle's Beach (West End)	Pillow basalt	Pillow basalt may be brown, yellow or dark green; well-defined pillows in some places; original feldspar and pyroxene altered to microscopic metamorphic minerals such as lawsonite and glaucophane.
Rock Crusher (Serpentine Quarry)	Serpentine	Green and very light green to white; slippery; foliated with ovoid masses of hard serpentine; occurs as craggy green outcrops.
Perle's Beach (East End)	Schist	Dark blue, brown, white; breaks into platy fragments; usually found as thin layers within pillow basalt or along the contacts between basalt or serpentine and other rocks.
Camp Reynolds (South End of Beach)	Blueschist	Schist with pronounced dark blue color; contains blue metamorphic minerals formed under conditions of very high pressure and relatively low temperature.



This geologic map shows the distribution of the different types of rocks that make up Angel Island. The cross section shows the surface along which the Angel Island terrane has been thrust over the Alcatraz terrane.

Ione Point

Most of the central and eastern parts of Angel Island consist of schistose sandstone of the Angel Island terrane. These rocks also form the crest of Mt. Caroline Livermore as well as Ione Point, Campbell Point, Simpton Point, and Blunt Point. The schistose sandstone is covered by vegetation over most of the interior of the island and is not well exposed. However, there are good exposures of the schistose sandstone in the road cuts along the Perimeter Road just south of Ione Point.

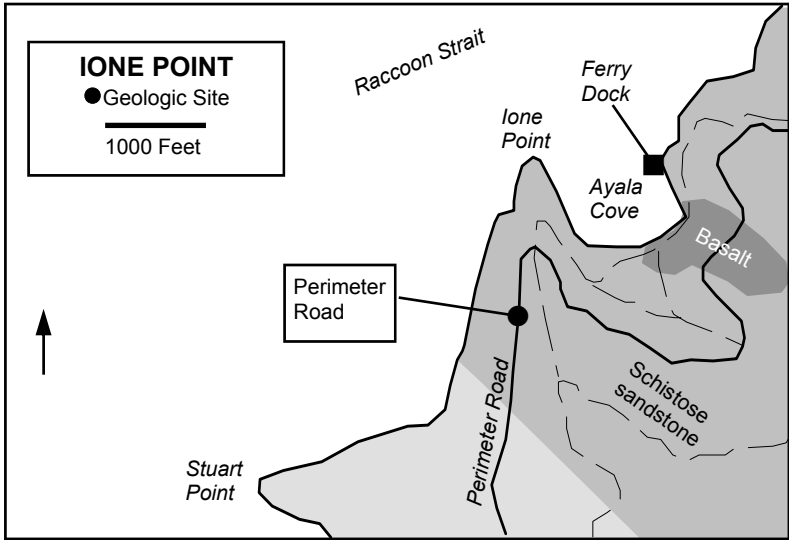
●Perimeter Road

To get to the Perimeter Road from the ferry dock, follow the path that goes west near the shoreline. This path connects with the Perimeter Road just south of Ione Point. The road cuts along the Perimeter Road for the next 800 feet to the south are in schistose sandstone.

This schistose sandstone was formed from graywacke sandstone that was subjected to a moderate grade of metamorphism. The grains of the original sandstone are still apparent, but the sand grains have been flattened by the high pressure that they were subjected to in the Franciscan subduction zone. If you look at a piece of the schistose sandstone with a magnifying glass you will see that it is composed of very thin layers of small flattened grains. These layers are parallel to the original bedding of the graywacke sandstone. The tendency of the rock to break into tabular pieces is called *schistosity*. The schistosity dips steeply to the north and west, indicating that the rocks were tilted in that direction some time after deposition.

In some places, pebbles can still be seen in the sandstone, and the pebbles are also flattened parallel to the schistosity. Look for some of these pebbles in the road cuts about 750 feet south of where you started walking on the Perimeter Road.

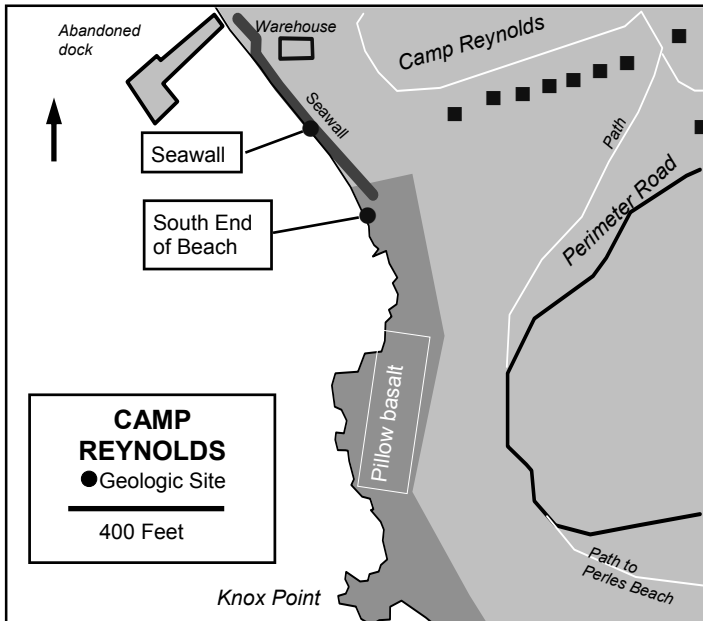
Although it is not apparent by looking at the sandstone, new metamorphic minerals have replaced many of the original grains in the sandstone. These minerals can be seen with the aid of a microscope when looking at a very thin slice of the sandstone. The metamorphic minerals include lawsonite, jadeitic pyroxene, aragonite, and crossite. These minerals were formed by altering the composition of the original grains that made up the sandstone. Studies have shown that the new minerals were formed by rearranging the material already in the rock, and without the addition of materials from outside the sandstone.



Ione Point, on the west side of Ayala Cove, is made up of schistose sandstone of the Angel Island terrane. The thin layering of the schistose sandstone can be seen in the road cuts along the Perimeter Road near Ione Point. This is the most common rock on Angel Island, but there are few good exposures.

Camp Reynolds

There are two geologic sites at Camp Reynolds, the seawall which has good examples of honeycomb weathering, and the south end of the beach where you will see some blueschists that are formed only in subduction zones.



The old seawall at Camp Reynolds has excellent examples of honeycomb weathering. At the south end of the beach are good exposures of pillow basalt with seams of blueschist.

● **Seawall**

To get to Camp Reynolds from Ione Point, continue southwest on the Perimeter Road 0.5 miles to Camp Reynolds, then follow the path to the old warehouse near the abandoned dock. The seawall extends along the shoreline to the south of the warehouse. The seawall was constructed between 1864 and 1877, mainly from sandstone from Quarry Point at Fort McDowell. The sandstone blocks in the lower part of the seawall have not been eroded to any significant degree, even though these blocks are subject to wave attack at high tide. The sandstone blocks at the top of the seawall are above high tide, but are constantly subjected to sea spray. The blocks subjected to the sea spray have been etched into an intricate honeycomb pattern of pits and holes. The etching is thought to have been caused by salt crystal growth during evaporation of the sea spray. The new and constantly forming salt crystals wedge out the sand



This view of Camp Reynolds looks west toward the warehouse (center), and dock (hidden by the trees). The seawall extends south from the warehouse.

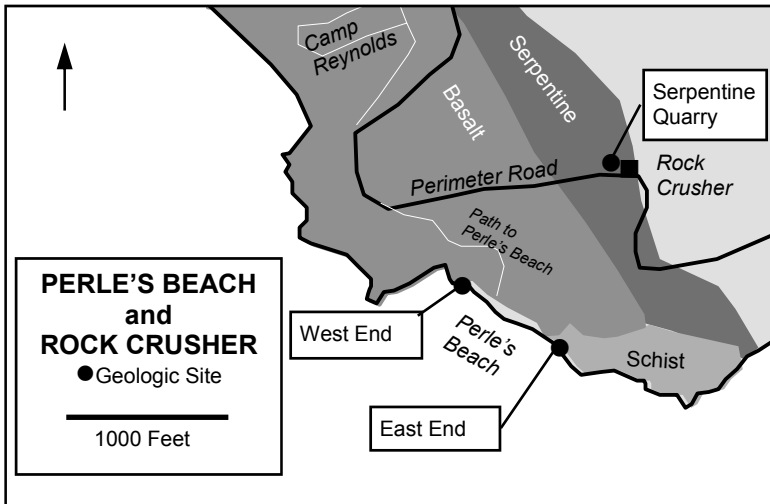
grains from the sandstone thereby forming pits on the surface of the sandstone. The seawall also contains boulders of gabbro and granite along with the sandstone. These boulders have not been affected by the sea spray. The sandstone that has been etched by the sea spray has retreated as much as six inches from the surface as defined by the gabbro and granite boulders, indicating an etching rate of about one-half inch per decade. Similar honeycomb weathering can be found all along the California north coast where thick sandstones are subjected to sea spray. Salt Point State Park in Sonoma County has some excellent examples of this type of weathering.

● **South End of Beach**

Follow the seawall to the south end of the beach. The rocks exposed along the bluff just south of the seawall are mainly pillow basalt. Within the pillow basalt there are some thin seams of deep blueschist an inch or so thick. In its former life, this blueschist was chert that had been interbedded with the basalt. The chert was altered to blueschist in the subduction zone. Look for flat pebbles of the blueschist in the pebbles along the shore at the south end of the seawall. These pebbles have been eroded from the seams of blueschist interlayered with the pillow basalt.

Perle's Beach

Perle's Beach lies near the contact between a thick unit of serpentine that cuts northwest across Angel Island and the pillow basalts that form the west end of Angel Island. A number of different types of schists have been formed along this contact zone, and these schists are well exposed in the sea cliffs at the east end of Perle's Beach. The pillow basalts that form the western part of Angel Island can be seen in the sea cliffs at the west end of the beach. To get to Perle's Beach from Camp Reynolds, continue south on the Perimeter Road 0.25 miles and take the path to the beach. The beach is about 200 yards long.



At the east end of Perle's Beach there are several different types of schist. These are the most highly metamorphosed rocks on Angel Island. The schists formed along the contact zone between pillow basalt and serpentine. The easy exchange of matter along this contact zone accelerated metamorphism.

●East End

The rocks at the east end of the beach are mainly layers of schists that have been highly metamorphosed. These rocks lie near the contact between the pillow basalts that form the west part of Angel Island and the thick belt of serpentine exposed at the serpentine quarry. The first rocks that jut out into the beach are serpentine. The serpentine is foliated and the foliations wrap around ovoid masses of harder serpentine. Further east, the serpentine contains large blocks of

sandstone. Still further east, the serpentine is in contact with brown schist that is thinly layered with a dark blue quartz-rich rock. The brown schist was likely shale before it was metamorphosed, and the dark blue quartz-rich rock was probably chert that had been interbedded with the shale. There are also some layers of blueschist at the east end of the beach. The blueschists get their deep blue color from the abundant blue minerals that were formed during metamorphism. The blue minerals, which include lawsonite and glaucophane, are formed only at abnormally high pressure and relatively low temperature, conditions found only in subduction zones. These conditions occur when cool rocks have been rapidly plunged to great depths and subjected to high pressure in the subduction zone and then uplifted before the rocks can be heated to the high temperatures usually found at those great depths. Laboratory studies show that these blue minerals form at pressures equivalent to rock burial depths of 12 to 30 miles and at temperatures of 100 to 300 degrees C. Normal temperatures at these depths are well over 300 degrees C.

The rocks that have been metamorphosed under these unusual conditions are referred to by geologists as the *blueschist facies*. Although all of the rocks in the Angel Island terrane are in the blueschist facies, they are not all colored blue, since most of the rocks contain only small amounts of the blue metamorphic minerals.

● **West End**

The southwest part of Angel Island is formed from pillow basalt. These rocks are well exposed at the west end of Perle's Beach. The pillow basalt occurs in layers a few feet thick and these layers dip steeply to the northwest. The best pillows are in the rocks at the extreme west end of the beach and can be reached only at low tide. Look for pillow-shaped masses a foot or so in diameter in these brown-colored rocks. In places, the pillow basalts are separated by layers of chert or other metamorphic rocks.

Although not apparent in a hand specimen, the pillow basalt is also metamorphosed to the blueschist facies. Microscopic studies show that the original basalt consisted mainly of pyroxene and plagioclase feldspar. Much of the original pyroxene and feldspar have been replaced by very small crystals of metamorphic minerals. The feldspar has altered to chlorite, lawsonite, crossite and jadeite. The pyroxene has been partly replaced by chlorite, glaucophane and green jadeite.



The serpentine quarry near Perle's Beach was used to supply rock for road building on Angel Island. The serpentine was crushed in the rock crusher to the right of the photo.



Angel Island was an important military base during the Civil War. Stuart Point, immediately north of Camp Reynolds, provides a commanding view of San Francisco Bay, as shown in this Civil War reenactment..

Rock Crusher

On the western part of Angel Island there is a northwest-trending belt of serpentine that is several hundred feet thick. This belt of serpentine separates the pillow basalts that form the westernmost part of the island from the schistose sandstones that form the central and eastern parts of the island. One of the best places to see this serpentine is at the serpentine quarry next to the rock crusher near Perle's Beach. The serpentine is also exposed along the shoreline east of Perle's Beach, but access to this part of the beach is difficult and not recommended.

●Serpentine Quarry

To get to the serpentine quarry from Perle's Beach, continue east 0.25 miles on the Perimeter Road to the quarry. The quarry is flanked by a large rock crusher that is no longer in operation. The crushed serpentine was used for road building on Angel Island and for construction of a dam to the east of the quarry. If you look through the holes in the asphalt pavement along the Perimeter Road, you can see the green serpentine rocks that were used as the road base in many places.

The serpentine in the quarry is pale green, feels very slippery, and is intensely foliated. This foliated serpentine contains ovoid masses of very dense serpentine, usually darker green in color. In places there are also ovoid masses of other rocks within the serpentine, including gabbro, sandstone, and metamorphic rocks. Some of these metamorphic rocks were formed by alteration of basalt or diabase inclusions within the serpentine.

The belt of serpentine exposed at the serpentine quarry is the largest unit of serpentine on Angel Island. This serpentine represents a chunk of oceanic crust that was incorporated into the Angel Island terrane, probably as the Angel Island terrane was being digested in the Franciscan subduction zone. Other small blocks of serpentine occur in several places on Angel Island, mainly within the pillow basalts from Perle's Beach to Camp Reynolds.

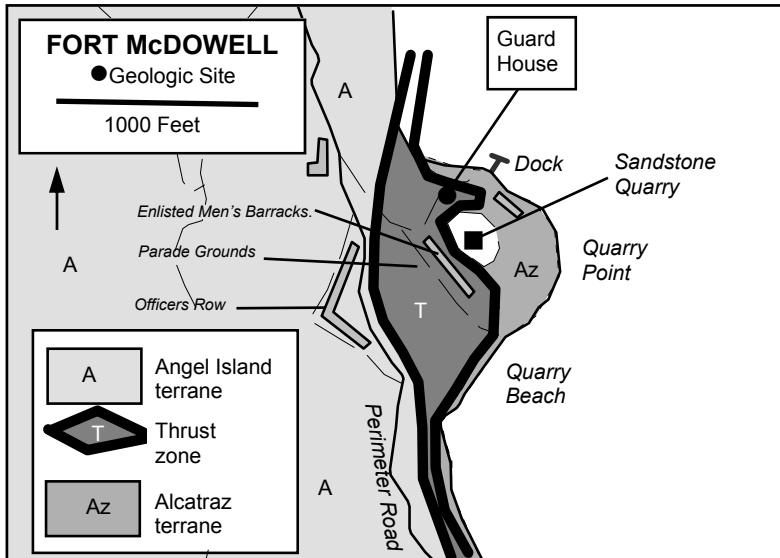
For more details on the origin of serpentine refer to the Fort Point geologic site on the trip to San Francisco. You will also see more serpentine during the geologic trip to Ring Mountain.

Fort McDowell

After the Angel Island terrane was emplaced in the Franciscan subduction zone, the Alcatraz terrane was carried into the subduction zone and thrust under the Angel Island terrane. The rocks along the zone of thrusting were ground up to form a layer of clay and rounded boulders. Fort McDowell is sprawled across this zone of thrusting. Quarry Point is formed from rocks of the Alcatraz terrane below the thrust. The Enlisted Men's Barracks and Parade Grounds lie within the zone of thrusting. The Officers Row above the Parade Grounds is situated on the Angel Island terrane above the thrust. At Fort McDowell you will go to the Guard House near Quarry Point where you can stand in the zone of thrusting and see good exposures of the Alcatraz sandstone in the sandstone quarry below the thrust.

● Guard House

To get to the Guard House at Fort McDowell from the serpentine quarry, continue east on the Perimeter Road 2.0 miles to Fort McDowell then follow the path to the dock at Quarry Point. The Guard House is near the dock. There is a visitor center in the Guard House. Go to the backyard of the Guard House, where you can get a good view of the quarry. The quarry is fenced off, but you can see that the rocks in the



Quarry Point consists of sandstones of the Alcatraz terrane. These rocks underlie and are separated from the Angel Island terrane by a thrust fault that extends from Quarry Beach to north of Quarry Point. See page 81 for a cross section view.



The Alcatraz sandstone is exposed in the walls of the quarry (left) at Quarry Point. The flat surface above and to the right of the quarry is the exhumed thrust fault that separates the Alcatraz terrane from the overlying Angel Island terrane. The Angel Island terrane has been eroded from the top of the thrust fault in this area.

quarry are thick-bedded and similar to the Alcatraz sandstone on Alcatraz Island.

The zone of thrusting that separates the Alcatraz sandstone from the Angel Island terrane is nearly flat and consists of a melange several tens of feet thick. The melange is difficult to see because the clay is soft and easily eroded. What you can see is the nearly flat surface formed by the hard rocks of the Alcatraz terrane that forms the lower boundary of the thrust zone. At the top of the quarry you are standing on this surface. The Enlisted Men's Barracks and the Parade Grounds west of the barracks also lie on this surface. From the barracks, the thrust zone slopes gently to the north and intersects the beach just north of Quarry Point. To the south, the zone of thrusting lies just above Quarry Beach and intersects the shoreline further south toward Blunt Point.

It is somewhat unusual for metamorphosed rocks to overlie unmetamorphosed rocks. It appears that the rocks of the Angel Island terrane reached the Franciscan subduction zone first and became metamorphosed during the earlier and hotter stages of subduction. The rocks of the Alcatraz terrane were inserted under the Angel Island terrane later when the subduction zone was cooler.