Serpentinite | Pillow Basalt | Ribbon Chert | Graywacke Sandstone

Franciscan Rocks of the Marin Headlands Terrane

Introduction

The Marin Headlands Terrane contains rock types typical of the Franciscan Complex including the following: 1) sedimentary sandstone and shale (deposited by submarine landslides along the continental margin), 2) oceanic basalt (erupted from underwater volcanoes and commonly altered to a rock called greenstone), 3) ribbon chert (made of the silica-rich shells of single-celled Radiolaria), and 4) serpentinite (formed from altered upper mantle rock). Limestone and several metamorphic rock types, like blueschist (produced under high-pressures), amphibolite and eclogite (formed under high-temperatures) also are present in smaller amounts.

Melange containing four main Franciscan rock types. Marin Headlands Terrane at Baker Beach at the Presidio.

Pillow basalt with red chert beds at Point Bonita. Chert layers were deposited at times of volcanic quiescence.

Sandstone and Shale

Sandstone is the most common clastic rock in the Marin Headlands Terrane. It is made of a mixture of angular feldspar, quartz, and volcanic rock fragments. The volcanic fragments give the sandstone a greenish-gray color and hence its common name, graywacke. These rocks were deposited by submarine landslides, called turbidites, that slid off the continental margin and flowed into the deep trench developed at the subduction zone.

The sandstone beds are mostly 1-2 m (3-6 feet) thick but can reach over 20 m (66 feet) in thickness. The beds may have cobbles or pebbles at their bases and contain progressively finer sandstone, silt and shale particles upwards. This progression results from decreasing transport energy after slide events. As the energy decreased, smaller and smaller particles dropped out of suspension and were deposited.

Serpentinite

Serpentinite, the California State Rock, is made of serpentine-group minerals, which include chrysotile (asbestos), lizardite, and antigorite. These minerals give a blue-green color to serpentinite blocks and the clay zones that surround them. In outcrop, rounded serpentinite blocks, typically 1 to 2 m (3 to 6 feet) in diameter, are surrounded by sheared, flaky serpentine called slickentite.

Serpentinite in the Franciscan Complex is made of fragments of oceanic crust and mantle (ophiolite) that were plastered onto the margin of North America rather than being subducted under it. Hot fluids flowing through the subduction zone altered the iron- and magnesium-rich minerals of these rocks to serpentine, making the rocks lighter and more easily deformed.

Because serpentinite is altered mantle rock, its chemistry is unlike other continental rocks. Serpentinite is low in potassium and calcium, which are important plant nutrients. It also contains high levels of magnesium, nickel and chromium that can be toxic to plants. Therefore, plants living on serpentine soils are specially adapted to these unusual chemical conditions and some species only grow at one or a few outcrop areas. Many of the rare plant species in the Golden Gate National Recreation Area are specifically adapted to serpentine soils.

Serpentinite block showing shiny relict crystal textures (bastite replacements of pyroxene crystals) and a lacy network of 1-2 mm asbestos veins.

Rounded pillow structures in basalt altered to greenstone at Point Bonita. Pillows form in underwater volcanic flows.

Oceanic Basalt

The chemistry of basalt in the Marin Headlands Terrane indicates that it was erupted from mid-ocean ridge volcano. Hot sea water at the eruption site changed minerals in the basalt to chlorite and pumpellyite, giving it a dark green color and hence the name, greenstone.

Most basalt of the Marin Headlands Terrane exhibits rounded forms shaped like pillows and is known as pillow basalt. Most pillows are less than a meter across (3 feet) and have rounded tops and downward projecting keels molded by the tops of the older underlying pillows. These forms show which direction was originally up and demonstrate an underwater origin for the flows.

At some places sedimentary chert lies between the pillows. At other places pelagic limestone is present between pillow forms. The occurrence of these slowly-deposited sedimentary rocks indicates periods of volcanic quiescence between eruptions.

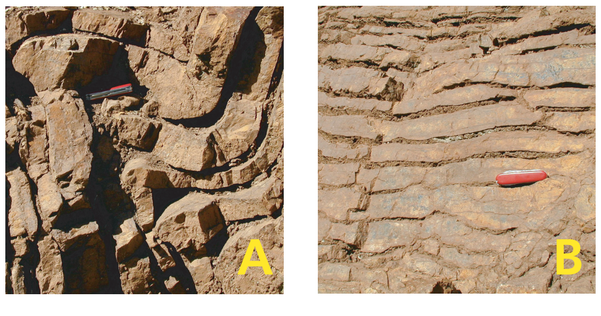
The presence of limestone indicates that the eruption site was above carbonate compensation depth (CCD - the depth below which all carbonate material dissolves in sea water), which is around 4 km (2.4 miles) deep in today's oceans. The lack of limestone in the chert layers above shows that the oceanic plate quickly descended below CCD.

Chert

Chert of the Marin Headlands Terrane contains abundant fossil radiolaria. The tiny silica shells of these single cell organisms are smaller than a grain of sand but can be seen clearly with a hand magnifier. At most places, thin red chert layers alternate with thinner, dark red shale beds. The red color indicates that the iron in the rock is oxidized. Some green to white chert beds also are present. Because of the thin bedding, these rocks are commonly called ribbon chert. Chert deposited near the pillow basalts (at the base of the sedimentary rock sequence) is stained black by manganese oxide that precipitated from manganese-rich waters circulating near the volcano.

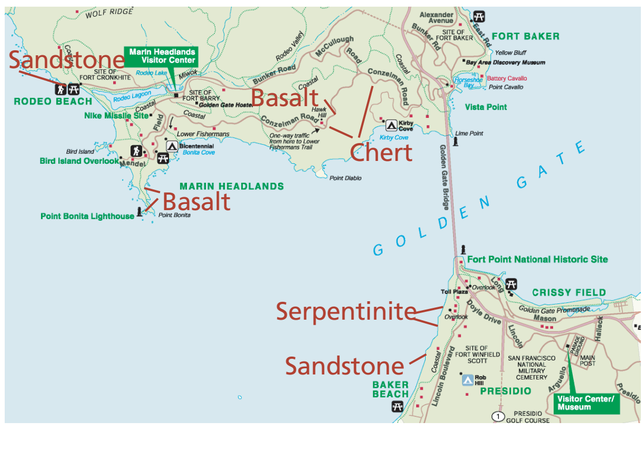
Locally, the chert is intensely folded. Most likely, this folding occurred when the rocks were wedged against the continental margin and faulted to there present position. However, abrupt changes from only slightly to highly folded areas and unbroken sharply folded beds suggest that some of the contorted folding reflects submarine slumping prior to the muddy ooze becoming hard rock.

The rhythmic bedding of the chert is one of its most distinguishing features. The contrast between hard chert beds and intervening shale beds was increased as silica moved from less silica-rich zones to more silica-rich beds during burial and transformation of the mud into chert.



Ribbon chert on Conzelman Road in the Marin Headlands. A) Tight folds lacking fractures suggest the folding occurred before the sediments were hard. B) Migration of silica from clay-rich intervals into silica-rich zones enhanced the chert beds, making them look ribbon-like.

The thin dark layers separating sandstone beds reflect the slow deposition of mud between the slide events.

Carbonized plant material is sometimes concentrated at the tops of sandstone beds, perhaps floating to the top of the soupy sand soon after a turbidite event.

Where You Can See These Rocks