Geology 101 for Stewards Docents

1.28.22

Due to fracturing from faults, the disruption from subduction of the Farallon Plate, uplifting of coastal rocks and sediments, and other factors, California's geology is very complex. In *Roadside Geology of Northern California*, the authors refer to the Coast Ranges as "A nightmare of rocks."

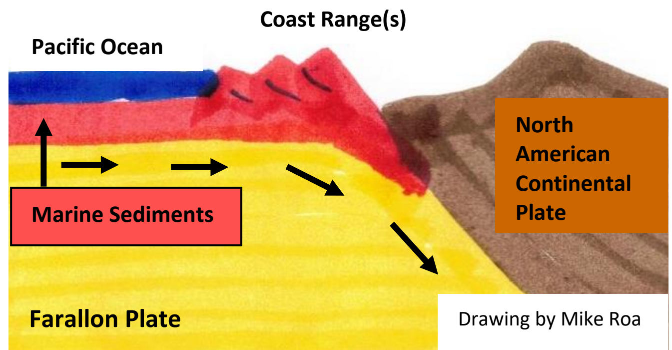
This short document is intended to give docents a very basic understanding of the "nightmare" geology of Armstrong Woods and Pomo Canyon. Even though it has just the basic information, it includes more than you will ever teach a group. But knowing about the geology of the area will help you answer some questions and generally feel more confident when leading groups.

To understand the geology of the coast mountain range(s), one must know a bit about plate tectonics. Basically, the continents are sort of rafts of relatively light (less dense) material such as granite and basalt "floating" on more dense material such as peridotite. Hot, molten material from the mantle of the Earth rises to the surface, primarily under the sea floor, forming mid-ocean ridges. As new material is pushed upward, the older, cooled material is pushed away from the ridges.

When the dense seafloor material collides with the "rafts" of less dense continental material, the sea floor rock is pushed under the continental crust material in a process called subduction. In the process,

a. some of the seafloor material is scraped off by the overlying continental crust and

b. some of the scraped off material and some of the continental crust is pushed upward. (Think of a slice of pizza being pushed under a door. Some of the topping will be scraped off, wrinkled, and pushed upward.)



The seafloor material is not just solid basalt, though. The seafloor, especially near the coasts, is covered with thick layers of both sediments washed from the continents and the "shells" of microorganisms that lived and died in the oceans. Many of the shells contain high amounts of silica, which makes them very hard and durable. Over millions of years, those layers of organic and inorganic sediments are compressed and heated. Sedimentary rocks thus compressed and heated form metamorphic rocks. The coast mountain ranges of California are made up mostly of sedimentary and metamorphic materials scraped from the top of the subducting Farallon Plate.

Unsurprisingly, the subduction process isn't smooth. Where pieces of crust collide, faults form. Sometimes plates subduct; other times they slide past each other, and not smoothly. The San Andreas fault is an example. The San Andreas fault lies just off the Golden Gate, runs through Tomales Bay and Bodega Bay, and then continues just off of the coast west of Jenner. Bodega Head contains material that has been brought from southern California by the northwestern movement of the Pacific Plate.

In addition to faults, these plate movements cause the sediments to heat up, resulting in the formation of metamorphic rocks. Magma from deep in the crust forms chains of volcanoes along the coast. This is the source of the obsidian ("volcanic glass") found at Annadel and elsewhere, and of the volcanic ash that buried the redwood forest that is now the petrified forest found north of Santa Rosa.

For more information on geology, see *Roadside Geology of Northern California*, by Alt and Hyndman. We have a copy in the Stewards docent library at the Volunteer Office.

For more information on the situation in the Willow Creek Watershed, see the *Willowcreek Watershed Management Plan*, which is available in the Stewards Volunteer Office and the Willow Creek Watershed Restoration document at: https://www.stewardscr.org/willow-creek-watershed-restoration.html. drawing by Mike Roa

Credits: Rebecca Perlroth, of the SRJC Geology Dept. and Nicole Meyers, of the SSU Geology Dept., helped with this document.

Constant Change: Morphology of Streams and Valleys

Erosion moves silt and rocks of various sizes into valleys. Some particles may get deposited in the valley as alluvium, while other particles are carried away by streams, so there is a constant battle between accumulation and erosion of the alluvium. The floor of Pomo Canyon, like the floor of Armstrong Woods, is filled with alluvium accumulated over thousands of years.

Willow Creek

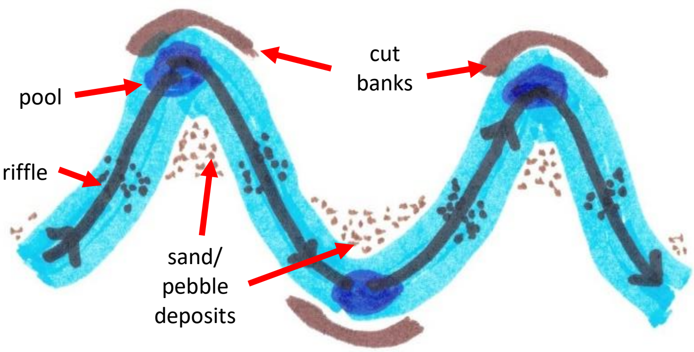
Streams do not maintain the same course forever. They flow wherever the alluvium is loosest, cutting new channels and meandering through the alluvial flats in the bottom of their canyons.

As creeks turn and “meander” through valleys, they tend to cut into (incise) banks that they hit “head-on,” forming steep banks and scouring out pools.

On the other side of the bend, sand and gravel are often deposited; the banks may be less steep.

(**Note**: This process is not universal. At places in Pomo Canyon the opposite is true…the outside of the bend slopes gently while the inside of the bend is steep.)

“Riffles” often form in the shallow water between bends.



Roots from trees and other plants can <u>help</u> hold the soil and gravel in place, but streams can still erode the stream banks.

Strongly eroded banks at the outside of the bend.

Sand and pebble deposits on the inside of the bend.

Of Silt and Sand and Stuff

“**Silt**” is a term for small particles that are between clay and sand in size. When rubbed between the fingers, individual particles can<u>not</u> be felt. Particles are less than 1/16 mm in diameter.

“**Sand**” particles are larger than silt. When rubbed between the fingers, individual particles <u>can</u> be felt. Particles of sand can be up to about 2 mm (a little less than 1/8”) in diameter.

“Granules” are between 2 mm and 4 mm across.

“**Pebbles**” are larger particles between 4 mm and 64 mm (1/8” to 3.5”) across.

“**Cobbles**” range in size from 64 mm to 256 mm (3.5” to 10”) across.

Even larger rocks are referred to as “**boulders**.”

Small particles are more easily moved downstream (or downhill) than larger ones, so a gently flowing stream may remove silt, leaving gravel. However, a rapidly flowing stream may undercut stream banks, adding silt and sand to the stream bed.

images and drawing by Mike Roa

Erosion and Salmonid Habitat

The normal flow of water in streams causes some erosion of the stream banks, especially as streams change course (meander) in fragmented soils such as found in Fife Creek and Pomo Canyon. Road construction, building, farming, landslides, heavy rain, logging and other factors can increase erosion of the land and cause the addition of sediments to streams.

Erosion of stream banks can undercut roads and topple trees along the stream. In order to prevent undercutting of roads and trees along Fife Creek in Armstrong Woods, portions of the creek were lined with logs and bags of concrete after the northern California floods of 1964. Such erosion control efforts disrupt the natural flow of not only water but also sand and gravel in the creek, negatively affecting fish reproduction.

Pomo Creek undercutting its bank. Note the exposed tree roots.

Erosion control efforts in Fife Creek

above images by Mike Roa

Logging in the Willow Creek watershed, 1911. (Courtesy Western Sonoma Co. Historical Society)

Logged over hillside near Guerneville, 1910. Note the devastation of the creek. (Courtesy Sonoma Co. Library)

Since before 1900, agriculture, road building and, especially, logging, resulted in huge amounts of silt being added to Willow Creek. Attempts to keep the stream from flooding the farms and roads by altering the location, shape, and depth of the creek further degraded it so much that by 2001 the stream bed was essentially filled with sediment in some areas, with no bed or banks remaining. Both upstream movement of adult salmon and downstream migration of juveniles were blocked.

Since the 1960s, sediment addition to the creek has decreased. Changes in the roads and bridges (especially the second bridge) and general use patterns in the watershed have improved the stream quality of Willow Creek so that salmonids are now beginning to re-establish themselves in the creek.

Healthy Streams for Healthy Fish

Salmonids (salmon, trout, steelhead rainbow trout) swish their tails to hollow out "nests", called **redds**, in which they lay their eggs. To make their redds, they need gravel that is loose enough to move so that silt and sand can be washed away, leaving space for the eggs between the gravel particles. The gravel protects the eggs and young fish ("fry") from predation. If silt and sand are not cleared out by moving water, the gravel can become embedded so firmly that the fish can not build their redds. If silt is added on top of the eggs, they can be smothered and killed.

Russian River steelhead making a redd. The female, at left, is flipping her tail to excavate a redd. The male, at the right, waits for the female to expel the eggs so that he can fertilize them, and "guards," keeping other fish from eating the eggs before they are covered with gravel. source of photo: U.C. San Diego Sea Grant Program

Silt and fine sand can bury the eggs and kill them. If poor logging practices, landslides, road building, or something else causes silt to be washed into the stream, salmonids can be extirpated from an area, as they were from Willow Creek. Willow Creek is now recovering from decades of sedimentation and once again provides salmon and steelhead breeding habitat.

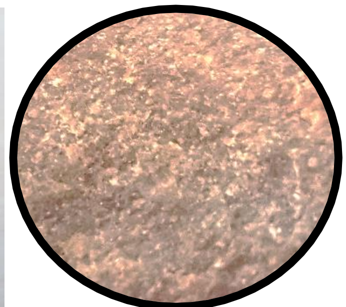
In addition to gravelly stream beds for building redds, salmonids need **cold water**. (Cold water holds more dissolved oxygen. Active fish such as salmonids need lots of dissolved oxygen.) Pools formed at bends in rivers and creeks and behind obstructions such as logs ("large woody debris") provide deep, cool water, especially if the stream is lined with trees and shrubs that provide shade and the water splashes over logs and rocks in riffles. Streamside vegetation also provides habitat for insects that are an important food source for fish.

Pool behind large woody debris in creek
Note bubbling, which adds oxygen to the stream.
(in Lassen Volcanic National Park)
image by Mike Roa

Since before 1900, agriculture, logging and road building added huge amounts of silt to Willow Creek, degrading the salmonid habitat so much that the fish were extirpated. Since the 1960s, sediment addition to the creek has decreased. Changes in the roads and bridges and general use of the watershed have improved the stream quality of Willow Creek so that salmonids are now beginning to re-establish themselves in the creek. Stewards, State Parks, and other organizations continue to work to improve the quality of the Willow Creek Watershed.

Sedimentary Rocks: Sandstone

Sandstone is formed when small rock particles are compressed. and cemented together. This usually happens when sediments are in the ocean or other large bodies of water, so such rocks are called sedimentary rocks. Since the sediments are laid down in layers, sandstone is often layered, but the layers may be very thick and, therefore, not evident in a small sample. Rock/sand particles in sandstone are usually pretty homogeneous in size. Most of the rocks found in Fife Creek and the creek at Pomo Canyon are sandstone.



Above: Sandstone at entrance to Armstrong Redwoods State Reserve, in Guerneville

Greywhacke is a type of sandstone. It is generally harder than other sandstones and the grains tend to be angular and **vary in size**. (Most sandstone has grains that are all of similar size and shape.) Greywacke deposits were formed by undersea landslides or turbidity currents, so sand and clay particles of varying sizes are mixed.

The rocks may be brownish-gray on the outside, but when split, the rocks are usually gray in color. (Greywacke often "weathers" to a brown color.) But greywacke can range from light tan to brown to black in color. In heavily shaded areas such as Pomo Creek, exposed rocks are often covered with a coating of algae, making them appear greenish.

Where to find/see: Greywacke is common on Sonoma Coast beaches.

Greywacke rocks at Russian Gulch beach

Greywacke sandstone along Hwy 1 just south of Jenner

Greywacke in Pomo Canyon, showing algal coating

Photos by Mike Roa

Sedimentary Rocks: Chert

Chert is a hard, <u>sedimentary</u> rock composed of the quartz skeletons of microscopic organisms such as diatoms and radiolarians ("siliceous ooze"). Chert can be many colors: reddish, green, brown, black, or even white. Locally, red is the most common color of chert.

Native Americans used chert for tools such as arrowheads, knives, and scrapers if obsidian was not available. Local Indians, however, could obtain obsidian from the Annadel area. Both obsidian and chert are very hard and can be shaped by conchoidal fractures. ("Conchoidal" fractures result in flakes and marks on the rocks that look sort of like (clam) shells.)

conchoidal fracture in flint, a very hard form of chert

Where to find/see: Chert rocks are common on Sonoma coast beaches. "Red Hill," between Shell Beach and Pomo Canyon is apparently named for red chert found there.

Chert rocks at Russian Gulch beach

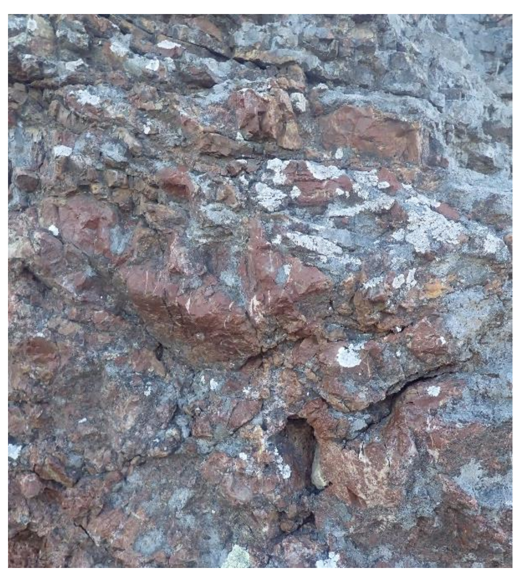
chert knife or scraper

chert bird point

obsidian bird point

Tools life-size. Not from Sonoma Co.

Flint is an especially hard form of chert. It can be used to spark a fire or ignite gunpowder, as in a "flintlock" gun.



Photos by Mike Roa

Sedimentary Rocks: Petrified Wood

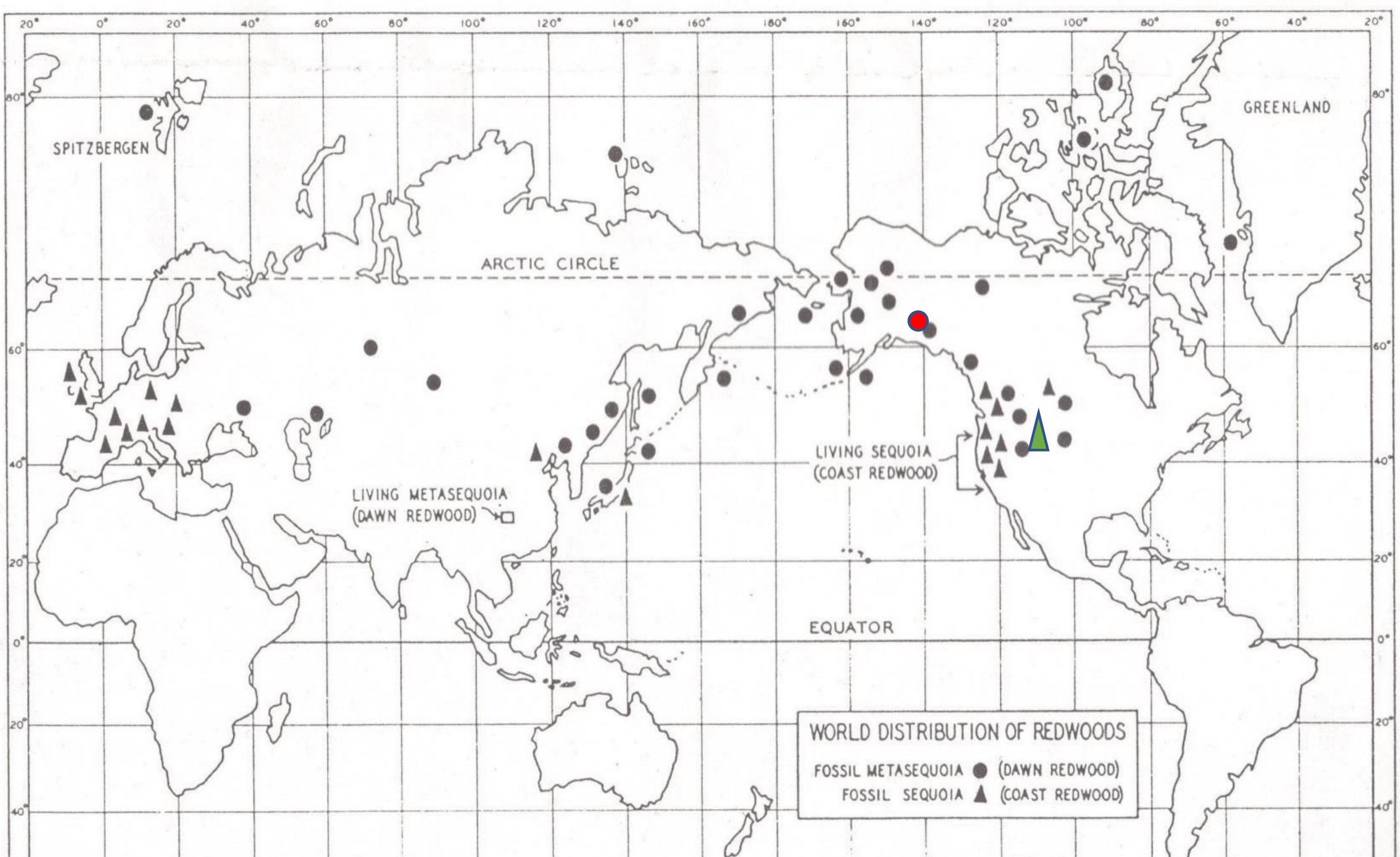
The Petrified Forest, between Santa Rosa and Calistoga, consists of "petrified wood" formed as a result of an eruption in the area of Mt. St. Helena about 3.4 million years ago. The eruption blew the redwood trees (*Sequoia langsdorfii*) over and covered them with ash. Over millions of years, water percolated through the ash, picking up minerals as it did so. The minerals, mostly silica compounds such as quartz and opal, precipitated out of solution and were deposited in the interiors of the cells, with the cell walls acting as a template. Thus, the minerals took the shape of the cells and show growth rings and other features.

Where to find/see: The Petrified Forest is a great place to see petrified wood. It can sometimes be found in other areas, and occasionally a piece is carried by creeks and rivers all the way to the coast.

Fossil Redwoods

Some fossils, such as the redwood needle fossils pictured below, are imprints of leaves that were buried in layers of ash, sand or other sediments. Others, such as the cone pictured below are formed when bone, wood, or other material is buried in ash or other material. Over millions of years, water percolates through the ash, picking up minerals as it does. Minerals, mostly silica compounds such as quartz and opal, precipitate out of solution and are deposited in the interiors of the cells, with the cell walls acting as a template. Thus, the minerals take the shape of the buried material.

Map copyright by Save-the-Redwoods League.



About 60-50 million years ago, both *Sequoia* and *Metasequoia* were widely distributed in the northern latitudes. Since then, climate change has reduced their range. Fossils are common in the northwestern U.S. images by M. Roa

Metamorphic Rocks: Serpentinite

Serpentinite is formed by a hydrothermal metamorphic process, typically involving hot seawater. It ranges from light to very dark green, and often is smooth, with a slippery "greasy" feel. (The rock can feel like a smooth snake skin, hence **serpent**inite. It and often contains veins of asbestos.

Soil above serpentinite is rich in magnesium, chromium, and nickel, which are toxic to most plants, and are poor in calcium, so most plants don't grow well in serpentine soils.

Serpentinite can contain water, resulting in unstable soils above sometimes leading to landslides

Serpentinite rocks tumbled in ocean waves are light green. When wetted, they become a darker green.

Some serpentinite is soft enough to be carved with a knife and is called soapstone, although other rock types are also called soapstone. A variety of products are made from soapstone.

Where to find/see: Serpentinite is exposed on some Hwy 1 roadcuts. There is an outcrop at Goat Rock. There are some large serpentinite rocks in Fife Creek. The rocks pictured above are a little south of the bridge south of the picnic area.

Above and left: **Serpentinite** in an outcrop at south parking area at Goat Rock

Metamorphic Rocks: Schists

Schist is a metamorphic rock with medium-sized grains. The mineral grains are oriented such that the rock is easily split into flakes or plates. This is because the minerals themselves are “platy,” displaying parallel alignment. Schist is often made up of micas, talc, chlorite, or graphite, interspersed with more granular minerals such as feldspar or quartz. Several forms of schist can be found locally, with shist, blueschist, and greenschist being the most common.

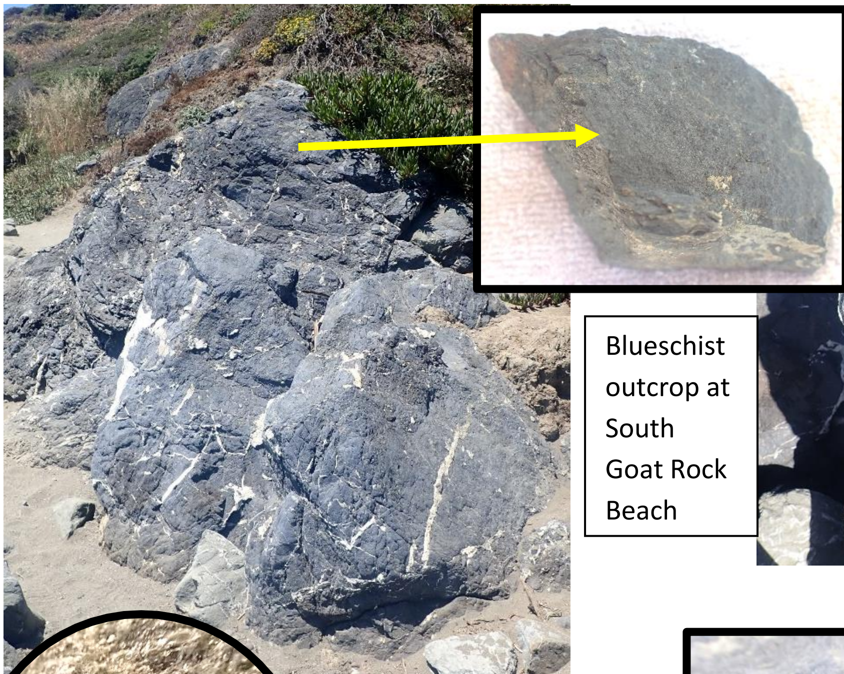
Schist

Photos by Mike Roa

Metamorphic Rocks: Blueschist

Blueschist is a metamorphic rock formed from basalt at low temperatures and high pressure, typically in subduction zones such as along our coast. Our local blueschist is very fine-grained, hard, and **may** include red-brown garnet crystals, which may look like tiny rust spots in the rock.

Where to find/see: Blueschist rocks are common on Sonoma Coast beaches. The outcrop shown below is at Goat Rock.



Blueschist outcrop at South Goat Rock Beach

Tiny garnets can **sometimes** be found in blueschist.

Blueschist from Austin creek

a blueschist rock at Russian Gulch beach (dry and wet)

Photos by Mike Roa

Metamorphic Rocks: Gneiss

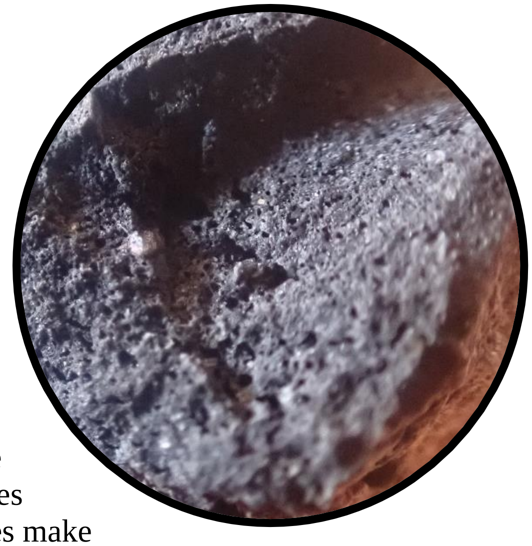
Gneiss is a coarse-grained metamorphic rock that has a distinct banding. Unlike schist, though, the bands or layers don't tend to cleave or split into layers. The bands or layers are often wavy in appearance.

Gneiss is not common in Sonoma County, but it does occur in some places.

Where to find/see: Some gneiss is exposed south of the creek at Kehoe Beach in Point Reyes.

Photos by Mike Roa

Igneous Rocks: Basalt



Basalt is an extrusive igneous rock formed by rapid cooling of magma (lava) on the surface. ("Extrusive" rocks are formed from magma that cools on the surface of the Earth, as opposed to "intrusive" rocks that form from magma that cools and solidifies beneath the surface.) Basalt is rich in magnesium and iron. Various forms of basalt make up more than 90% of Earth's volcanic rock.

When magma cools rapidly, there isn't time for large crystals to form, usually resulting in fine grained rock.

Basalt often contains holes, called vesicles. Vesicles are formed when dissolved gases bubble out of the magma as it approaches the surface of the Earth and decompress. The erupted lava then solidifies before the gases can escape, leaving holes in the rock. If the vesicles make up a substantial portion of the rock and have thick "walls", it is called scoria.

Where to find/see: Trione-Annadel state park has lots of basalt. Landscape supply places sell it as "field stone."

above: basalt "field stones" from landscape supply company (scoria at right)

Left and above: basalt at Trione-Annadel State Park

photos by Mike Roa

Igneous Rocks: Granitic Quartz Diorite

Granite is an intrusive igneous rock made up mostly of quartz, feldspar, and plagioclase. It is formed when magma cools and solidifies underground (hence, intrusive). Granite makes up most of the continents' bedrock. Since granite is less dense than basalt, when basaltic magma pushes against the continental granite, the denser basaltic magma "dives" beneath the granite, which, essentially, "floats" on the denser basalt.

Quartz diorite is a granite-like rock, but it has a higher quartz content than true granite.

Since granite (and diorite) are formed underground, the molten material cools slowly, which allows relatively large crystals to form. These large crystals are large enough to be easily seen with the naked eye.

Where to find/see: The San Andreas Fault runs just offshore along most of the Sonoma Coast. However, it cuts through Bodega Bay. Bodega Head is made of rock that is west of the San Andreas Fault. The chunk of quartz diorite that is Bodega Head was once at least 300 miles to the south. The composition of the rocks match up with rock in the Tehachapi Mountains. (Some geologists feel that they match best with the rocks in Baja California, even farther to the south!)

The Bodega Head quartz diorite granite was probably formed about 100 million years ago. The gray colored granite is overlain by brown sandstone deposits, but is visible along the shore.

Photos by Mike Roa

Igneous Rocks: Rhyolite

Rhyolite is the most silica-rich type of volcanic rock. Rhyolite magma is very viscous, which often results in explosive eruptions (as opposed to the flowing magma of basalt).

Sometimes the rhyolite ash settles into layers, which solidify into tuff.
Water filtering through the ash of Mt. Saint Helena picked up silica minerals that helped form the petrified wood found at the Petrified Forest near Calistoga.

Where to find/see: The Mayacamas Mountains, including Pepperwood Preserve, have lots of rhyolite tuff deposits.

Sometimes rhyolite lava forms rock with lots of bubbles, resulting in a type of rock called pumice.

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Pumice

Pumice is a kind of rock made of tiny bubbles (vesicles) with thin walls of extrusive igneous rock. It is generally light colored, but can be various colors, including black. Like obsidian, it has no crystal structure. The “bubbles” in pumice have thin walls that make it less dense than water, so it floats. (Scoria has thicker walls and doesn’t float.)

Pumice

Where to find/see: Landscape supply companies sometimes have pumice rocks. Rhyolite pumice is used as a skin exfoliant and can be bought at stores such as Bed, Bath, and Beyond.

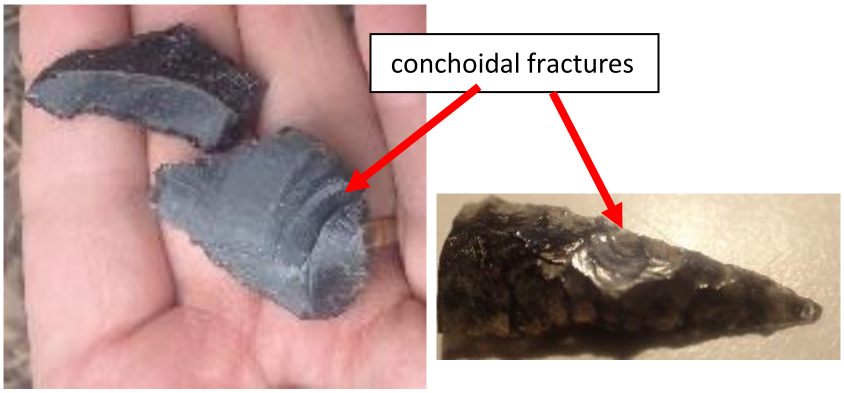
Photos by Mike Roa

Igneous Rocks: Obsidian

Obsidian is an extrusive igneous rock formed by very rapid cooling of magma (lava) on the surface. ("Extrusive" rocks are formed from magma that cools on the surface of the Earth, as opposed to "intrusive" rocks, such as granite, that form from magma that cools and solidifies beneath the surface.) Obsidian is rich in silica. Obsidian often forms when lava has sudden contact with air or water.

When magma cools rapidly, there isn't time for large crystals to form, usually resulting in fine grained rocks. In the case of obsidian, the lava cools so rapidly that crystals don't form at all, resulting in a glassy material. Rather than splitting in straight lines, obsidian (and chert) chip in what are called "conchoidal" fractures, which allowed Native Americans to fashion very sharp tools. Even today, scalpels that are sharper than steel blades are made from obsidian.

Obsidian from the Trione-Annadel area was a valuable trading commodity.



Dissolved gases bubble out of the magma as it approaches the surface of the Earth and decompresses. The erupted lava sometimes solidifies before the gases can escape, leaving holes in the rock. Those holes are called vesicles. Thin-walled vesicles in obsidian form pumice. (See previous page.)

Obsidian flakes found at Trione-Annadel State Park

Where to find/see: Obsidian can be found at Trione-Annadel State Park. Flakes can be found in many locations because the Indians would bring rocks to their campsites and villages and work it there. Gophers sometimes bring the flakes to the surface at Spring Lake in Santa Rosa and Ragel Park in Sebastopol. There's even an Obsidian Road in Santa Rosa!

Photos by Mike Roa