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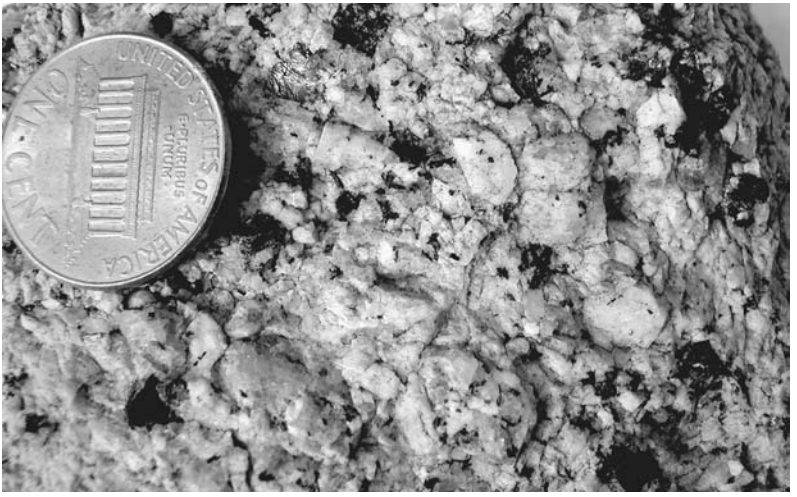
ROCKS OF THE SIERRA NEVADA			
Type		**Name**	**Locality**
Granitic		Granite Granodiorite Quartz monzonite	Yosemite Tuolumne Meadows Southern Sierra Tahoe Area
Mafic		Diorite Diabase Gabbro	Mother Lode Northern Sierra
Ultramafic		Peridotite Serpentine	Mother Lode Northern Sierra
Volcanic	Lava flows	Rhyolite Andesite Basalt	Mammoth Area Mono Lake
	Volcaniclastic	Tuff Lahar	Northern Sierra
Sedimentary	Clastic	Sandstone Gravel Conglomerate Shale Limestone	Northern Sierra
	Chemical precipitate	Chert Tufa	Mother Lode Mono Lake
Metamorphic		Slate Phyllite Schist Greenstone Marble Hornfels	Mother Lode Northern Sierra Roof Pendants

Composition of the Earth	
Element (Percent)	**Element (Percent)**
Iron (34.6)	Nickel (2.4)
Oxygen (29.5)	Aluminum (1.9)
Silicon (15.2)	Titanium (0.05)
Magnesium (12.7)	Other (3.65)

ROCKS OF THE SIERRA NEVADA

The geologic map shows that most of the Sierra is made up of four main types of rocks - granitic, volcanic, sedimentary, and metamorphic. Each of these can be further broken down into many different specific rocks. A basic understanding of these rocks is necessary for understanding the geology of the range. The rocks tell us how and when the mountains were formed. They also determine the shape and color of the mountains and valleys. Some of the rocks even carry valuable minerals like silver and gold. And some rocks are decorative and just nice to look at.

Fortunately, out of the dozens of different rocks that make up the Sierra, just a few are really common. These rocks are described in more detail in the following pages. Each of these rocks was formed in a different manner and has its own characteristics of color, hardness, grain size, and mineral content. When you become familiar with these rocks, you'll do just fine during your geologic trips in the Sierra Nevada. But don't necessarily try to learn all of the rocks now. With the accompanying table you can easily look up and identify the rocks during your geologic trips.



Granite is one of the most common rocks in the Sierra Nevada. The white grains with sharp edges are feldspar. Irregular patches of light gray quartz fill spaces between the feldspar crystals. The dark grains are biotite and hornblende.

Rock-forming Minerals

All of the granitic, volcanic, sedimentary and metamorphic rocks that you will see in the Sierra are formed from minerals. The minerals are the building blocks of the rocks, and usually appear as grains in the rock, giving the rock a granular texture. Some rocks consist of grains of a single mineral, whereas other rocks are composed of grains of several different minerals. Like pieces of fruit in a fruit cocktail, the minerals in each of these rocks can be distinguished by their color, shape, hardness, and other physical and chemical characteristics. But what are minerals?

Minerals are composed of elements that are combined in a regular crystalline structure. The elements in the mineral behave like soldiers standing in formation. Each soldier stands in a specific spot relative to the other soldiers, based on rank, file and organization. Similarly, each element in a crystal has a specific spot where it stands relative to the other elements, and has closer ties to some elements than to others.

As you know, there are about 100 elements on earth. These elements can combine in many different ways to form hundreds and hundreds of different minerals. However, of all these hundreds of minerals, there are only a dozen or so that are common rock-forming minerals. These are briefly described on the accompanying table. Most of these minerals are silicates that contain various proportions of sodium, potassium, aluminum, calcium, iron, and/or magnesium. The few minerals listed in this table are the major components of most all of the granitic, volcanic, sedimentary, and metamorphic rocks that you will see in the Sierra. If you can recognize these few minerals, you will be well on your way toward identifying and understanding most all of the rocks you will see in the Sierra.

By knowing what minerals are in a rock, the composition of the minerals, and the size and shape of the mineral grains, it is possible to tell much about how the rock was formed. Each mineral forms only under very specific conditions of temperature, pressure, and chemical composition. Minerals with a high content of iron, magnesium, and/or calcium generally form at high temperatures, whereas minerals with high content of silica, sodium, potassium, and aluminum crystallize at relatively low temperatures. Large crystals take a long time to develop, usually from magma that cools slowly deep in the earth. Small crystals form more rapidly, usually from magma that chills rapidly on or near the earth's surface. Some minerals even tell us how old they are. If the mineral contains radioactive elements, the age of the mineral can be determined based on the known rate of radioactive decay. It seems that

COMMON ROCK-FORMING MINERALS	
Quartz	Glassy; hard; conchoidal fracture; common in sedimentary, igneous and metamorphic rocks; usually granular when constituent of rocks, but may form clear six-sided crystals; SiO_2.
Plagioclase feldspar	Light to dark gray; hard; flat cleavage; very common in igneous rocks; (Na,Ca)Al silicate.
Potassium feldspar	White, pink; hard; flat cleavage; commonly twinned, prism-shaped crystals or granular; common in igneous rocks with high silica content; KAl silicate.
Muscovite	White mica; highly perfect cleavage; breaks into thin elastic plates; common in granite and many metamorphic rocks; water-bearing KAl silicate.
Biotite	Black mica; also brown or dark green; flat flakes, single perfect cleavage; common in many metamorphic and igneous rocks; water-bearing K(Mg,Fe) Al silicate.
Hornblende	Dark greenish-black elongated and striated crystals; occurs in many igneous and metamorphic rocks; water-bearing (Ca,Na) (Mg,Fe) (OH_2) Al silicate.
Pyroxene	Black, green, brown; short eight-sided crystals or granular masses; occurs mainly in diorite, gabbro, basalt, andesite; (Mg,Fe) (Ca,Na) Al silicate.
Olivine	Yellowish green to olive green; glassy rounded grains; no cleavage; occurs in gabbro, peridotite and basalt; crystallizes at high temperature; (Mg,Fe) silicate.
Clay	Fine-grained; feldspar typically alters to clay when exposed to weathering; water-bearing Al silicate.
Calcite	White; soft; occurs in many sedimentary and metamorphic rocks; $CaCO_3$.
Common accessory minerals	Sphene: yellow or brown crystals in granite; CaTi silicate. Garnet: red crystals in metamorphic rocks; Ca,Mg,Fe,Al silicate. Pyrite: yellow crystal; all types of rock; FeS_2. Zircon: crystallizes as tetragonal prisms; various colors; $ZiSiO_4$.

we know more about some rocks than we do about many of our closest friends. We know what temperatures they like, how much pressure they can stand, how long it takes them to cool off, and we even know how old they are.

Now that you're familiar with these common rock-forming minerals, let's take a more detailed look at the rocks that you will see during your trips to the Sierra. As you will see, most of these rocks are identified by the types and proportions of their component minerals.

Granitic Rocks

As seen on the geologic map, granitic rocks are widely exposed in the core of the Sierra Nevada. These rocks are typically light-colored, granular, and coarse-grained. They consist of a mixture of quartz, plagioclase feldspar, and potassium feldspar, with lesser amounts of biotite, hornblende, and other minerals. These minerals crystallized from magma that cooled deep within the earth's crust, generally at depths of from three to six miles. At these depths, the magma cooled slowly, so there was sufficient time for large crystals to form. If you look at a granitic rock with a magnifying glass, you can see the sharp edges and flat surfaces of many of these crystals.

Prior to crystallization, the molten rock in the magma chamber was a mixture of ions of silicon, oxygen, aluminum, calcium, sodium, potassium, iron, and magnesium. These ions moved around in the magma in a disorganized manner, like soldiers circulating in the gathering area for a parade. As the magma cooled, the parade began, with iron and magnesium in the lead. The iron and magnesium quickly found some calcium and aluminum and grabbed all the silicon and oxygen that they needed. Having formed their unit, they left the gathering area as crystals of pyroxene and hornblende. After their departure, the magma was richer in the remaining elements and continued to cool. Next, plagioclase feldspar and potassium feldspar formed their units. They used up most of the remaining calcium, sodium, potassium and aluminum, and took as much silicon and oxygen as they wanted. After a while, only silicon and oxygen remained. Finally, at relatively low temperatures, the silicon and oxygen joined to form quartz. Since quartz was the last mineral to crystallize, the quartz had to squeeze between the earlier crystals.

As shown below, there are several types of granitic rocks, depending on the relative proportions of quartz, plagioclase, and potassium feldspar. Although the term *granite* technically refers to a specific rock, as indicated in the table, geologists also use the term to loosely refer to all of these related granitic rocks.

GRANITIC ROCKS		
Granite	Light gray, coarse grained; equal proportions of quartz, plagioclase and potassium feldspar.	Yosemite
Granodiorite	Similar to granite, but less potassium feldspar and more plagioclase feldspar.	Yosemite Tuolumne M. Sequoia
Quartz monzonite	Similar to granite, but less quartz.	Lake Tahoe Alabama Hills

Mafic and Ultramafic Rocks

Ultramafic rocks are dark and heavy because they are rich in iron and magnesium-bearing minerals such as pyroxene, olivine, and serpentine. These rocks form most of the earth's mantle and the lower part of the earth's oceanic crust. In the Sierra Nevada, most of the ultramafic rocks occur as irregular bands and layers of pyroxenite and serpentine in the metamorphic rocks of the Western Metamorphic Belt. The Feather River Belt and the Smartville Complex have extensive exposures of these heavy dark rocks.

The ultramafic rocks of the Western Metamorphic Belt represent slices of the earth's mantle and oceanic crust that were caught up in one or another of the subduction zones that bordered North America during much of Paleozoic and Mesozoic time. In subduction zones, most of the heavy ultramafic rocks are subducted and carried below the continental crust. However, in the Western Metamorphic Belt, some of these rocks were tacked onto the edge of the continent rather than being subducted.

Mafic rocks differ from ultramafic rocks mainly in that they contain plagioclase feldspar in addition to pyroxene and olivine. The most common mafic rocks in the Sierra Nevada are gabbro and diabase. These rocks are the same composition as basalt, but differ in that gabbro is coarse-grained and crystallized at depths of several miles in the earth's crust, diabase is fine-grained and crystallized at shallow depths, and basalt is a very fine-grained and solidified from a lava flow.

MAFIC AND ULTRAMAFIC ROCKS		
Mafic: dark colored; typically contain plagioclase feldspar and pyroxene.		
Diorite	Medium gray; composition between granite and gabbro.	North American Wall of El Capitan
Diabase	Dark gray; fine grained; same composition as gabbro, but crystallized at shallow depth in earth's crust.	Western Metamorphic Belt
Gabbro	Dark gray; coarse grained; large crystals; crystallized at great depth in the earth's crust.	Western Metamorphic Belt
Ultramafic: very dark colored; consist mainly of pyroxene and olivine.		
Peridotite	Heavy; dark; coarse-grained; little or no feldspar.	Western Metamorphic Belt
Serpentine	Green; breaks along shiny, smooth, curved surfaces; slippery; waxy.	Melones fault Goodyear Bar

Volcanic Rocks

Volcanic rocks are formed when magma erupts from a vent on the surface of the earth. Since volcanic rocks cool rapidly, they are mostly fine grained. Some volcanic rocks also contain a few large crystals of feldspar, hornblende, or other minerals. These *phenocrysts* represent crystals that began to form early in the magma.

Most volcanic rocks occur as *lava flows* or as *volcaniclastic* rocks. Lava flows are formed when magma is extruded from the vent as a flow of molten rock. In contrast, volcaniclastic rocks are formed when particles of solid volcanic rock are expelled from the vent. Although there are many different types of volcanic rocks, virtually all of these rocks were formed from basaltic, andesitic, or rhyolitic magma. Each type of magma results in a different type of volcanic rock.

Basalt magma is very fluid and typically forms widespread flows of black fine-grained lava. Basalt is rich in iron and magnesium, and has the same composition as gabbro. On land, lava flows often develop columnar jointing as they cool. When extruded under water, basalt magma typically forms pillow basalt.

Andesite has the same composition as diorite, intermediate between basalt and rhyolite. Andesite is fairly viscous and typically occurs as short flows of volcanic rubble. Many volcanoes are composed of layers of andesite rubble and tuff. Latite is intermediate between andesite and rhyolite, and has phenocrysts of plagioclase and potassium feldspar.

Rhyolite is the same composition as granite, and is found only in continental areas. Rhyolite magma is very viscous and typically oozes from a vent like toothpaste. Most rhyolite is light-colored and fine-grained. If the rhyolite magma has no water content and chills very rapidly, the rhyolite may solidify as dark glassy obsidian. If there is sufficient gas in the magma, the rhyolite can form frothy layers of white pumice. Rhyolite magma typically forms plugs, short steep-sided flows, and volcanic domes.

In many volcanic eruptions, volcanic rocks are thrown from the vent into the air as a shower of volcanic ash. The ash is usually rhyolitic in composition. When volcanic ash falls to the ground and becomes consolidated into a rock, the rock is referred to as tuff. Coarse tuff is usually deposited near the volcano, often forming a rim around the vent. Tuff can also be deposited in water, where it may be stratified and form various slumping features. Very fine volcanic ash may be carried by the wind and deposited as a thin layer that can extend hundreds of miles

VOLCANIC ROCKS		
Lava flows: formed when magma flows from a vent at the earth's surface.		
Rhyolite	Light colored, fine-grained; occurs as volcanic plugs, domes, and short steep-sided flows. May also occur as dark glassy obsidian or white frothy pumice.	Panum Crater North Coulée Obsidian Dome Big Pumice Cut
Andesite	Red, brown, and yellow volcanic rubble; fine-grained; often has phenocrysts of plagioclase and dark minerals.	Mammoth Mtn.
Basalt	Occurs as flows of black fine-grained lava. Forms columnar jointing on land and pillow basalt under water.	Devils Postpile
Volcaniclastic rocks: clastic rocks composed of volcanic material of any volcanic origin.		
Ash	Volcanic ash is composed of particles of solid volcanic rock ejected into the air from a volcano. Air-fall ash refers to ash deposited from the air. An ash flow is formed from a hot gaseous glowing cloud of volcanic material extruded from a volcano. A welded tuff is formed if the hot fragments of an ash flow weld together.	Big Pumice Cut Owens Gorge Soda Springs Chile Gulch Panum Crater Big Bear Lake
Tuff	Tuff is a general term that includes all consolidated pyroclastic rocks.	As above
Lahar	A mudflow of volcanic ash and other volcanic debris; can cover hundreds of square miles.	Mokelumne Hill (Mehrten Fm.)

from the vent. Eruptions of ash are formed when a volcanic vent is plugged by viscous rhyolitic magma and steam builds up under the plug until the volcano explodes.

In some eruptions, volcanic ash flows from the vent as an incandescent cloud of hot gaseous particles. The particles in these ash flows are kept in suspension by gas expelled from the fragments. If the ash flow is thick and cools slowly, the fragments can weld together, forming a welded tuff.

Volcanic ash from a new eruption is sometimes mixed with rainwater and forms mud flows, called lahars. Lahars can travel tens of miles.

Sedimentary Rocks

There are two main types of sedimentary rocks: clastic and chemical precipitate. Clastic sedimentary rocks are composed of particles of preexisting rocks. Typical clastic sedimentary rocks include sandstone, conglomerate, gravel, shale, and limestone. These rocks contain clastic fragments of various sizes and compositions. The clastic fragments were carried by streams and rivers, and deposited in river channels, lakes, and in the ocean. Thousands of feet of sedimentary rock can accumulate in active subsiding sedimentary basins such as the Great Valley. When the deeper layers of sediment are subjected to high heat and pressure, they become consolidated. Sand becomes sandstone and mud becomes shale. When sedimentary rocks accumulate in a sedimentary basin, the oldest sedimentary layers are at the base of the stack, since they were deposited first, and the youngest layers are at the top.

Sedimentary rocks may also form by precipitation of chemicals from supersaturated water. Salt precipitates from sea water, chert from water saturated with SiO_2, and tufa from water saturated with $CaCO_3$.

Metamorphic Rocks

Most of the metamorphic rocks in the Sierra Nevada occur in the Western Metamorphic Belt. Some metamorphic rocks also occur as roof pendants within the Sierra Nevada batholith. Metamorphic rocks are formed when pre-existing rocks are subjected to high heat and/or pressure. At high temperatures and/or pressures new minerals are formed from the previous minerals in the rocks. At low grades of metamorphism, only some minerals are altered, and the identity of the original rock is still apparent. At very high grades of metamorphism, all traces of the original rock may be obliterated. At very high temperatures, the original rock may be remelted and become an igneous rock. Nature thus has its own way of recycling rocks.

Most metamorphism occurs in subduction zones, where sedimentary and volcanic rocks are carried to depths of up to 30 miles. Rocks at these great depths are subjected to very high pressures and temperatures, and many of the minerals in the rocks are altered under these conditions. Sandstone may be changed into quartzite, shale into phyllite and schist, and limestone into marble. Fine-grained rocks altered mainly by high temperatures, usually near granitic intrusions, are referred to as *hornfels*. Metamorphosed sedimentary rocks are often referred to as *metasedimentary rocks* and metamorphosed volcanic rocks are commonly referred to as *metavolcanic rocks.*

SEDIMENTARY ROCKS		
Clastic: composed of particles of preexisting rocks.		
Sandstone	Yellow or gray; hard; feels sandy and rough. Consists of sand grains cemented to a hard rock.	Gold Run Malakoff D.
Gravel	Similar to sandstone, but clastic fragments are gravel-sized. Fragments mainly consist of quartz or various types of granitic, volcanic, or metamorphic rocks.	Gold Run, Malakoff D.
Conglomerate	Similar to gravel, but fragments are larger, about the size of walnuts and oranges.	Gold Run Malakoff D.
Shale	Dark gray; soft; smooth; breaks into platy fragments. Composed of mud or clay cemented into rock by burial.	
Limestone	Gray; most limestone is composed of fragments of sea shells cemented together; fragments may be fine or coarse; $CaCO_3$.	Crystal Cave
Chemical precipitate: composed of minerals precipitated from supersaturated water.		
Chert	Red, black; hard; smooth. Composed of silica precipitated from water. Most red chert was precipitated from silica-rich sea water in the vicinity of spreading centers. Other colors of chert precipitated from silica-rich ocean water or silica-rich groundwater.	Western Metamorphic Belt
Tufa	White; chemical precipitate of $CaCO_3$ from hot volcanic water.	Mono Lake

METAMORPHIC ROCKS		
Slate	Dark gray; platy; very fine-grained. Metamorphosed mudstone.	Mariposa Slate
Phyllite	Dark gray; platy; fine grained; silky sheen. Similar to slate but more highly metamorphosed.	Western Metamorphic Belt
Schist	Gray; platy; large crystals; flakes of mica. Highly metamorphosed sandstone and shale.	Ladies Canyon
Greenstone	Green; fine- to coarse-grained. Metamorphosed pillow basalt and other volcanic rocks.	Western Metamorphic Belt
Marble	Light gray; mostly fine-grained. Metamorphosed limestone.	Crystal Cave
Hornfels	Dark; hard; non-foliated. Formed at intrusive contacts.	Ellery Lake