Rocks and minerals: the oldest storytellers.

A.D. Posey
Author

Geologists have a saying: “Rocks Remember.”

Neil Armstrong
Astronaut

Many people encounter rocks right in their homes. Places that sell natural stone counters call them all “granite countertops.” They are not, and the difference is important. A marble countertop looks beautiful, but consists mainly of the mineral calcite, which has a Mohs hardness of 3. Granite contains quartz and feldspar, which have a hardness of 7 and 6, respectively. True granite will withstand the wear and tear of a kitchen; marble won’t.

Just as elements and compounds are the building blocks of minerals, minerals are the building blocks of rocks. Some rocks consist of just one kind of mineral. Most rocks are assemblages of different minerals that have been melted, compacted, or cemented together into hard, solid materials.

The cement that holds rock together is usually precipitated from groundwater, which carries the minerals in solution owing to high temperature or pressure. Groundwater moves through the pores between mineral grains and leaves cementing minerals behind, much as tap water leaves mineral deposits on your sink and faucet. Common mineral cements include calcium carbonate (calcite), silica (quartz), iron oxide (limonite), anhydrite (gypsum), barite, and clays.

Rocks are divided into three main groups based on their origin: sedimentary (made up of sediments), igneous (“from fire”), and metamorphic (changed in form).

Sedimentary Rock

Sedimentary rocks form when sediments are deposited by wind or water and settle into layers. Sedimentary rocks that consist of grains are called clastic and include shale, siltstone, sandstone, pebble conglomerate, cobble conglomerate, and boulder conglomerate (Figures 3.1 and 3.2). Deposition and accumulation occur along beaches (both above and below the water line), in river channels and deltas, in estuaries, on river floodplains, in swamps and lakes, in deserts as sand dunes, and as valley fill deposits. The only requirement is that space is available for the sediment to accumulate.

If clastic rocks have a volcanic origin, they are pyroclastic. Volcanic agglomerates contain large, angular volcanic fragments spewed from vents, and volcanic ash is fine-grained
FIGURE 3.1
Dark-colored Cretaceous Mancos Shale on the lower slopes of the Book Cliffs west of Green River, Utah. Erosion-resistant sandstone forms the top of the cliff. (Courtesy of G. Prost.)

FIGURE 3.2
Some common sedimentary rocks. (a) Siltstone. (Courtesy of NASA; http://mars.nasa.gov/mer/classroom/schoolhouse/rocklibrary/source/siltstone.html.) (Continued)
FIGURE 3.2 (CONTINUED)
Some common sedimentary rocks. (b) Sandstone, Antelope Canyon, Arizona. (Courtesy of Meckimac; https://commons.wikimedia.org/wiki/File:Lower_Antelope_Canyon_478.jpg.) (c) Conglomerate. (Courtesy of G. Prost.) (Continued)
volcanic material that settles out of the air; if compacted while still hot, it melts together to form a **tuff.** Sedimentary rocks that consist mainly of shell fragments are called **coquina.**

Another type of sedimentary rock is the **chemical precipitate.** This includes **evaporites** (salt and gypsum formed by evaporation of mineral-saturated surface water), limestone and travertine (calcium carbonate that precipitates from solution in caves or hot springs; Figure 3.3), and chert (silica nodules precipitated from groundwater in limestone). Oolite shoals consist of calcite grains that precipitate in warm, calcium carbonate-saturated seawater and thus are both precipitates and clastic sediments (Figure 3.4).

Sedimentary rocks are classified on the basis of grain size, composition, and texture (Table 3.1).

**Organic sediments,** such as **coal** beds, form when plant material is deposited in swamps or bogs and then gets buried, dewatered, compacted, and heated to varying degrees (Figure 3.5). Organic phosphate deposits result from the accumulation of guano, mainly of seafowl and, to a lesser extent, bats. These deposits lie near coasts or on islands and may weigh up to several hundred thousand tons. **Phosphorite,** or phosphate rock, has extensive

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*FIGURE 3.2 (CONTINUED)*

Some common sedimentary rocks. (d) Clastic limestone, Ordovician Kope Formation near Cincinnati, Ohio. (Courtesy of Jim Stuby; https://commons.wikimedia.org/wiki/File:Limestone_etched_section_KopeFm_new.jpg.)

(Continued)
FIGURE 3.2 (CONTINUED)
sedimentary layers containing at least 15% phosphate minerals (Figure 3.6). The phosphate is derived from animal bones and teeth, or from igneous mineral veins. Dissolved phosphate moves through pore spaces between sedimentary grains as part of the groundwater system before it is deposited, usually in a sandstone or limestone.

Igneous Rock

Igneous rocks cool and solidify from molten magma. If they cool underground, they are called intrusive or plutonic. If they erupt and cool at the surface, they are called extrusive or volcanic.

Igneous rocks are classified based on texture and mineralogy (Figure 3.7). Light-colored igneous rocks that consist largely of quartz and feldspar are called felsic (a splicing of the words feldspar and silica). Dark igneous rocks that contain iron- and magnesium-rich minerals are called mafic (from the words magnesium and ferric).

Volcanic (Extrusive) Rocks

Because volcanic rocks erupt as lava and cool quickly at the surface, the minerals in them do not have time to form large crystals. Most minerals in volcanic rocks are too small to see. Silica-rich lava produces light-colored rock called rhyolite. Rhyolite lava erupts at about 800°C and consists mainly of quartz and sodium-rich plagioclase feldspar. This silica- and gas-rich lava is viscous (sticky) and tends to erupt explosively. Because it doesn't
FIGURE 3.4
(a) Oolitic limestone grains precipitate from warm calcium carbonate-saturated seawater, Itaborai, Brazil. (Courtesy of Eurico Zimbres, FGEL/UERJ; https://commons.wikimedia.org/wiki/File:CalcarioEz.jpg.) (b) Satellite image of oolite shoals (light blue) west of Eleuthera Island, Bahamas. (Courtesy of NASA.)
### TABLE 3.1
Sedimentary Rock Classification Chart

<table>
<thead>
<tr>
<th>Texture</th>
<th>Grain Size</th>
<th>Composition</th>
<th>Comments</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic, land-derived sedimentary rocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clastic (grains and rock fragments)</td>
<td>Pebbles, cobbles,</td>
<td>Quartz, feldspar, clay minerals,</td>
<td>Rounded fragments</td>
<td>Conglomerate</td>
</tr>
<tr>
<td></td>
<td>or boulders in sand,</td>
<td>rock fragments</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>or silt, or clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sand (0.6 to 20 mm)</td>
<td></td>
<td>Angular fragments</td>
<td>Breccia</td>
</tr>
<tr>
<td></td>
<td>Silt (0.04 to 0.6 mm)</td>
<td></td>
<td>Fine to coarse</td>
<td>Sandstone</td>
</tr>
<tr>
<td></td>
<td>Clay (smaller than</td>
<td>Fine grained</td>
<td>Siltstone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.04 mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very fine</td>
<td>Shale or mudstone</td>
<td></td>
</tr>
<tr>
<td>Transitional</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitate clastic</td>
<td>Sand (0.6 to 20 mm)</td>
<td>Calcite</td>
<td>Warm tropical marine</td>
<td>Oolitic sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>setting</td>
<td></td>
</tr>
<tr>
<td>Crystalline precipitate</td>
<td>Varied</td>
<td>Halite</td>
<td>Crystals from evaporites</td>
<td>Halite (salt)</td>
</tr>
<tr>
<td></td>
<td>Varied</td>
<td>Gypsum</td>
<td>Gypsum or anhydrite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Varied</td>
<td>Calcite</td>
<td>Hot spring and cave</td>
<td>Travertine</td>
</tr>
<tr>
<td></td>
<td>Varied</td>
<td>Dolomite</td>
<td>deposits</td>
<td>Dolomite</td>
</tr>
<tr>
<td>Bioclastic (organic fragments)</td>
<td>Microscopic to coarse</td>
<td>Calcite</td>
<td>Cemented shell fragments</td>
<td>Limestone, chalk, coquina</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>or biologic precipitates</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Varied</td>
<td>Carbon</td>
<td>Plant remains</td>
<td>Coal</td>
</tr>
<tr>
<td></td>
<td>Sand (0.6 to 20 mm)</td>
<td>Phosphate minerals in sand</td>
<td>Guano, bones, or hydrothermal</td>
<td>Phosphorite</td>
</tr>
<tr>
<td>Volcanically derived sedimentary rock</td>
<td>Varied</td>
<td>Varied</td>
<td>Fine ash to large bombs</td>
<td>Tuff</td>
</tr>
<tr>
<td>Pyroclastic</td>
<td>Varied</td>
<td>Varied</td>
<td>Fine material</td>
<td>Ash</td>
</tr>
<tr>
<td></td>
<td>Sand and smaller</td>
<td>Varied</td>
<td>Coarse material</td>
<td>Agglomerate</td>
</tr>
<tr>
<td></td>
<td>Sand and larger</td>
<td>Varied</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.5**
Pennsylvanian coal at Point Aconi, Nova Scotia. (Courtesy of Michael C. Rygel via Wikimedia Commons; https://en.wikipedia.org/wiki/Coal.)
**FIGURE 3.6**

**FIGURE 3.7**
Igneous rock classification chart.
flow easily, rhyolite forms lava domes. Well-known rhyolite domes include Lassen Peak and Mammoth Mountain in California, Popocatépetl in Mexico, and Chaitén in Chile (Figure 3.8). When rhyolite cools with a lot of gas bubbles, it’s called **pumice**, which is the only rock that will float on water. If rhyolite flows into a body of water such as a lake, it chills rapidly and forms **obsidian**, a volcanic glass. The composition of rhyolite is similar to granite, which solidifies below the surface.

![Figure 3.8](http://mars.nasa.gov/mer/classroom/schoolhouse/rocklibrary/index3.html)

(a) Rhyolite. (Courtesy of NASA; http://mars.nasa.gov/mer/classroom/schoolhouse/rocklibrary/index3.html.)

(b) Rhyolite dome at Chaitén, Chile, is the circular feature at center. (Courtesy of NASA Goddard Space Flight Center/Robert Simmon; https://commons.wikimedia.org/wiki/File:Chait%C3%A9n_Volcano_Lava_Dome,_Chile.jpg.)
**Basalt** is rich in iron and magnesium, silica-poor, and almost black (Figure 3.9). It erupts at about 1100°C and flows readily, forming low-relief shield volcanos—like the Hawaiian Islands—and extensive lava fields. Basalt contains mainly plagioclase, pyroxene, and olivine. Other examples include the Columbia River flood basalts (thick basalt that flowed over large areas), the Deccan Traps of central India (“**trap**” is another term for flood basalts),

![Basalt shield volcano](image1)

![Basalt flow, Craters of the Moon National Monument, Idaho](image2)

**FIGURE 3.9**
(a) Basalt shield volcano. (b) Basalt flow, Craters of the Moon National Monument, Idaho. (Courtesy of G. Prost.)
and the Siberian Traps, which covered an area in Siberia roughly the size of Europe. The composition of basalt is similar to that of gabbro, which cools underground.

Lavas of intermediate composition, between that of rhyolite and that of basalt, produce the rocks **andesite** and **dacite** (Figure 3.10). Andesite contains mostly plagioclase feldspar, pyroxene, and amphibole, and is closer to rhyolite. Andesite was named after the Andes, where it is common.

Dacite has a composition closer to basalt and contains plagioclase feldspar along with biotite, amphibole, and pyroxene. Dacite was first described in Romania and is named after the former Roman province of Dacia (present-day Romania).

Another volcanic rock, **kimberlite**, originates in the Earth’s mantle, at depths greater than 40 km (24 mi). When there is a weak spot in the overlying crust, the gas-charged lava erupts

![Image of Andesite](https://commons.wikimedia.org/wiki/File:Olearyandesite.jpg)  
![Image of Dacite](https://www.daviddarling.info/encyclopedia/D/dacite.html)

**FIGURE 3.10**  
(a) Andesite, O’Leary Peak, Arizona. (Courtesy of Jstuby at en.wikipedia; https://commons.wikimedia.org/wiki/File:Olearyandesite.jpg)  
(b) Dacite from Lassen Peak, California. (Courtesy of US Geological Survey; http://www.daviddarling.info/encyclopedia/D/dacite.html)
Rocks

explosively from a diatrem(m (pipe) that connects the mantle to the surface. The supersonic eruption forms a crater that is filled with chunks of rock from the mantle and crust. These eruptions are rare, and they’re the source of rare minerals, notably diamond (Figure 3.11a).

An eruption of more than 50% molten carbonate is called a carbonatite (Figure 3.11b). These rare lavas form by separation of carbonate material from other components of a magma. The Ol Doinyo Lengai carbonatite volcano in Tanzania has the lowest temperature lava in the world, erupting at 500°C–600°C.

Plutonic (Intrusive) Rocks

Intrusive igneous rocks cool and crystallize in the subsurface. The slow cooling process allows mineral crystals to grow larger than in lavas.

Granite, the most abundant felsic rock, is similar to rhyolite in composition. Granite contains various feldspar minerals along with quartz, biotite, muscovite, and hornblende. Its characteristic pink color comes from orthoclase, a potassium-rich feldspar.

Granodiorite is often called “salt-and-pepper granite.” It has less orthoclase and more biotite, hornblende, and augite than true granite. In composition, it resembles dacite (Figure 3.12).

Diorite is a little darker, having more mafic minerals. It underlies the Andes and is equivalent to Andesite in composition.

Gabbro is a dark intrusive rock with very little quartz and feldspar (Figure 3.13). Its composition resembles that of basalt. A finer-grained version of gabbro is diabase (North America) or dolerite (rest of the world).

When magma remains in place for a long time, the heavy minerals sink to the bottom of the magma chamber, and the lighter minerals rise to the top. This magmatic differentiation produces ultramafic rocks, which usually occur in the Earth’s mantle at depths greater than 40 km. Ultramafic rocks are dark, rich in iron and magnesium, and low in silica and potassium. They are characterized by the minerals peridotite, pyroxene, olivine, hornblende, and calcium-rich plagioclase (anorthite).

Plutonic Structures

A batholith is a large body of plutonic rock that extends for more than 100 km². They usually consist of coarse-grained rocks like granite and granodiorite. An example is the Sierra Nevada batholith of California.

Dikes and sills are flat, or planar, intrusions. The difference is their orientation; dikes are nearly vertical, whereas sills are nearly horizontal. A dike usually indicates a feeder channel for a surface eruption. Sills are sheet-like intrusive rocks that are injected parallel to the surrounding rock layers. Dikes and sills can be of any composition.

Pegmatites are intrusive igneous dikes with uncommonly large crystals. The composition is usually granitic, and they can contain large gemstones. Aplites are intrusive igneous dikes of granitic composition with unusually small crystals.

A laccolith is a shallow intrusion that is injected parallel to strata, like a sill, and pushes up the overlying rock layers (Figure 3.14). Like dikes and sills, laccoliths can be of any composition. The La Sal Mountains of southeastern Utah are composed of laccoliths.

Lopoliths are rare, large, lens-shaped mafic or ultramafic intrusions that are injected roughly parallel to the surrounding rock layers. They contain important mineral deposits like nickel, copper, and platinum. At least one lopolith, the Sudbury complex in Sudbury, Ontario, is thought to be the result of a large meteorite impact.
FIGURE 3.11
(a) Kimberlite with 1.8 carat (6 mm), diamond crystal from Finsch Diamond Mine, South Africa. (Courtesy of StrangerThanKindness; https://commons.wikimedia.org/wiki/File:Diamond_-_South_Africa_-_Finsch_Mine.jpg.) (b) Carbonatite, Jacupiranga, Brazil. (Courtesy of Eurico Zimbres; https://en.wikipedia.org/wiki/Carbonatite.)
FIGURE 3.12
(a) Mt. Sinai granite, Sinai, Egypt. 2 Euro coin for scale. (Courtesy of G. Prost.) (b) Granodiorite, Yosemite National Park, California. (Courtesy of D. Monniaux; https://en.wikipedia.org/wiki/El_Capitan_Granite.)
FIGURE 3.13
(a) Diorite. (Courtesy of Siim Sepp; https://en.wikipedia.org/wiki/Diorite.) (b) Gabbro, from Thalhorn, near Felling in Haut-Rhin, France. (Courtesy of Museum of Natural History and Ethnography in Colmar, France; Ji-Elle; https://commons.wikimedia.org/wiki/File:Gabbro-Talhorn-Mus%C3%A9e_d'histoire_naturelle_et_d'ethnographie_de_Colmar.jpg.)
Rocks

Metamorphic Rock

Metamorphic rocks are any rocks—igneous, sedimentary, or already metamorphic—altered by heat, pressure, or both. When buried at great depths, rocks are subjected to heat from the earth, which is caused by radioactive decay, and to pressure from the weight of overlying rock. Tectonic stress can also pull or squeeze rocks, altering them.

Different levels of temperature and pressure produce different metamorphic facies. (Here, *facies* refers to an assemblage of minerals formed under similar conditions.) Metamorphic facies are classified by their composition and the amount of heat and pressure they have undergone. Most facies are named after their dominant minerals (Figure 3.15).

**Ophiolites** are a metamorphic assemblage caused by emplacement of oceanic crust onto continental crust or by injection of mantle rocks into continental crust. The assemblage is characterized by serpentine, diabase, chert, and pillow lava (lava erupted onto the seafloor at oceanic spreading centers). Their significance is that they reveal areas, usually in mountain belts, where ocean basins have been consumed by plate tectonic movements.

**Metamorphic core complexes** expose the deep crust in areas of extension. They are thought to form in areas with thick crust that is extending, as in the Basin-and-Range province of western North America. As the upper crust extends along low-angle faults, the middle and lower crust is progressively unroofed and rises buoyantly (by **isostatic rebound**). The lower crustal rocks are characterized by high-grade metamorphism (eclogite, granulite, and amphibolite facies), and the fault zones are characterized by mylonite and ductile deformation. **Mylonite** is a fine-grained, often banded, recrystallized metamorphic rock caused by crushing and grinding of rock along fault zones.

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**FIGURE 3.14**
Difference between a laccolith and a lopolith.
Metamorphic rocks (as opposed to metamorphic facies) are classified by composition and texture. Rocks altered more by heat than by pressure have a recrystallized, uniform texture. Rocks altered more by pressure than by heat have a foliated (layered or striped) texture (Table 3.2).

Foliation refers to the alignment of platy minerals, such as micas, in a metamorphic rock (Figure 3.16). Foliation indicates changes in the degree or direction of pressure as the rock was being altered; it tends to occur along cleavage planes. Rock cleavage (as opposed to mineral cleavage) is a metamorphic fabric consisting of planar partings (Figure 3.17).

Pressure solution involves dissolving minerals at grain-to-grain contacts, which are areas of high stress. Stylolites, serrated partings, form where material was dissolved (Figure 3.18). Axial planar cleavage is a metamorphic fabric formed parallel to the axis of folds as a result of pressure solution (Figure 3.19).

Where metamorphic rocks occur over a large area, it is described as regional metamorphism. Isolated metamorphic rocks suggest contact metamorphism, where local rock came into contact with magma or hot fluids (Figure 3.20). The contact zone, or metamorphic aureole, is a few meters to a few hundreds of meters wide, and it can contain important mineral deposits known as skarn deposits (see Chapter 15).

In prograde metamorphism, minerals lose “volatile” components such as water and carbon dioxide to become more stable at high temperature and pressure. For example, clay minerals progressively transform into micas and ultimately garnets. Retrograde metamorphism is the opposite. Metamorphic rock absorbs water in low-temperature, low-pressure environments and minerals such as garnet turn into micas and ultimately clay as temperature and pressure drops.
### TABLE 3.2
Metamorphic Rock Classification Chart

<table>
<thead>
<tr>
<th>Texture</th>
<th>Grain size</th>
<th>Composition</th>
<th>Type of metamorphism</th>
<th>Comments</th>
<th>Rock name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliated</td>
<td>Fine</td>
<td>Mica</td>
<td>Regional</td>
<td>Low-grade metamorphism of shale</td>
<td>Slate</td>
</tr>
<tr>
<td></td>
<td>Fine to medium</td>
<td>Quartz, Feldspar, Amphibole, Garnet</td>
<td>(Heat and pressure increase with depth of burial)</td>
<td>Foliation surfaces glitter due to mica crystals</td>
<td>Phyllite</td>
</tr>
<tr>
<td></td>
<td>Medium to coarse</td>
<td>Garnet, Pyroxene</td>
<td></td>
<td>Visible mica crystals</td>
<td>Schist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine to coarse</td>
<td></td>
<td>High-grade metamorphism, mineral segregation banding</td>
<td>Gneiss</td>
</tr>
<tr>
<td>Recrystallized (not foliated)</td>
<td>Fine</td>
<td>Variable</td>
<td>Contact (heat)</td>
<td>Hornfels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine to coarse</td>
<td>Quartz</td>
<td></td>
<td>Quartzite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
<td>Calcite and/or dolomite</td>
<td>Regional or contact</td>
<td>Marble</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
<td>Various minerals</td>
<td></td>
<td>Metaconglomerate</td>
<td></td>
</tr>
</tbody>
</table>

**FIGURE 3.16**
Foliation in gneiss as a result of compositional layering. Prague, Czech Republic. (Courtesy of Huhulenik; https://upload.wikimedia.org/wikipedia/commons/a/af/Orthogneiss_Geopark.jpg.)
FIGURE 3.17
Pencil cleavage in limestone. (Courtesy of Colinlangford; https://commons.wikimedia.org/wiki/File:Pencil_Cleavage.JPG.)

FIGURE 3.18
Styloites in Mississippian Salem Limestone, Bloomington, Indiana. (Courtesy of Michael Rygel; https://commons.wikimedia.org/wiki/File:Styloites_mcrl.jpg.)
FIGURE 3.19
Near-vertical axial plane cleavage in the Devonian Nisku Formation, Allstones Lake, Alberta. (Courtesy of G. Prost.) Bedding dips about 60° to the left.

FIGURE 3.20
Mount Gould, Glacier Park, Montana. Contact metamorphism is the light rim around the dike (dark band on cliffs). (Courtesy of G. Prost.)
Metamorphic Rock Types

Quartzite is recrystallized, quartz-rich sandstone used in countertops and buildings (Figure 3.21a). It resembles sandstone, but there’s an easy way to tell them apart: when you hit sandstone with a hammer, it goes “tunk”; when you hit quartzite with a hammer, it goes “tink.”

Marble, a recrystallized limestone or dolomite, is used in countertops, in sculptures, and as facing stone (Figure 3.21b). While attractive, marble is soft rock, and real marble countertops will scratch.

With increasing metamorphism, shale, a sedimentary rock, turns into slate (Figure 3.21c), phyllite (Figure 3.21d), schist (Figure 3.22a), and ultimately gneiss (Figure 3.22b). Slate is used in roofing, in flooring, and as paving stones. Gneiss is both recrystallized and foliated: the original rock may have been sedimentary, igneous, or metamorphic. Granite gneiss has been heated to the point where it starts melting (Figure 3.22c).

Serpentinite is a low-temperature metamorphic rock formed by the hydration of mafic and ultramafic rocks such as peridotite (Figure 3.22d). Abundant in the mineral serpentine (named for its green, serpent-like color), serpentinite is an important source of asbestos, chrome, and nickel.

Soapstone is formed by the retrograde metamorphism of peridotite, dunnite, or serpentinite. It consists mainly of talc, from which it gets its “soapy” feel. Soft and easy to carve, soapstone is used in arctic aboriginal art (Figure 3.22e).

Novaculite is a nonfoliated metamorphic rock composed almost entirely of silica derived from the shells of diatoms, a kind of single-celled marine algae.

Amphibolite is a dark, coarse-grained, nonfoliated metamorphic rock consisting mainly of amphibole (hornblende) and plagioclase feldspar (Figure 3.23a). It derives from the metamorphism of basalt, gabbro, or clay-rich sedimentary rocks. Amphibolite is used as aggregate or building stone.

Hornfels is a fine-grained, nonfoliated metamorphic rock formed by contact metamorphism. Light to dark in color, it has no characteristic composition (Figure 3.23b). It is used mainly as aggregate.

What Rocks Tell You

You can learn a lot from rocks. The composition of sedimentary rocks tells you how and where they were formed, and what their original source might have been. Their texture, grain size, grain shape, and grain sorting tell you about their depositional history. For example, conglomerates with large, angular cobbles rarely occur far from their source, whereas fine siltstone and mudstone can be found thousands of kilometers from their source. This is because the particles get ground, crushed, and broken into progressively smaller grains as they travel. A quartz sandstone with frosted round grains suggests strongly that the rock is a windblown deposit: the frosting is from grains bumping into each other. A rock containing a large assortment of grain compositions and grain sizes, both rounded and angular, suggests a flood or landslide deposit that mashes everything together.

Pore spaces in sedimentary rocks contain traces of fluids or minerals, revealing the history of fluids that moved through the rocks (hot water, oil, gas) and the temperature and
FIGURE 3.21
Moderately metamorphosed rocks. (a) Quartzite. Note how the rock breaks through the grains, not around them. Near Loch Assynt, Scotland. (Courtesy of Lysippos; https://commons.wikimedia.org/wiki/File:Quartzite_assyn_u.jpg.) (b) Marble. (Courtesy of NASA; http://mars.nasa.gov/mer/classroom/schoolhouse/rocklibrary/index3.html.) (Continued)
pressure history of the rock. For example, pores can be filled with silica that was dissolved from grains in a high-temperature and high-pressure environment and redeposited in areas of lower temperature and pressure. Pores can be destroyed by pressure that causes interlocking grains. New pores can be formed by dissolving minerals.

Likewise, the composition, texture, and grain size of igneous and metamorphic rocks tell their cooling or deformation history. Coarse-grained rocks cooled slowly; fine-grained rocks cooled quickly. Rocks with compositional banding or alignment of platy minerals formed under high temperatures and pressures. Rocks containing minerals like staurolite, kyanite, and sillimanite indicate medium-pressure, high-temperature metamorphism. Granite-gneiss indicates high-temperature metamorphism to the point of melting. Stylolites in limestone indicate low temperature but high pressure that caused pressure solution of calcite minerals.

Rocks are found in the earth either as layers (sedimentary or volcanic strata) or in massive igneous or metamorphic bodies. The study of rock layers is called stratigraphy, and in order to understand what the layers mean, we will review some basic concepts (Chapter 4).
A Sampling of Geologic Guidebooks

There are a number of guidebooks to the geology of parks and regions. Examples in North America include the Roadside Geology series and U.S. Geological Survey Bulletins. A few of these are listed below. Check Amazon.com for more.


FIGURE 3.21 (CONTINUED)
Moderately metamorphosed rocks. (d) Phyllite. From Prague, Czech Republic. (Courtesy of Chmee2; https://commons.wikimedia.org/wiki/File:Phyllite_in_Geopark_on_Altbertov.JPG.)
FIGURE 3.22
Highly metamorphosed rocks. (a) Garnet schist from Syros, Greece. Euro coin for scale. (Courtesy of Graeme Churchard (GOC53); https://commons.wikimedia.org/wiki/File:Garnet_Mica_Schist_Syros_Greece.jpg.) (b) Folds in Gneiss. (Courtesy of Anne Burgess; https://commons.wikimedia.org/wiki/File:Folds_in_Gneiss_-_geograph.org.uk_-_1370873.jpg.) (Continued)
Rocks

FIGURE 3.22 (CONTINUED)
Highly metamorphosed rocks. (c) Port Deposit granite gneiss, Maryland. Width is approximately 10.7 cm (https://commons.wikimedia.org/wiki/File:Foliated_granite_PlateVIII_MD_Geological_Survey_Volume_2.jpg). (d) Serpentinite (8.6 cm across) from Tasmania. Greenish = serpentine; purplish = stichtite. (Courtesy of James St. John; https://commons.wikimedia.org/wiki/File:Stichtitic_serpentinite,_Dundas_Ultramafic_Complex.jpg.) (Continued)
FIGURE 3.22 (CONTINUED)
Highly metamorphosed rocks. (e) Inuit soapstone carving. (Courtesy of G. Prost.)

FIGURE 3.23
Nonfoliated metamorphic rocks. (a) Amphibolite, Val di Fleres, Italy. (Courtesy of Bernabè Egon; https://en.wikipedia.org/wiki/Amphibolite.) (Continued)
Maps

Geologic road maps and national park geologic maps present geology graphically. Some examples are as follows:


