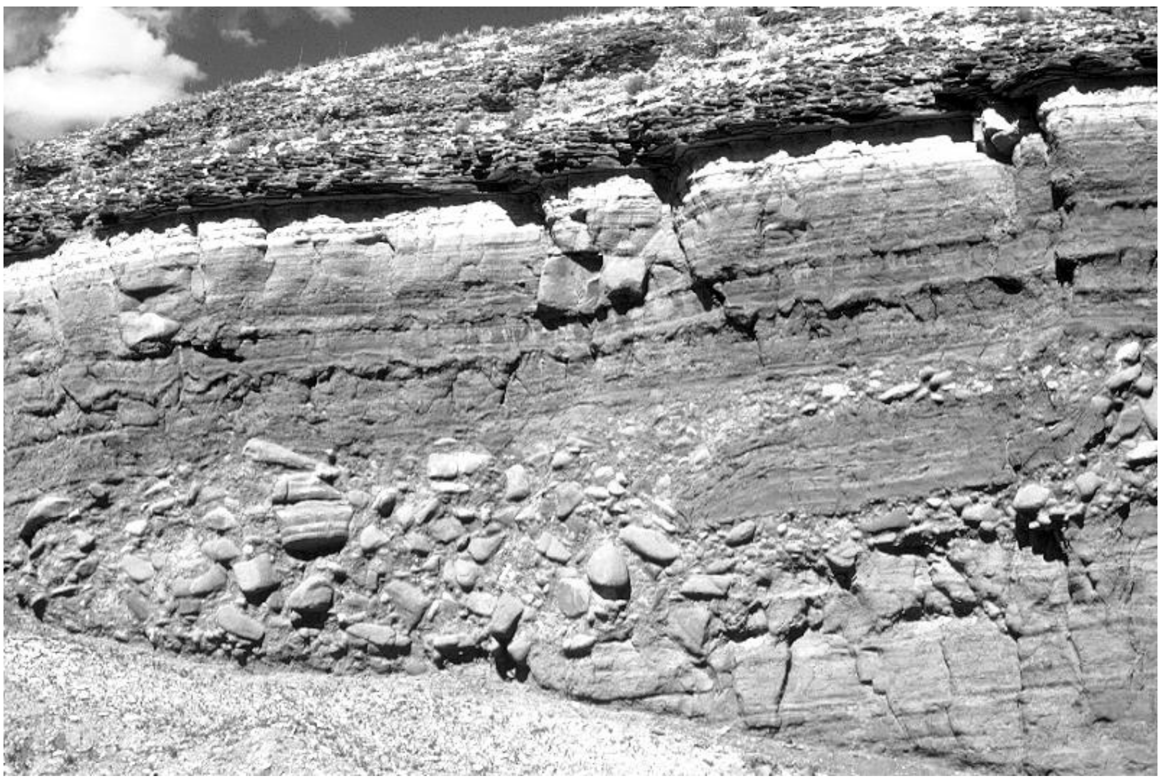
Sedimentary and Metamorphic Rocks: Interpreting Ancient Environments of Painted Canyon (Lab 2)

Synopsis

This week you will examine some common environments and the rocks formed in these environments. You will use the computers to examine different present-day environments (like beaches and rivers) and the types of loose sediments and rocks they form. You will then examine a reference suite of rocks formed from some common sedimentary environments and then observe, describe, and identify some sedimentary rocks from Painted Canyon. Then, you will examine what can happen to sedimentary and igneous rocks if they are taken to depth and changed into new kinds of rocks (metamorphic rocks). You will learn how to classify and identify these new kinds of rocks by using several reference collections.



Coarse clasts in a conglomerate, Hopi Buttes, Arizona.

Introduction

Rocks deposited in “normal” environments, such as within rivers and beaches, are an important part of Painted Canyon. The reconnaissance team has put together some computer-based and rock-based materials to help you learn about the kinds of rocks formed in such environments. In Painted Canyon, these rocks contain resources, like limestone for cement, which will be essential to your settlement.

Goals for This Week

- Observe photographs of various natural environments, identify the processes that occur in each environment, and predict the kinds of deposits each environment forms.
- Observe and characterize several kinds of sedimentary rock.
- Describe, identify, and propose an environment for unknown sedimentary rock samples from Painted Canyon.
- Observe various types of metamorphic rocks and identify unknown metamorphic rock samples from Painted Canyon.

Exercise 2A: Interpreting Environments of Sedimentary Rocks

In preparation for interpreting the environments of rocks from Painted Canyon, you will use the computers to observe photographs for many common environments like sand dunes, river channels, and beaches. You will want to note such things as color, size and shape of grains and how well the grains are sorted.

☐ Examine *Figure 2-1* below to see how different geologic environments could exist at the same time.

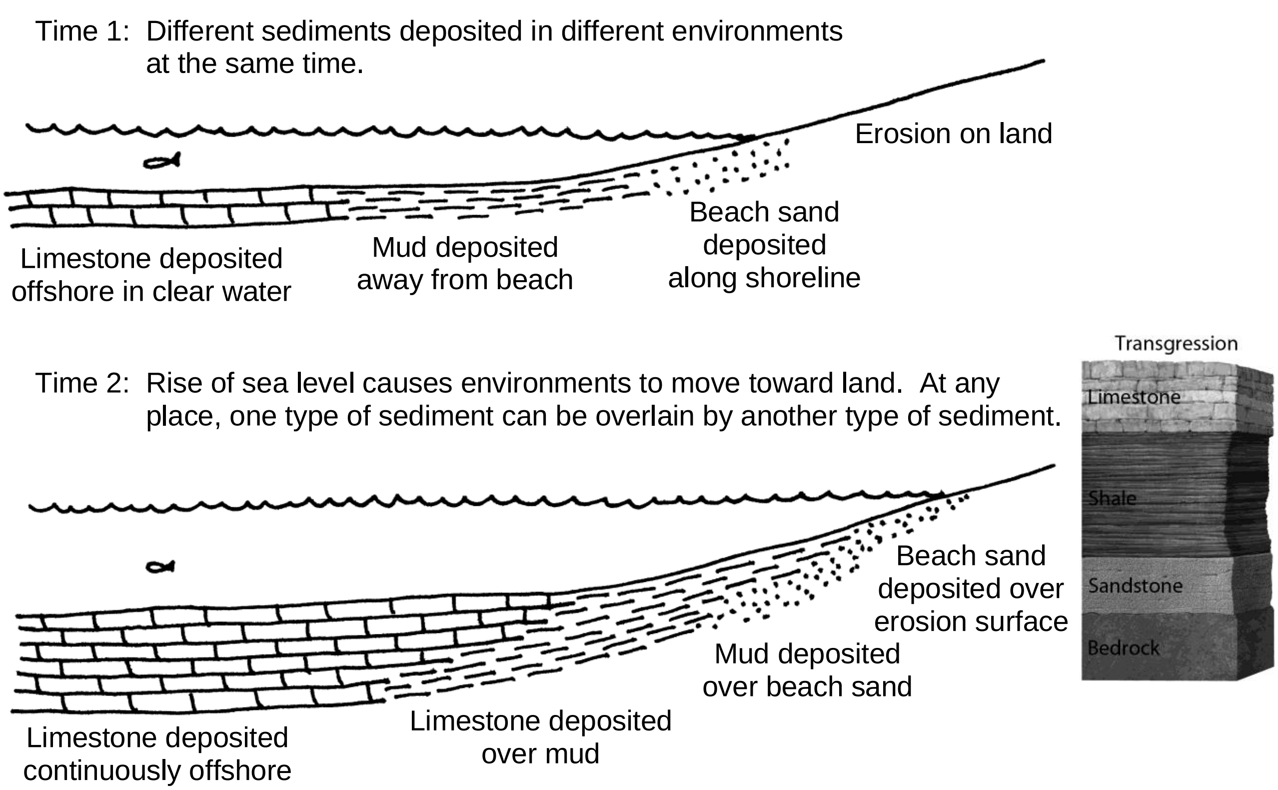


Figure 2-1. Sedimentary environments change from place to place and can migrate over the surface of the Earth, depositing a sequence of different sedimentary layers. Such processes help explain why there are different layers in Painted Canyon. When sea level rises, as in the case above, it is called a "transgression". When sea level drops, it is a "regression".

- ☐ Examine *Figure 2-2* for a description of rounding and sorting – this will help your observations in the next steps.
- ☐ On the computer, go to the home page for SES 123 and choose Lab 2:

  (http://reynolds.asu.edu/SES123).
- ☐ Follow the instructions for Lab 2.
- ☐ For each environment, there are four photographs. The first two photographs show present-day examples of this environment, and the next two photographs show examples of sedimentary rocks deposited in this environment. After observing all the photographs for a single environment, fill in your observations for that environment in ***Worksheet 2A***.

Exercise 2B: Observing Sedimentary Rocks from Painted Canyon and Interpreting their Environments

You will observe a reference suite of sedimentary rocks and then describe and identify samples from one of the units in Painted Canyon. *Box 2-1* presents tips on how to identify rocks, including how to distinguish between igneous, metamorphic, and sedimentary rocks.

- ☐ On the computer, examine where the samples were collected by opening the SES 123 home page and clicking on the appropriate link. You do not have to do anything with this location, but it's always best to know where samples were collected so you can consider their geologic context.
- ☐ Examine *Figure 2-2* for a description of rounding and sorting, and then complete *Table 2-1*.
- ☐ On the side counter are labeled boxes, each containing several samples of a single kind of sedimentary rock. Take one box at a time from the counter and carefully observe the samples in the box. If you want, you may use hand lenses and other diagnostic tools. To use a hand lens, place it close to your eye and bring the rock sample closer until the rock is in focus.
- ☐ When you have looked at all the samples in that box, write a generalized description, in your own words, for this kind of rock in ***Worksheet 2B-1***. Also, refer to *Figure 2-2* when describing grain size, rounding, and sorting of grains in the samples. You are describing the grains in the rock, not the size and shape of the rock sample itself.
- ☐ Follow the same procedure for each box in the reference set.
- ☐ Only after you have finished all rock types in the reference suite should you compare your descriptions with those in *Table E-4* (Common Sedimentary Rocks) in Appendix E.
- ☐ Go to the side counter and get one of the unidentified rock samples from Painted Canyon, and observe and describe the rock in ***Worksheet 2B-2***. Assign a name to each sample by comparing it to your observations from the reference suite and the rock descriptions in *Table E-4* in Appendix E. You are not allowed to compare it to rocks in the reference suite.
- ☐ For each Painted Canyon sample, propose a reasonable interpretation for the environment in which this rock was deposited. To do this, use your observations of each rock sample and your knowledge of sedimentary environments. With the limited amount of information you have for each sample, there may be more than one possible answer. Record your environmental interpretation in ***Worksheet 2B-2***. When completed, your table records the various environments that existed in this place at one time or another. You will use this type of information in several weeks when you reconstruct the entire geologic history of Painted Canyon.
- ☐ Using *Figure 2-1* as a guide, discuss with your partner some possible explanations for the changes from one environment to the next (e.g., rising or falling sea level, wet to dry climate, uplift and erosion of a nearby mountain belt, etc.).

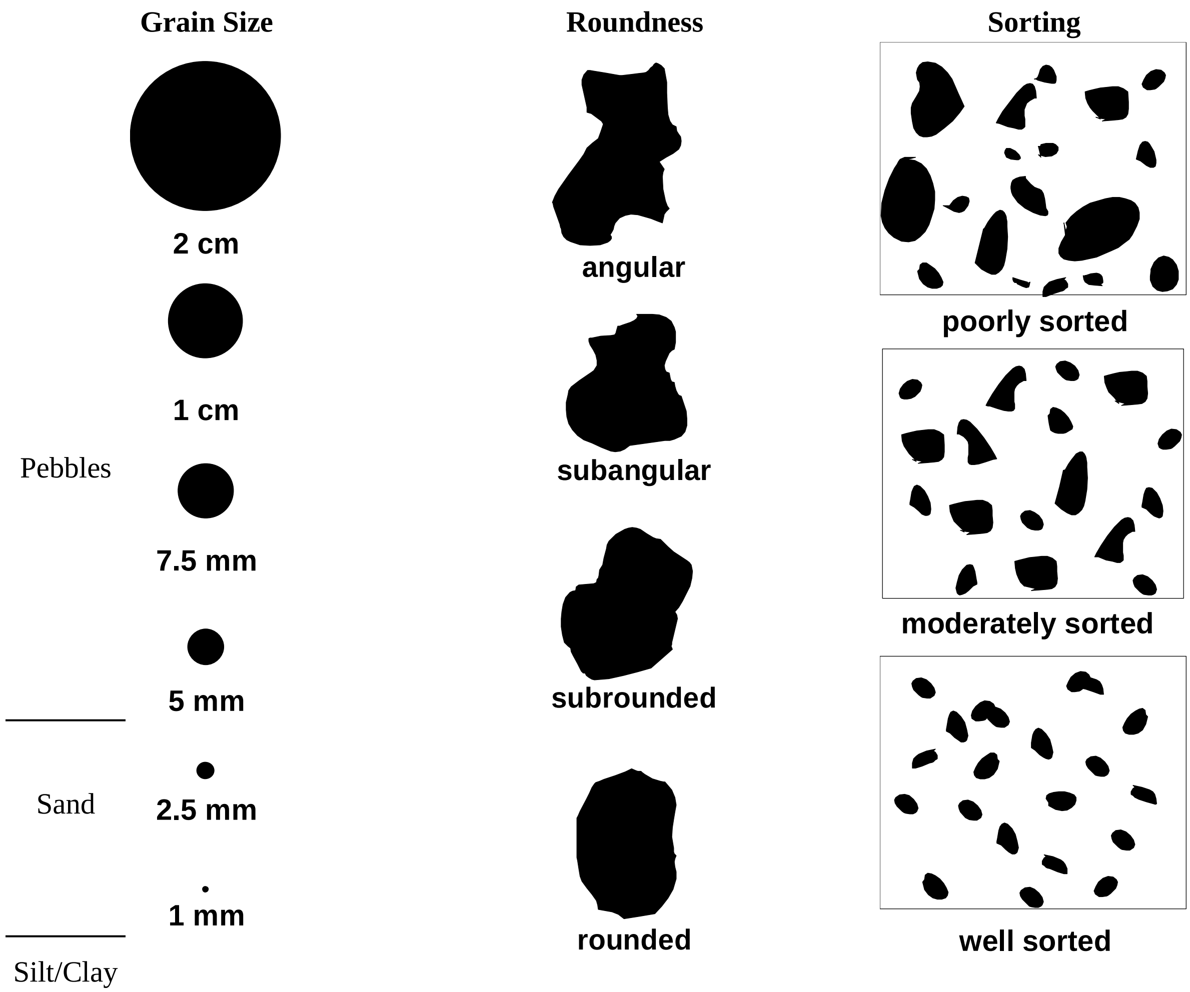
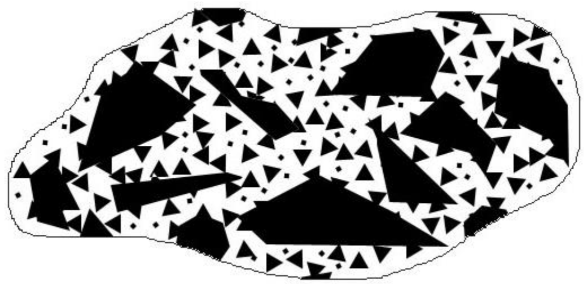


Figure 2-2. Grain size, rounding, and sorting of clasts. You can make the following generalizations:

1. **Size** of clasts mostly reflects how energetic the environment is (e.g., how fast and turbulent the water in a stream is). A very energetic environment, such as a steep mountain stream, can easily move large boulders. A less energetic environment, like slow-moving water in a lake, can transport only mud- or clay-size particles. Waves in oceans may look like they could move big clasts, but they only move suspended clay and mud.
2. **Rounding** of a clast generally reflects how far the clast has been transported. Clasts that have not been transported far from their source are angular, whereas those that have traveled far down stream (tens of kilometers) are more rounded. Pebbles can also become very well rounded by constant pounding by waves on a beach, and sand grains become rounded by being blown by the wind.
3. **Sorting** reflects what size of clasts is available to an environment and whether the energy of the environment is constant. If only one size of clast is available and the energy of the environment varies only slightly, the deposits will be *well sorted* (all the clasts are approximately the same size). If the environment can pick up mud, sand, and boulders at once, then the resulting deposits will be *poorly sorted* (there is a large amount of variation within the size of clasts).

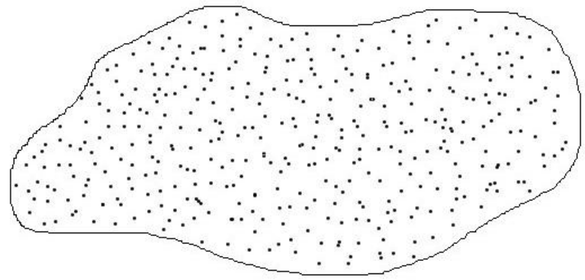
See *Figure 2-3* for an illustration of these changes as clasts are transported away from their source.

Table 2-1. Rounding and sorting within rock samples. In the spaces below, indicate whether the rock sample portrayed in each sketch is poorly, moderately, or well sorted, and whether the clasts are rounded or angular (circle the answers below each sample). For rounding, you are looking at the shape of the clasts *within the rock sample*, not the shape of the sample itself. See *Figure 2-2* for an explanation of sorting and rounding.



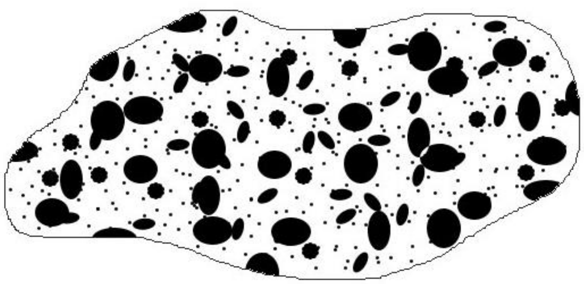
A. Sorting: poor – moderate – well

Roundness: rounded – angular



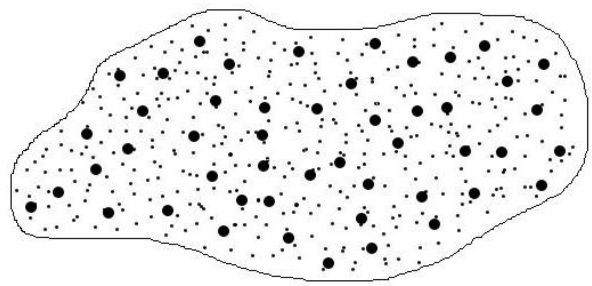
B. Sorting: poor – moderate – well

Roundness: rounded – angular



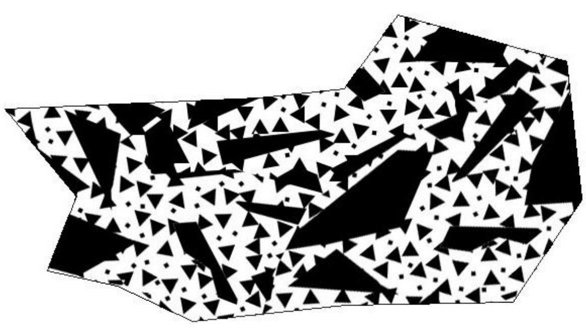
C. Sorting: poor – moderate – well

Roundness: rounded – angular



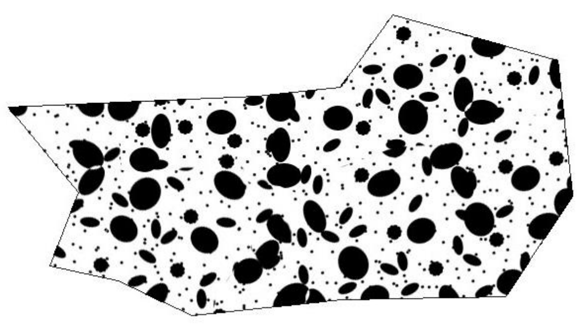
D. Sorting: poor – moderate – well

Roundness: rounded – angular



E. Sorting: poor – moderate – well

Roundness: rounded – angular



F. Sorting: poor – moderate – well

Roundness: rounded – angular

Answers: A: poor/angular; B: well/rounded; C: moderate/rounded; D: moderate/rounded; E: poor/angular; F: moderate/rounded

Exercise 2C: Examining Some Metamorphic Rocks

There is a reference suite of metamorphic rocks to help you recognize different varieties created by three main factors: (1) the starting rock type (called the protolith), such as limestone versus sandstone; (2) what kind of temperature and pressure conditions were imposed on the protolith; and (3) whether metamorphism was accompanied by deformation and what type of deformation. Once you have studied the reference samples, you will try to identify some unknown samples from Painted Canyon.

- ☐ On the side counter are labeled boxes, each containing several samples of a single kind of rock, such as slate. Take only one or two boxes at a time from the counter and carefully observe the samples in the box. If you want, you may use magnifying glasses and other diagnostic tools. Write a generalized description, in your own words, for this kind of rock in ***Worksheet 2C***.
- ☐ Follow the same procedure for each box in the reference set.

Exercise 2D: Observing Metamorphic Rocks from Painted Canyon

Use the table you developed (***Worksheet 2C***), in addition to the rock names in *Table E-2* and *Table E-3* in Appendix E, to identify the rock samples collected by the reconnaissance team in Painted Canyon.

- ☐ On the computer, examine where the samples were collected by opening the SES 123 home page and clicking on the appropriate link. You do not have to do anything with this location, but it's always best to know where samples were collected so you can consider their geologic context.
- ☐ Compare your descriptions in ***Worksheet 2C*** with those in *Table E-3* in Appendix E, which also lists the geologic setting and uses for each kind of rock.
- ☐ Samples from Painted Canyon are in boxes on the side counter. Get one sample at a time, carefully observe it, and write your description of it in ***Worksheet 2D***. Assign a name to this sample based on your description, your knowledge from the reference suite, and the rock names in *Table E-3* in Appendix E.
- ☐ Repeat this, one at a time, with all the samples from Painted Canyon.

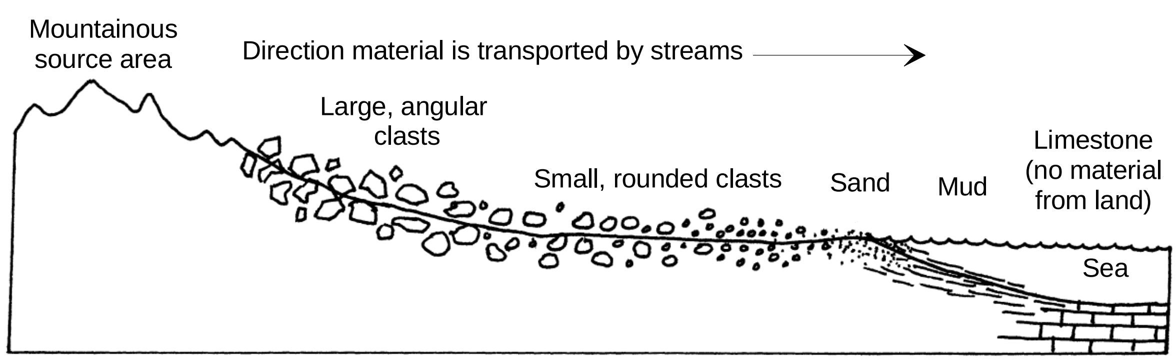


Figure 2-3. Cross section illustrating clasts becoming smaller, better rounded, and better sorted as they are transported away from their source. Larger clasts can be carried in high-energy environments (like steep mountain streams), but cannot be carried in low-energy environments (like calm lake waters).

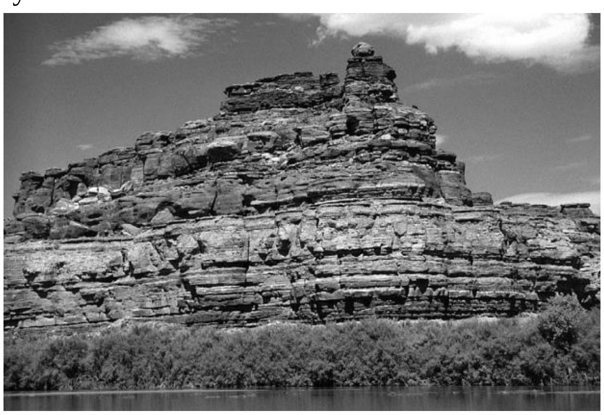
Box 2-1: How to Identify Rocks and Distinguish Between Igneous, Metamorphic, and Sedimentary Rocks

To identify rocks, we use the composition and physical characteristics of the rocks and – when possible – observations we make from a distance and at the outcrop scale (i.e., looking at a rock face several meters high). Rocks are named based on their physical characteristics and mineral composition, and two rocks with the same name, such as granite, would have common characteristics, with some variations.

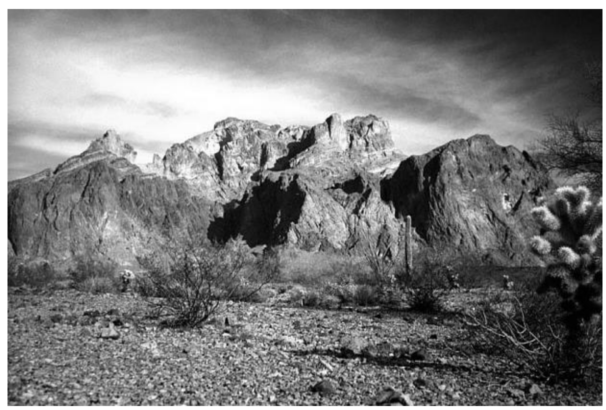
At the *outcrop scale*, we are most interested in observing if the rocks are layered or nonlayered, and are variable or homogenous (don't change from one part to another). Rocks that are non-layered and homogeneous are usually igneous rocks. Granite, for example, is typically a gray, homogeneous rock with fractures, but no layers. In contrast, sedimentary rocks generally have layers that reflect changes in the environmental conditions when the sediments were being deposited. Layers of mud, for example, may be deposited in a lake, except when a powerful flood deposits a thin layer of sand. Or a floodplain may receive silt during spring floods, but otherwise be dry and subject to weathering and erosion. Either of these situations will form layers.

Many volcanic rocks form in layers. Some of these, especially volcanic ash deposits, have well-defined layers, but many volcanic layers are too thick to be seen up close, only from a distance.

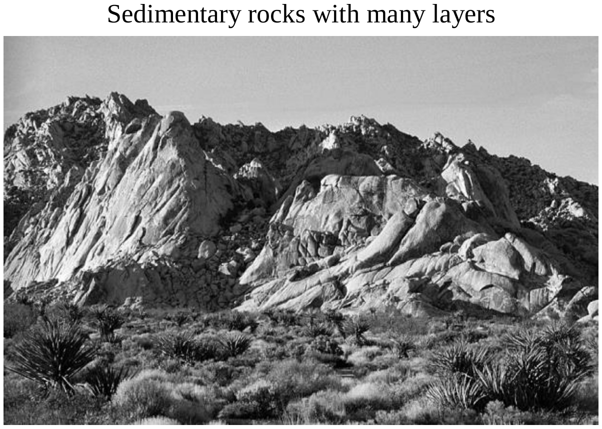
Metamorphic rocks also commonly have layers, which are formed by growth of new minerals and dissolution of existing ones, and by pressure and deformation. These layers will be defined by crystals that are parallel to each other or by adjacent light- and dark-colored bands. Both these types of layers in metamorphic rocks are called **foliation**. Metamorphic layers tend to be shiny because of the aligned crystals of biotite and muscovite.



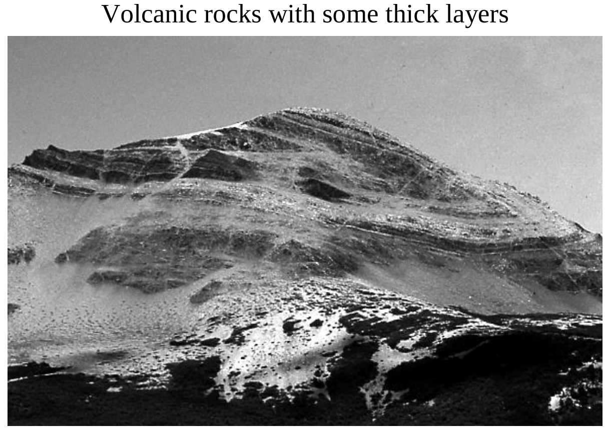
Sedimentary rocks with many layers



Volcanic rocks with some thick layers



Granitic rocks with fractures but no layers



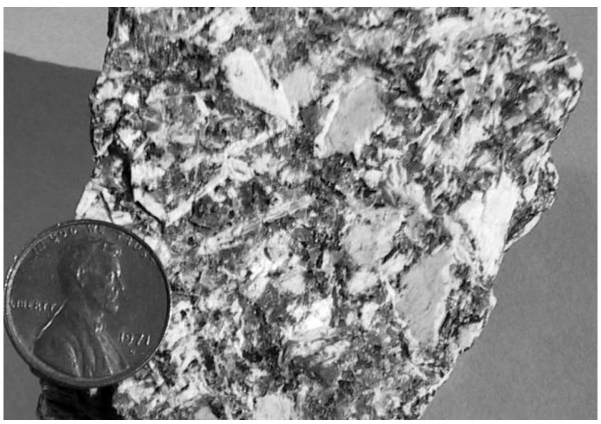
Metamorphic rocks with complex, folded layers

Box 2-1: How to Identify Rocks (continued)

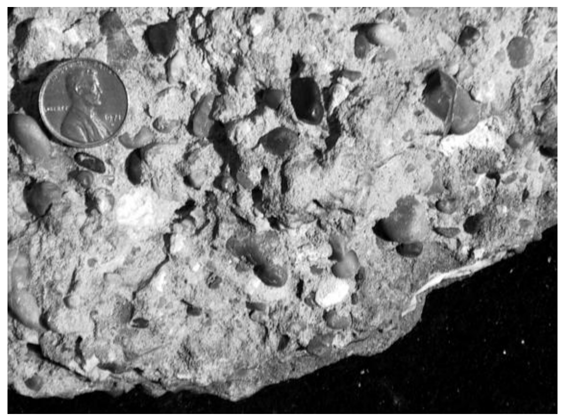
Crystalline versus Clastic Rocks

At the *hand-specimen* or *hand-lens* scale, we observe whether the rock is composed of crystals or clasts (e.g., grains). Although this distinction can be difficult, especially with a rock sample taken out of its natural context, it is probably the most important way to distinguish between different kinds of rocks. If a rock is composed of crystals that are interlocking (i.e., look like they grew together), then the rock probably formed at depth under relatively high temperatures. Rocks composed of crystals include: (1) igneous rocks that form when a magma cools and crystallizes at depth; (2) metamorphic rocks in which crystals grew in the solid state (not molten), generally as a result of increased temperature and pressure; and (3) rocks with crystals that grew from hot water. Crystals can also be present in volcanic rocks, and many of these probably grew in the magma chamber, at depth, prior to eruption. Salt deposits, such as those formed from evaporating seawater, are one type of sedimentary rock that is composed of crystals.

In contrast, clastic rocks are composed of grains and other pieces of rock that are cemented together. Clastic rocks are generally deposited on the Earth's surface, such as by winds, rivers, and beaches. Mudflows may form rocks composed of huge, angular boulders in a sandy or muddy matrix. Some volcanic rocks are also composed of clasts, all mixed together during an eruption of volcanic ash. Volcanic rocks with clasts can also be formed from lava flows that break up as they flow; in this case, the individual fragments are composed of glass.



Crystalline texture in igneous rock, with interlocking crystals



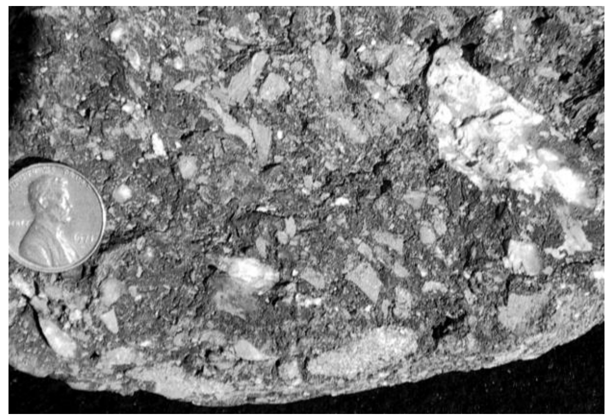
Clastic texture in sedimentary rock, with rounded pieces of rocks

Box 2-1: How to Identify Rocks (continued)

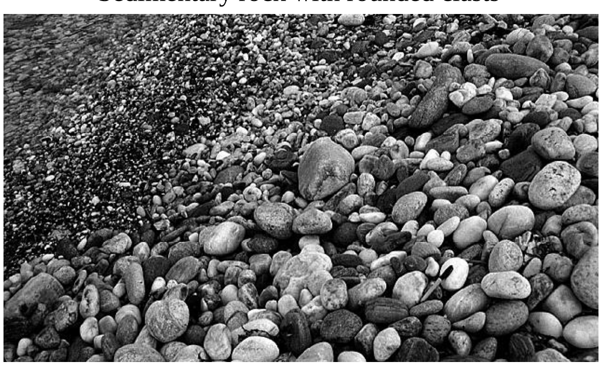
In addition to the crystalline-clastic distinction, we name rocks based on the size of the crystals or clasts. The classification of igneous rocks uses the size of crystals to distinguish granite from rhyolite, even though the two rock types have the same chemical composition and kinds of minerals. Sedimentary rocks likewise use the size of clasts to distinguish sandstone from conglomerate and mudrocks (includes shale and mudstone). For sedimentary rocks with large clasts, we also use whether the clasts are angular or rounded to name the rock.

Some rocks have components that are too small to see even with the aid of a hand lens. These are the most difficult to identify and name, because we cannot tell whether the rock is crystalline or clastic and what the minerals are. The context of such rocks is usually the most helpful information; if a fine-grained, gray rock occurs as a thin layer within sedimentary rocks, it too is likely to be sedimentary.

Sedimentary rock with rounded clasts



Sedimentary rock with angular clasts



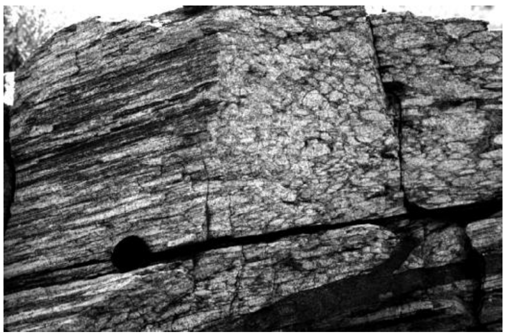
Modern beach, one environment that produces rounded clasts (note marking pen for scale in lower right)

Modern mountain front, an environment that produces rocks with angular clasts

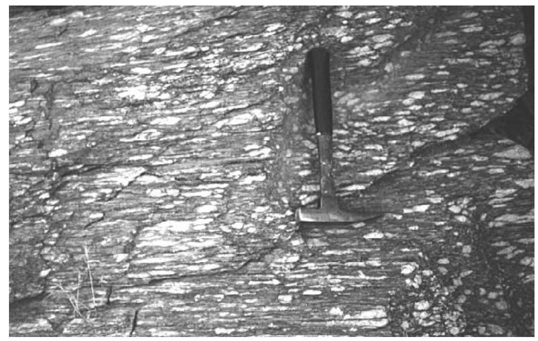
Box 2-2. Metamorphic Rocks and How They Form

Rocks, once formed, can be buried, heated, and squeezed, and as a result change in mineralogy, internal structure, and overall appearance. Such changed rocks are called **metamorphic rocks**, and are common where deeper levels of the crust have been uplifted and exposed at the surface. Metamorphic rocks are widely exposed in major mountain belts of the world, and comprise much of the Precambrian "basement" in the Southwest.

Sedimentary rocks are formed at the surface, but can be taken to depth if they are buried by later sediments or pushed down by tectonics (plate motions and other types of mountain building). As they become deeper, they heat up and are subjected to higher pressures due to the weight of the overlying rocks. Rocks can also be heated up if magma rises next to them. Most metamorphic rocks are also affected by tectonic forces, which cause them to be folded, sheared, flattened, and stretched. Cobbles and sand grains that were once spherical become shaped like pancakes, cigars, or toothpicks.



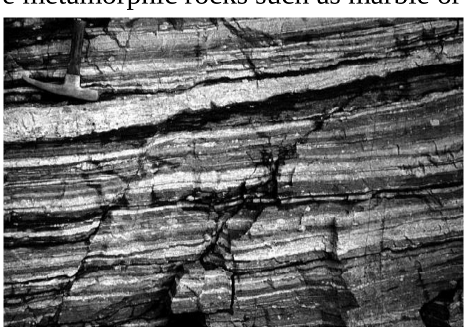
Stretched pebbles in a metamorphosed conglomerate



Stretched crystals in a metamorphosed granite

Which minerals grow during metamorphism is controlled by the conditions of metamorphism (i.e., temperature, pressure, and the presence of fluids) and the starting composition of the rock. Some metamorphic minerals, such as metamorphic garnet, only form under certain temperatures and pressures, and can therefore be used to tell how hot and deep the rocks were when they were metamorphosed. Other minerals, such as quartz and calcite, are stable over a wider range of temperatures and pressures, and only become more coarsely crystalline as they are heated to higher temperatures. In this manner, calcite in limestone becomes more coarsely crystalline in marble.

The processes that form metamorphic rocks commonly produce layers, of several types and at various scales. A general name for such layers is **foliation**. Foliation may reflect a preferred orientation of minerals that grew under the influence of directed pressure. Such minerals typically grow with an orientation perpendicular to the directed pressure. This preferred orientation of minerals, such as mica minerals in schist, gives most metamorphic rocks a shiny appearance, or sheen. Such shiny, foliated texture, or **schistosity**, is one of the most diagnostic features of metamorphic rocks. Some exceptions to this are metamorphic rocks such as marble or quartzite, which lack sufficient mica to have a sheen.



Foliation in a metamorphic rock (gneiss)

Folded schistosity in a metamorphic rock (schist)

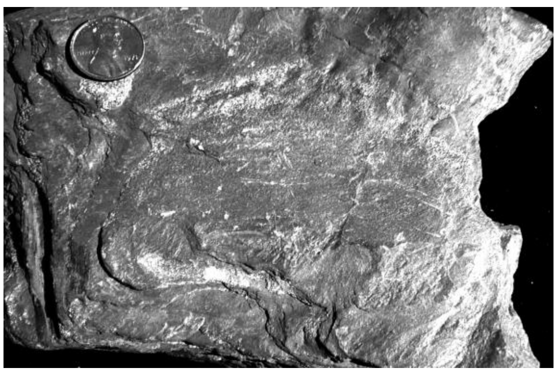
Box 2-2. Metamorphic Rocks and How They Form (continued)

Layers in metamorphic rocks can also be inherited from layers in the original rocks. Interlayered sandstone and mudrocks, for example, would produce a metamorphic rock with layers of **quartzite** and **schist**. Other layers are formed during metamorphism, as fluids and small amounts of magma form quartz veins and thin layers of pegmatite, respectively. Such veins and thin layers commonly are the light-colored layers in the banded metamorphic rock **gneiss**.

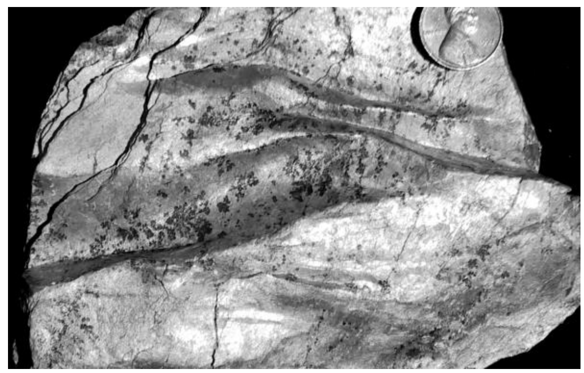
There are complete gradations in the Earth from low temperatures and pressures near the surface to higher temperatures and pressures at depth. As a rock is heated and buried, it goes through a progression of changes, becoming more and more metamorphosed. Subjecting a sedimentary mudrock (like a fine-grained shale) to increasing pressure and temperature will result in the following metamorphic succession:

shale ⇒ slate ⇒ phyllite ⇒ schist ⇒ gneiss

A slate, like the original shale, is very fine grained, but has new metamorphic planes along which the rock breaks. Phyllite has a distinctive sheen caused by mica crystals that are too small to see. Schist has a reflective sheen and visible mica crystals. Higher temperatures cause quartz and feldspar to be mobilized into metamorphic fluids or into melt, forming the light-colored layers characteristic of gneiss. Gneiss also commonly has many folds formed by shearing of the solid, but hot and weak, rock.



Slate (breaks along plane, but not very shiny)



Phyllite (shiny but no visible mica crystals; this sample has folds bending the layers)

Schist (shiny with visible crystals of mica and other minerals)

Gneiss (light- and dark-colored layers, some of which are shiny like schist)

Because of such gradations, metamorphic rocks are not always easy to distinguish from igneous rocks or even from sedimentary rocks. Metamorphic rocks are composed of visible crystals, except the most finely crystalline metamorphic rocks, like slate. Many, but not all, metamorphic rocks contain some type of metamorphic layering, whereas layering is not common in coarsely crystalline igneous rocks, like granite. The context of the rock (i.e., the geologic setting and the kinds of rocks that are nearby) is an important clue to whether the rock is metamorphic, igneous, or sedimentary.

Appendix E

Table E-4. Common **Sedimentary Rocks** and Their Properties

Rock Name	Physical Properties	Geologic Setting	Industrial Uses
Breccia ***(clastic)***	Coarse-grained, **angular fragments** (> 2mm) in a fine-grained matrix; commonly poorly sorted. Matrix can be sandy or muddy, as in debris flows, or crushed rock, as in rockfalls.	Landslides, debris flows, mudslides, and talus slopes; meteorite impacts; fault zones.	
Chert ***(chemical)***	Composed of microcrystalline (extremely fine crystals–cannot see individual crystals) quartz; commonly occurs as lenses or blobs in limestone. Color varies, but is usually white or gray. Chert is characterized by a **hardness of 7** and **conchoidal fracture**.	Deposited by groundwater along layers and in the pore spaces of limestone, or by deep-sea oozes.	Used in ancient times for tools and weapons, such as knives and arrowheads.
Conglomerate ***(clastic)***	Coarse, with **well-rounded** boulders, cobbles, and pebbles (>2 mm in diameter) in a matrix of sand, mud, and clay; grains in the matrix commonly cemented together. Cobbles and pebbles may consist of any mineral or rock, but generally are resistant materials, such as quartz, quartzite, chert, and volcanics.	Alluvial fans, river channels, and beaches. Well-rounded clasts indicate farther transport by a river or intense rounding on beach.	
Limestone ***(chemical or clastic)***	Composed of **calcite** with various textures, including fine-grained microcrystalline calcite, calcite sand and pebbles, stacks of shells, and interlocking coarse crystals if recrystallized. Fossils, such as shells and coral, may be present. **Reacts with weak hydrochloric (HCl) acid.**	Typically forms in shallow seas, especially in warm, tropical settings, such as coral reefs and calcite sands on and near the shoreline.	Mined for the production of cement and lime. One source of organic material for the natural formation of petroleum.
Sandstone ***(clastic)***	Consists mostly of rounded to angular **sand grains** ranging from 1/16 to 2 mm in diameter. Commonly colored buff, red, brown, or yellowish tan. Quartz is the most common mineral; calcite, quartz, and iron oxide are the main cementing materials.	Beaches, sand dunes, floodplains, and deltas; channels of slow rivers; accumulates in a wide variety of environments.	Quartz sandstone is used in glass making as well as a flux during the smelting of metallic ores.
Mudrock ***(clastic)*** *Includes* ***shale*** *and mudstone*	Composed of **very fine grained particles** (too small to see without magnification) less than 1/256 mm in diameter; characteristically laminated or thin bedded; commonly gray to black, or greenish gray; fine-grained quartz, mica, and clay minerals are most common.	Particles accumulate in quiet-water environments, such as shallow-marine waters, lagoons, floodplains, and lakes.	Source of fine material for construction of clay pipes. One source of organic material for the natural formation of petroleum.

Table E-3. Common **Metamorphic Rocks** and Their Properties.

Rock Name	Physical Properties	Metamorphic Setting	Industrial Uses
Gneiss *(derived from shale or granite)*	Typically coarsely crystalline (visible crystals) characterized by **alternating bands of dark** (amphibole and pyroxene) **and light minerals** (quartz and feldspar).	High temperature and pressure; very high grade metamorphism.	Tile, ornamental stone, crushed aggregate for concrete.
Greenstone *(derived from andesite or basalt)*	Generally **finely crystalline and greenish**; dark; commonly no visible foliation, but may be foliated; composed of fine amphibole, greenish mica (chlorite), and feldspar; may preserve volcanic features or phenocrysts.	Low to moderate temperature and pressure.	Associated with certain types of submarine copper deposits.
Marble *(derived from limestone or dolostone)*	Crystalline (visible crystals), generally white and uniformly crystalline, but locally veined and colored; usually recrystallized to larger crystals than the original rock; **reacts with HCl**; principally composed of calcite or dolomite.	Contact with hot magma, or confining pressure from deep burial.	Tiles, building material, sculpting.
Quartzite *(derived from sandstone)*	Hard, generally light colored, but may be red, green, or gray. Composed primarily of recrystallized quartz and may have "sugary" appearance. **Rock breaks across grains and has sharp edges**; does not feel sandy like sandstone.	Contact with hot magma, or confining pressure from deep burial.	Crushed aggregate for concrete.
Schist *(derived from mudrocks, basalt, impure limestone)*	Variably colored rock with **parallel metamorphic minerals,** defining a **schistosity** (sparkly, **shiny** appearance). Typically medium to coarsely crystalline (individual minerals may be seen). Common minerals include muscovite-mica, biotite-mica, chlorite, talc, epidote, quartz, plagioclase, and potassium feldspar.	Intermediate to high temperature and pressure; moderately high-grade metamorphism.	
Slate *(derived from mudrocks)*	Very finely crystalline (typically too small to see), dark-colored (commonly gray to black), rock with chlorite, muscovite-mica, sodium plagioclase, and quartz. **Slate tends to split into thin plates** (slaty cleavage)**;** dull luster.	Relatively low temperature and pressure; low-grade metamorphism.	Roofing tile, slate blackboards, billiards tables, floor tiles.