Chapter 3 Rocks: Materials of the Solid Earth

Rocks: Materials of the Solid Earth opens with a discussion of the rock cycle that presents a general overview of the origins and processes involved in forming the three major rock groups—igneous rock, sedimentary rock, and metamorphic rock. A discussion of the crystallization of magma is followed by an examination of the classification, textures, and compositions of igneous rocks. After presenting the processes of mechanical and chemical weathering, the chapter discusses the classification of sedimentary rocks, as well as some of their common features. The chapter also examines the agents of metamorphism, the textural and mineralogical changes that take place during metamorphism, and some common metamorphic rocks. In conclusion, resources from rocks and minerals are investigated.

FOCUS ON CONCEPTS

After reading, studying, and discussing the chapter, students should be able to:

3.1 Sketch, label, and explain the rock cycle.
3.2 Describe the two criteria used to classify igneous rocks and explain how cooling influences the crystal size of minerals.
3.3 List and describe the different categories of sedimentary rocks and discuss the processes that change sediment into sedimentary rock.
3.4 Define *metamorphism*, explain how metamorphic rocks form, and describe the agents of metamorphism.
3.5 Distinguish between metallic and nonmetallic mineral resources and list at least two examples of each. Compare and contrast the three traditional fossil fuels.

TEACHING TIPS

Students should have a good grasp on minerals before attempting this chapter. Much of the discussion of rock composition relies on understanding the basics of the minerals that make up the rocks. As with mineralogy, it is useful to have handy in class hand samples of the various rocks so students have a tangible way of relating your notes to the actual rocks.

- After introducing students to the three basic rock types, it is useful to have them construct their own rock cycles in their notes without consulting any other information. In this way they need to understand why and how the rock cycle works the way it does, and they will retain the information better.
- If your course has a laboratory component, consider leaving the memorization of different rock types for the lab. In the lab, students will have more and longer access to actual rock specimens and can explore their properties firsthand.
- Regardless of whether or not your course has a lab, bring hand samples that exemplify different rock types to class so students can see what the actual rocks look like.
- Sometimes students have difficulty seeing granite as a felsic rock because it has dark minerals in it. It can be useful to show several varieties of granite along with a chart depicting the rough percentages of light and dark colored minerals present in this rock.

- Ask students why they think most fossils are found in sedimentary rocks before explaining it to them. It doesn't occur to many students that the magma that forms igneous rocks and the heat and pressure that shape metamorphic rocks are not conducive to fossilization.
- Have students list as many resources from rocks and minerals as they can think of before you teach this topic. Many students think of coal or oil but are surprised to learn drywall comes from gypsum, for example.
- When teaching about the types of oil traps, diagrams are critical. Descriptions of these environments alone are tricky for students to understand.
- Have students in groups or individually think of analogies from their lives for the three different rock types. For example, making a sandwich could be analogous to the deposition of sedimentary strata. Relating these concepts to students' everyday lives can help improve retention.

CONCEPT CHECK ANSWERS

Concept Check 3.1

1. **Sketch and label the rock cycle. Make sure your sketch includes alternative paths.**
   Refer to Figure 3.1.

2. **Use the rock cycle to explain the statement "One rock is the raw material for another."**
   The rock cycle illustrates that any rock type can be transformed into any other rock type. As an example, igneous rocks may be weathered and compacted into sedimentary rocks. Those sedimentary rocks may be subjected to heat and pressure to become metamorphic rocks. Depending upon the conditions, rocks can be continually transformed into different types of rock.

Concept Check 3.2

1. **What is magma? How does magma differ from lava?**
   Magma is liquid, molten rock. It is found underground, whereas lava is found extrusively, or outside Earth's interior.

2. **In what basic settings do intrusive and extrusive igneous rocks originate?**
   Intrusive igneous rocks cool below the surface of the Earth. Extrusive igneous rocks cool outside the Earth's interior.

3. **How does the rate of cooling influence crystal size? What other factors influence the texture of igneous rocks?**
   Faster cooling correlates with smaller crystal size. Other influential factors include the composition of the magma and the presence of gases, such as in a volcano, that can cause a vesicular texture.

4. **What does a porphyritic texture indicate about the history of an igneous rock?**
   A porphyritic texture, where the rock has some large and some small crystals, indicates that the rock started to cool slowly and then experienced a change of environment or cooling temperature where the rest of the rock cooled more quickly.

5. **List and distinguish among the four basic compositional groups of igneous rocks.**
   - Granitic – felsic or light colored rocks where the dominant minerals are quartz and potassium feldspar.
   - Andesitic – intermediate rocks where the dominant minerals are amphibole and plagioclase. These are neither light nor dark.

- Basaltic – mafic or dark colored rocks with high amounts of magnesium and/or iron. The dominant minerals are pyroxene and plagioclase feldspar.
- Ultramafic – these are uncommon rocks with very high amounts of magnesium and/or iron. The dominant minerals are olivine and pyroxene.

6. **How are granite and rhyolite different? In what way are they similar?**
   Granite has a phaneritic, or coarse-grained texture whereas rhyolite is aphanitic, or fine-grained. They are compositionally similar, being granitic or felsic rocks. They could be from the same magma type but rate of cooling has affected their crystal sizes.

7. **What is magmatic differentiation? How might this process lead to the formation of several different igneous rocks from a single magma?**
   Magmatic differentiation occurs as magma cools and crystals of minerals with higher melting temperatures crystallize out of the magma, changing the magmatic composition. By depleting the magma, or melt, of these minerals, the next rocks to form from the cooling magma will have a different composition than those that formed at higher temperatures.

Concept Check 3.3

1. **Why are sedimentary rocks important?**
   Sedimentary rocks contain almost all of the fossil record. Sedimentary rocks make up about 75% of continental rock outcrops and contain clues to the history of the Earth's surface. They also have economic importance; for example coal is a sedimentary rock and other natural resources are extracted from sedimentary rocks.

2. **What minerals are most abundant in detrital sedimentary rocks? In which rocks do these sediments predominate?**
   Quartz and clay minerals, especially from feldspars, are most abundant. These rocks predominate in conglomerate, breccia, sandstone, arkose, siltstone, and shale.

3. **Distinguish between conglomerate and breccia.**
   Both are made of large sized sedimentary grains. However, conglomerate consists of grains that have been rounded before compaction and breccia contains angular grains of rock and minerals.

4. **What are the two categories of chemical sedimentary rock? Give an example of a rock that belongs to each category.**
   Chemical and biochemical. A chemical sedimentary rock is travertine limestone. Another is chert. A biochemical rock is coquina or coal.

5. **How do evaporites form? Give an example.**
   Evaporites form when minerals are dissolved in solution, and the water of that solution evaporates away. One example is rock salt.

6. **Describe the two processes by which sediments are transformed into sedimentary rocks. Which is the most effective process in the lithification of sand and gravel-sized sediments?**
   - Compaction occurs where pressure is placed on loosely packed sediment. Volume of the sediment is reduced and water is squeezed out.
   - Cementation occurs when mineral-bearing water circulates among the grains, hardens, and cements the sediment grains together. This process is most effective for lithifying sand and gravel-sized sediments.

7. **List three common cements. How might each be identified?**
   - Calcite – effervesces when a drop of weak HCl is placed on it.
   - Silica – hardest cement, will scratch glass.
   - Iron oxide – oxidizes to a rusty red color.

8. **What is the most characteristic feature of sedimentary rocks?**
   Layers, or strata as these rocks are laid down.

Concept Check 3.4

1. ***Metamorphism* means "change form." Describe how a rock may change during metamorphism.**
   Mineralogy, texture, and sometimes chemical composition may change. Intense heat and/or pressure will alter the grains of the original rock, whether it is igneous, sedimentary, or metamorphic.

2. **Briefly describe what is meant by the statement "every metamorphic rock has a parent rock."**
   Metamorphic rocks are existing rocks that have been altered by heat and/or pressure. Therefore, every metamorphic rock was another type of rock, the parent rock, initially.

3. **List the four agents of metamorphism and describe the role of each.**
   - Heat – triggers chemical reactions that result in recrystallization of existing minerals and formation of new minerals.
   - Confining pressure – buried rocks experience even pressure from all directions, which creates a more compact, denser rock.
   - Differential stress – often occurs during mountain building where rocks experience unequal forces from different directions. This creates rocks that have been deformed, often with flattened mineral grains.
   - Chemically active fluids – ion-rich fluids invade the rock and enhance ion migration. Often hot, these fluids can generate mineral recrystallization.

4. **Distinguish between regional and contact metamorphism.**
   Regional metamorphism is associated with mountain building and involves large amounts of pressure and high temperatures. It results in large-scale rock deformation. Contact metamorphism occurs when rock is in contact with hot magma. In these cases, metamorphism is heat-related.

5. **What feature easily distinguishes schist and gneiss from quartzite and marble?**
   Schist and gneiss are foliated.

6. **In what ways do metamorphic rocks differ from the igneous and sedimentary rocks from which they formed?**
   Metamorphic rocks are typically more compact than the parent igneous and sedimentary rocks. Metamorphic rocks may also exhibit minerals aligned in one particular direction rather than randomly dispersed in the rock. Minerals also may segregate during metamorphism.

Concept Check 3.5

1. **List two general types of hydrothermal deposits.**
   Vein deposits and disseminated deposits.

2. **Nonmetallic resources are commonly divided into two broad groups. List the two groups and give some examples of materials that belong to each.**
   Building materials – aggregate, crushed rock, gypsum, clay, and limestone.

Industrial minerals – fluorite, limestone, corundum, garnet, sylvite.

3. **Why are coal, oil, and natural gas called *fossil fuels*?**
   These are all created from organisms that lived long ago. In the case of coal, it is lithified plant matter, for example.

4. **What is an oil trap? Sketch two examples.**
   An oil trap is a geologic environment that allows for significant amounts of oil and gas to accumulate. See Figure 3.35 for pictures of examples.

5. **What do oil traps have in common?**
   Porous, permeable reservoir rock and a cap rock that is impermeable to oil and gas.

GIVE IT SOME THOUGHT ANSWERS

1. **Refer to Figure 3.1. How does the rock cycle diagram—in particular, the labeled arrows—support the fact that sedimentary rocks are the most abundant rock type on Earth's surface?**
   The rock cycle supports the fact that sedimentary rocks are most abundant on Earth's surface because each rock type, once exposed at the surface, is subjected to uplift, weathering, and erosion. The resulting sediment will eventually be transformed into sedimentary rock.

2. **Would you expect all the crystals in an intrusive igneous rock to be the same size? Explain why or why not.**
   No. Crystal size in igneous rocks is a direct function of the rate of cooling and since a given body of magma could experience differential rates as it cools and solidifies, different sizes of crystals in the same rock would be common.

3. **Apply your understanding of igneous rock textures to describe the cooling history of each of the igneous rocks pictured on the right.**
   A) Rapid rate of cooling resulting in mainly microscopic crystals; B) a very slow rate of cooling followed by a more rapid period of cooling as evidenced by the porphyritic texture; C) relatively slow, steady rate of cooling resulting in larger crystals of about the same size; D) extremely rapid rate of cooling as indicated by the glassy texture.

4. **Is it possible for two igneous rocks to have the same mineral composition but be different rocks? Support your answer with an example.**
   Yes, rhyolite and granite are a good example of two rocks with similar compositions. Rapid cooling of lava results in the aphanitic texture typical of rhyolite while granite exhibits large, visible crystals due to slow cooling of magma.

5. **Use your understanding of magmatic differentiation to explain how magmas of different composition can be generated in a cooling magma chamber.**
   Remember that Bowen's Reaction Series not only predicts the sequence of crystallization for minerals from magmas, but it also provides the order in which those minerals will melt as temperature increases for a given rock. If only partial melting (as opposed to complete melting) occurs, the resulting magma will only contain those chemical elements from the minerals whose melting temperatures have been achieved. Therefore, the magma could have a significantly different chemical composition than the original rock. In addition, varying degrees of partial melting could produce several different magmatic compositions from the original rock.

6. **Dust collecting on furniture is an everyday example of a sedimentary process. Provide another example of a sedimentary process that might be observed in or around where you live.**
   The accumulation of organic debris (leaves, stems, branches, etc.) and physical debris (mud, soil, etc.) around your home and in your yard are other examples of sedimentary processes.

7. **Describe two reasons sedimentary rocks are more likely to contain fossils than igneous rocks.**
   One reason why sedimentary rocks are more likely to contain fossils is because sediment accumulates in various environments (oceans, lakes, rivers, beaches, swamps, deserts, etc.) where both plants and animals already exist. As the organisms die, they accumulate with detrital sediments and often become incorporated into the final rock that is formed. Another reason is that the various processes involved in the formation of sedimentary rocks (erosion, deposition, and lithification) are often not so destructive as to obliterate the original form or at least some part of the original organism.

8. **If you hiked to a mountain peak and found limestone at the top, what would that indicate about the likely geologic history of the rock there?**
   The geologic history of the limestone layer would perhaps be the following: 1) formation of marine limestone in a warm, shallow ocean; 2) burial and lithification of limestone over a long period of time; 3) uplift of unit, most likely related to plate tectonic forces at or near a plate boundary; 4) erosion of younger units and exposure of limestone layer at the top of a present-day mountain.

9. **The accompanying photos each illustrate either a typical igneous, sedimentary, or metamorphic rock body. Which do you think is a metamorphic rock? Explain why you ruled out the other rock bodies.**
   Outcrop "B" is composed of metamorphic rock. Photograph "A" shows layers of sediment and coarse layers of gravel typical of sedimentary rocks. Photograph "C" displays an igneous rock with some sort of intrusion cutting through it. Also, photograph "B" shows highly banded rock layers with intense folding and kink banding, typical of metamorphic rocks.

10. **Examine the accompanying photos, which show the geology of the Grand Canyon. Notice that most of the canyon consists of layers of sedimentary rocks, but if you were to hike down into the Inner Gorge, you would encounter the Vishnu Schist, which is metamorphic rock.**
    a. **What process might have been responsible for the formation of the Vishnu Schist? How does this process differ from the processes that formed the sedimentary rocks that are atop the Vishnu Schist?**
    b. **What does the Vishnu Schist tell you about the history of the Grand Canyon prior to the formation of the canyon itself?**
    c. **Why is the Vishnu Schist visible at Earth's surface?**
    d. **Is it likely that rocks similar to the Vishnu Schist exist elsewhere but are not exposed at Earth's surface? Explain.**

    a) The Vishnu Schist could have formed from regional metamorphism involving increased temperatures and pressures associated with plate tectonics. This is a very different process from the various steps involved in the formation of the sedimentary rocks above it (weathering, erosion, deposition, and lithification). b) The Grand Canyon obviously had a much different geologic history involving regional metamorphism and perhaps various episodes of mountain building compared the modern erosion of the Colorado River. c) The Vishnu Schist has been exposed at Earth's surface due to uplift and the erosion of this region by the Colorado River. d) Yes, it is very likely that the Vishnu Schist exists in other areas since such rocks are typically formed by regional metamorphism (which takes place over large regions). It simply has not been exposed in most other areas.

EXAMINING THE EARTH SYSTEM ANSWERS

1. **The sedimentary rock coquina, shown at right, formed in response to interactions among two or more of Earth's spheres. List the spheres associated with the formation of this rock and write a short explanation for each of your choices.**
   The sedimentary rock coquina is a biochemical limestone that consists of loosely cemented shells and shell fragments that have accumulated on the ocean floor. The primary Earth spheres involved in its formation are the biosphere, hydrosphere, and atmosphere (the source of the carbon dioxide for the mineral calcite found in the shells). Shale, a detrital sedimentary rock, is composed primarily of clay, a product of weathering of several different minerals, and possibly some organic matter. The spheres involved in its formation are the biosphere, hydrosphere (where the sediment accumulates), atmosphere (which is involved in the weathering process), and solid earth (which supplied the material to weather into clay).

2. **Of the two main sources of energy that drive the rock cycle—Earth's internal heat and solar energy—which is primarily responsible for each of the three groups of rocks found on and within Earth? Explain your reasoning.**
   Igneous and metamorphic rocks are associated with Earth's internal heat. Sedimentary rocks, because they often contain organic matter and form in the sea, where the Sun is the energy source that drives waves and currents, are allied with both solar energy and Earth's internal heat.

3. **Every year about 20,000 pounds of stone, sand, and gravel are mined for each person in the United States.**
   a. Calculate how many pounds of stone, sand, and gravel will be needed for an individual during an 80-year lifespan.
   b. If 1 cubic yard of rocks weighs roughly 1700 pounds, calculate (in cubic yards) how large a hole must be dug to supply an individual with 80 years' worth of stone, sand, and gravel?
   c. A typical pickup truck can carry about a half cubic yard of rock. How many pickup truck loads would be necessary during the 80-year span?
   a. 20,000 pounds/year × 80 years = 1,600,000 pounds.
   b. If a cubic yard of rock weighs roughly 1700 pounds, the volume of rock that would be mined over 80 years is 1,600,000 pounds ÷ 1700 pounds = 941.2 cubic yards. 1 cubic yard = 27 cubic feet, so 941.2 cubic yards × 27 cubic feet/cubic yard = 25,412 cubic feet. This is the equivalent of a hole approximately 28.5 feet wide, 28.5 feet long, and 28.5 feet deep.
   c. 941.2 cubic yards / ½ cubic yard per pickup load = 1882 pickup loads.

DISCUSSION TOPICS

- What types of rocks exist near you?
- Why do different sedimentary rocks exist in different places?
- Why are there different types of granite?
- What would be a "real life" analogy to metamorphism?
- Why do we find very old rocks at Earth's surface in some places but younger rocks at the surface in other places?
- What are some of the advantages and disadvantages of using fossil fuels?

ADDITIONAL RESOURCES

DVDs and Movies

- *Sedimentary Rock Formation* – short video that demonstrates how clastic sedimentary rocks form. Annenberg Media, 3 minutes, 18 seconds. Free streaming video at http://www.learner.org/series/modules/express/pages/scimod_07.html
- *Earth Revealed, Episode 14: Intrusive Igneous Rocks* (1992) Annenberg Media, 30 minutes. Available on DVD or for free streaming video on demand from http://www.learner.org/resources/series78.html
- *Earth Revealed, Episode 17: Sedimentary Rocks: The Key to Past Environments* (1992) Annenberg Media, 30 minutes. Available on DVD or for free streaming video on demand from http://www.learner.org/resources/series78.html
- *Earth Revealed, Episode 18: Metamorphic Rocks* (1992) Annenberg Media, 30 minutes. Available on DVD or for free streaming video on demand from http://www.learner.org/resources/series78.html

Websites

- Rocks at Earth's Surface – from the Smithsonian National Museum of Natural History. Interactive program describing rock formation and changes over time. http://www.mnh.si.edu/earth/main_frames.html
- Igneous Rock Gallery – clear pictures showing textures and features of common igneous rocks. http://geology.com/rocks/igneous-rocks.shtml
- Sedimentary Rock Gallery – good pictures showing common sedimentary rocks. http://geology.com/rocks/sedimentary-rocks.shtml
- Metamorphic Rock Gallery – clear pictures of common metamorphic rocks and their features. http://geology.com/rocks/metamorphic-rocks.shtml
- Ultimate Rock Quiz – from Discovery Channel online. Test your knowledge of rocks. http://www.discovery.com/tv-shows/curiosity/topics/rock-quiz.htm
- Personal Energy Use Calculator – How much fossil fuel do you use? http://environment.nationalgeographic.com/environment/energy/great-energy-challenge/personal-energy-meter/