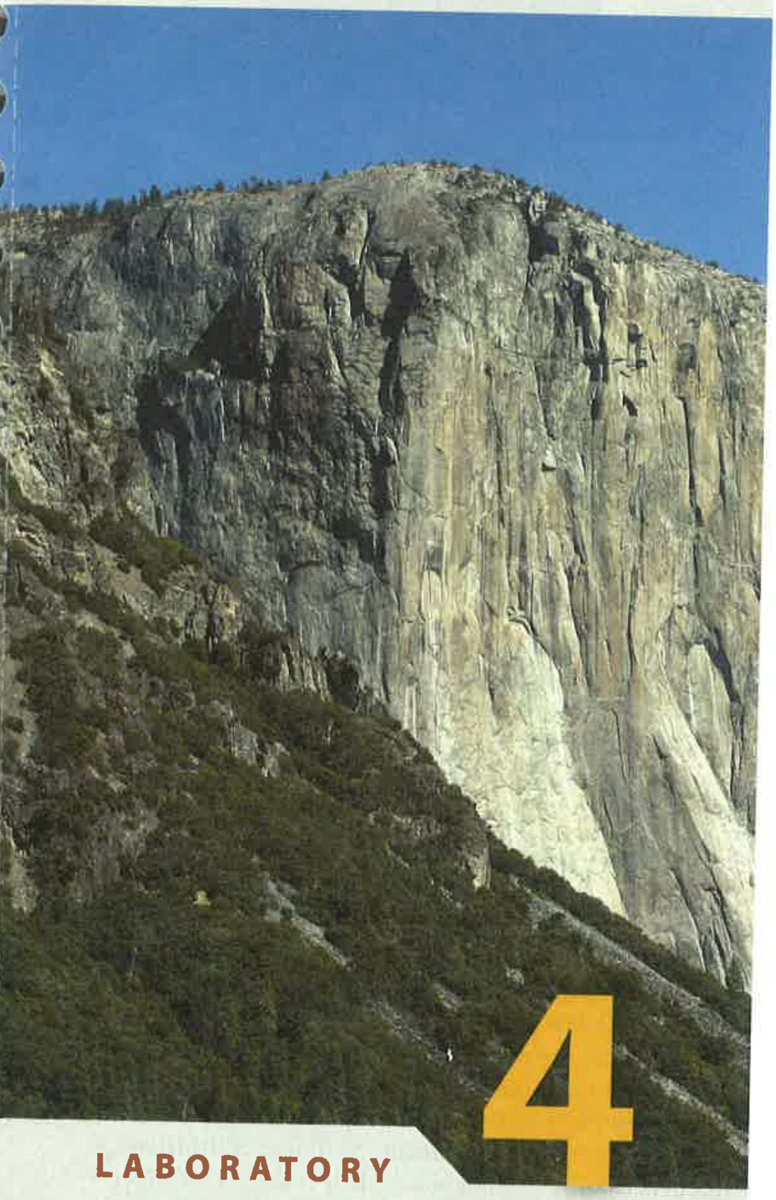


LABORATORY

4 Rock-Forming Processes and the Rock Cycle

El Capitan, Yosemite, California, is a large body of igneous rock that formed when magma cooled underground. The rock weathered from above it to reveal the igneous rock, which is crumbling to form sediment. (Henrik Lehnerer/Gamma/Glow Images)

BIG IDEAS

Rocks can be classified as igneous, sedimentary, or metamorphic on the basis of their present composition and texture and how they formed.The rock cycle model explains how all rocks can be formed, deformed, transformed, melted, and reformed as a result of environmental factors and natural processes that affect them.

FOCUS YOUR INQUIRY

THINK About It | What are rocks made of, and where and how do they form?

THINK About It | How are a rock's composition and texture used to classify it as igneous, sedimentary, or metamorphic?

THINK About It | How are rocks formed, deformed, transformed, melted, and reformed as a result of environmental factors and natural processes of the rock cycle?

Introduction

Rocks are the solid materials that make up most of Earth, our Moon, and the other rocky planets of our solar system. You might say that the largest rock on Earth is its entire rocky body, the geosphere. And like all bodies, it is a complex system of interacting parts and processes. Bedrock sticks out of the ground at "outcrops," where it is physically and chemically broken down into loose rock frgaments, mineral particles, and chemical residues. But at the same time, new bedrock is forming from cooling lava at volcanoes. The bodily function of the geosphere is its cycle of rock creation, deformation, and destruction—the "rock cycle." Every rock is part of the cycle and contains a story of where it has been on its path through the cycle. So the next time you see a rock, look closely for clues about its origin and the story it has to tell.

ACTIVITY

4.1 Rock Inquiry

THINK About It What are rocks made of, and where and how do they form?

OBJECTIVE Analyze rock samples and infer where and how they formed?

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:
   ____ pencil(s) with eraser
   ____ Activity 4.1 Worksheet (p. 121)
2. **Analyze both rocks, and complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet**, read about rocks and the rock cycle below and be prepared to discuss your observations, interpretations, and inferences with others.

Rocks and the Rock Cycle

Most rocks are solid aggregates of mineral grains (particles), either mineral crystals or clasts (broken pieces) of mineral crystals and rocks (e.g., pebbles, gravel, sand, and silt). There are, however, a few notable rocks that are not made of mineral grains. For example, *obsidian* is a rock made of volcanic glass, and *coal* is a rock made of plant fragments.

Three Main Groups of Rocks

Rock-forming materials come from Earth's mantle (as molten rock called *magma* while underground and *lava* when it erupts to the surface), space (meteorites), organisms (parts of plants and animals), or the fragmentation and chemical decay of mineral crystals and other rocks. Environmental changes and processes affect these materials and existing rocks in ways that produce three main rock groups (FIGURE 4.1):

- **Igneous rocks** form when magma or lava cool to a solid form—either glass or masses of tightly intergrown mineral crystals. The crystals are large if they had a long time to grow in a slowly cooling magma, and they are small if they formed quickly in a rapidly cooling lava.
- **Sedimentary rocks** form mostly when mineral crystals and clasts (broken pieces, fragments) of plants, animals, mineral crystals, or rocks are compressed or naturally cemented together. They also form when mineral crystals precipitate from water to form a rocky mass such as *rock salt* or cave stalactites.
- **Metamorphic rocks** are rocks deformed or changed from one form to another (transformed) by intense heat, intense pressure, and/or the action of hot fluids. This causes the rock to recrystallize, fracture, change color, and/or flow. As the rock flows, the flat layers are folded and the mineral crystals are aligned like parallel needles or scales.

The Rock Cycle

All rocks are part of a system of rock-forming processes, materials, and products that is often portrayed in a conceptual model called the **rock cycle** (FIGURE 4.2). The rock cycle model explains how all rocks can be formed, deformed, transformed, melted, and reformed as a result of environmental factors and natural processes that affect them.

Igneous Processes. An idealized path (broad purple arrows) of rock cycling and redistribution of matter is illustrated in FIGURE 4.2, starting with igneous processes. If magma (from the mantle or lower crust) cools, then it solidifies into igneous rocks that are masses of glass or aggregates of intergrown mineral crystals.

Sedimentary Processes. If these igneous rocks are uplifted, then sedimentary processes force other changes to occur. The igneous rocks are **weathered** (fragmented into grains, chemically decayed to residues, or even dissolved), **eroded** (worn away) and **transported** (moved to a new place), and later deposited to form **sediment** (an accumulation of chemical residues and fragmented rocks, mineral crystals, plants, or animals). Meteorites (dust and rocks from space) may be incorporated into the sediment. Sediment is **lithified** (hardened) into sedimentary rock as it compacts under its own weight or gets naturally cemented with crystals precipitated from water.

Metamorphic Processes. If the sedimentary rock is subjected to metamorphic processes (intense heat, intense pressure, or the chemical action of hot fluids), then it will *deform* (fold, fracture, or otherwise change its shape) and *transform* (change color, density, composition, and/or general form) to metamorphic rock. And if the heat is great enough, then the metamorphic rock will melt (an igneous process) to form another body of magma that will begin the cycle again.

Multiple Pathways Through the Rock Cycle. Of course, not all rocks undergo change along such an idealistic path. There are *at least* three changes that each rock could undergo. The arrows in FIGURE 4.2

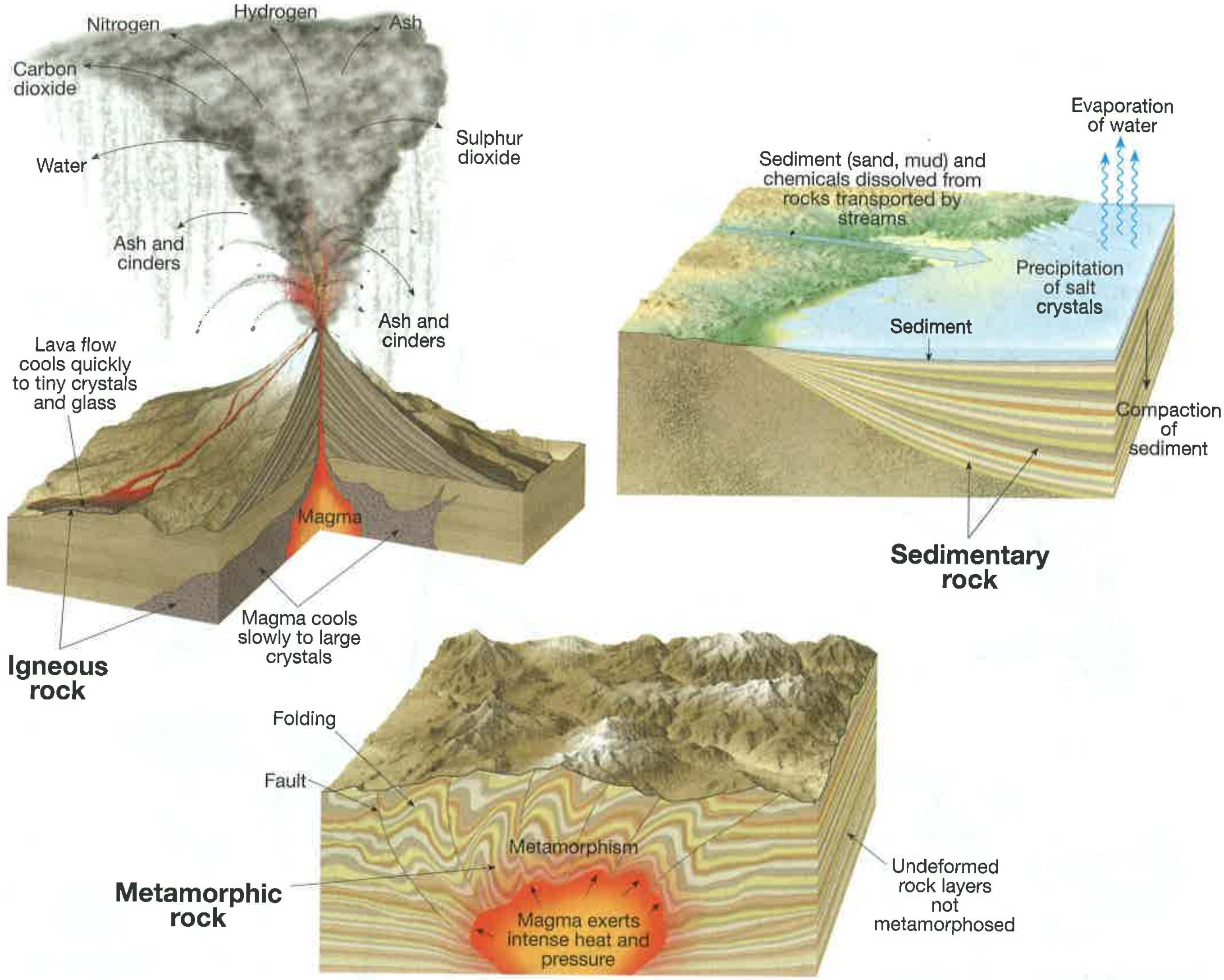


FIGURE 4.1 **The origin of igneous, sedimentary, and metamorphic rocks.**

show that any rock from one group can be transformed to either of the other two groups *or* recycled within its own group. Igneous rock can be (1) weathered and eroded to form sediment that is lithified to form sedimentary rock; (2) transformed to metamorphic rock by intense heat, intense pressure, and/or hot fluids; or (3) re-melted, cooled, and solidified back into another igneous rock. Sedimentary rock can be (1) melted, cooled, and solidified into an igneous rock; (2) transformed to metamorphic rock by intense heat, intense pressure, and/or hot fluids; or (3) weathered and eroded back to sediment that is lithified back into another sedimentary rock. Metamorphic rock can be (1) weathered and eroded to form sediment that is lithified into sedimentary rock; (2) melted, cooled, and solidified into igneous rock; or (3) re-metamorphosed into a different type of metamorphic rock by intense heat, intense pressure, or hot fluids.

ACTIVITY

4.2 What Are Rocks Made Of?

THINK About It **What are rocks made of, and where and how do they form?**

OBJECTIVE Analyze rock samples and describe what they are made of.

PROCEDURES

1. **Before you begin**, read about rock composition below. Also, this is **what you will need:**
   - ____ pencil with eraser
   - ____ Activity 4.2 Worksheet (p. 122)
2. **Then follow your instructor's directions** for completing the worksheets.

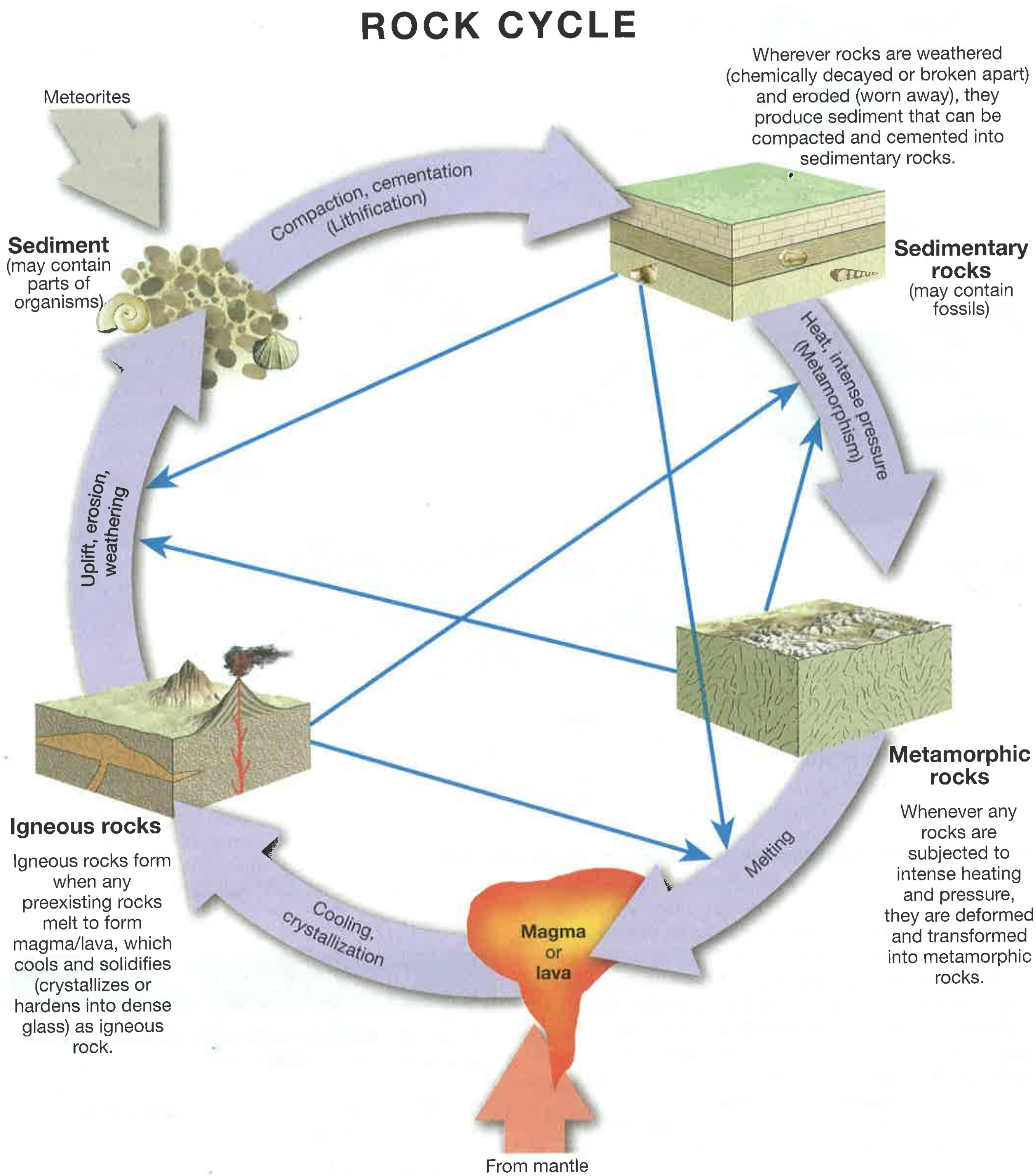


FIGURE 4.2 The Rock Cycle—a conceptual model of how all rocks can be formed, transformed, destroyed, and re-formed as a result of environmental factors and natural processes that affect them. Environmental changes and processes affect these materials and existing rocks in ways that produce three main rock groups. Arrows show that a rock from one group can be transformed to either of the other two groups, or it can be recycled within its own group. An *idealized rock cycle path* is shown by the broad large arrows. But there are *at least* two other changes that each rock could undergo.

Rock Composition

Composition of a rock refers to what it is made of. *Chemical composition* refers to the chemical elements that make up the rock. This determines how the rock will react with materials of different composition, such as whether or not it will react with and decay (tarnish, dissolve, chemically disintegrate) in air or water. It also determines rock color. For example, ferromagnesian-rich rocks (iron- and magnesium-rich rocks) generally have a dark color and ferromagnesian-poor rocks generally have a light color. But the chemical elements in a rock are normally bonded together in tangible materials like minerals that, in turn, make up most rocks. So the *physical composition* of rocks is a description of what visible materials they are made of, in whole or part. It is your job as a geologist, using your eyes and simple tools (like a hand magnifying lens), to describe and identify what physical materials are made of.

Volcanic Glass

Glass is an amorphous (containing no definite form; not crystalline) solid that forms by cooling molten (liquefied by heat) materials like melted rock (lava) or quartz sand (the main ingredient that is melted to make window glass). Volcanic glass (obsidian) looks and breaks just like window glass, except that it is usually dark colored. But how does it form? When a volcano erupts, and lava is erupted onto Earth's surface, it begins to cool. If the lava is fluid enough (has low viscosity), and stays liquefied long enough, then its elements and molecules will bond together and form mineral crystals. But if the lava is too viscous, and cools too quickly, then mineral crystals do not form and the solid material that remains is volcanic glass.

Grains in Rocks

Most rocks are made of **grains**—mineral crystals or other hard, visible particles. To view the grains in a rock hand sample, start with your own eyes and look closely. If you cannot see or identify the grains, then also try using a hand lens. Most geologists use a 10x hand lens, meaning that objects viewed through the lens appear ten times larger than in real life. Here is a list of the kinds of grains that comprise most rocks. You should look for the following:

- **Mineral grains.** Mineral crystals are the most common kind of grains in rocks. There are thousands of kinds of minerals, but twenty or fewer make up the bulk of most rocks and are known as rock-forming minerals (FIGURE 4.3). Whenever possible, try to identify and record what kind(s) of mineral crystals are present in any rock that you analyze. Also try to determine if the mineral crystals are *in situ* or not. **In situ mineral grains** are present in the rock where they originally formed. Examples are the intergrown mineral crystals in an igneous rock that formed from cooling of lava or magma and intergrown halite crystals in rock salt that formed in an evaporating sea. The intergrown mineral crystals lock together to form the rock. Also, *in situ* mineral crystals are usually arranged randomly, and they may be engulfed in glass or a mass of smaller intergrown crystals. **Detrital mineral grains** are not *in situ*—they are not intergrown, and do not lock together to form the rock. This is because they were removed from the place or rock where they originally formed and were transported by wind, water, ice, organisms, and/or gravity to a new place. There, they may become or have already become part of another rock. Most detrital mineral grains are clasts (see below), such as quartz pebbles.

- **Clasts.** Physical weathering is the cracking, crushing, and wearing away of Earth materials. The cracking and crushing causes big rocks, animal shells, and plants to be fragmented into broken pieces called **clasts** (from the Greek *klastós,* meaning broken in pieces). Plant fragments and shells or bones that have been separated or broken are often singled out as **bioclasts.** Broken mineral crystals are **detrital mineral grains** (described above), and broken pieces of rock are called **rock fragments.** Similarly, geologists have names for size classes of clasts (gravel, sand, silt, clay).

- **Gravel, sand, silt, and clay.** These terms are often used to describe what a rock or other feature is made of. For example, there is sand in a sandbox, and sandstone is made of sand. But the terms are actually names for size classes of clasts (called Wentworth size classes after C.K. Wentworth, who devised the scale in 1922). **Gravel** is a mass of grains that are mostly larger than 2 mm (like aquarium gravel, pebbles, cobbles, and boulders). **Sand** is a mass of grains that are mostly 1/16 to 2 mm in diameter (like sand in a sandbox or making up a sandy beach). **Silt** is finer than sand, so much that you can barely see and feel the grains. The grains are generally too small to identify with a hand lens or your unaided eye, so geologists refer to them collectively as silt. **Clay** is even finer than silt. If you ever played with pottery clay, then you know that it can dry on your hands as a light-colored slippery powder. You can tell it is there, but grains are too small to feel or see individually (even with a hand lens). Thus, geologists refer to these microscopic grains collectively as clay.

SOME COMMON ROCK-FORMING MINERALS				
Mineral	**Description**	**Occurs in Igneous Rocks**	**Occurs in Sedimentary Rocks**	**Occurs in Metamorphic Rocks**
Augite pyroxene	Very dark green to brown or dark gray, hard mineral (Hardness 5.5 – 6.0) with two cleavages about 90 degees apart.	as *in situ* crystals		
Biotite mica	Glossy black mineral that easily splits into thin transparent sheets along its excellent cleavage. Hardness 2.5 – 3.0.	as *in situ* crystals		as foliated *in situ* crystals
Calcite	Usually colorless, yellow, white, or amber. Breaks along three excellent cleavages (none at 90 degrees) to form rhombohedrons (leaning blocks). Hardness 3. Reacts with dilute hydrochloric acid (HCl).		as *in situ* crystals	as *in situ* crystals
Chlorite	Green mica-like mineral that splits into thin glossy transparent sheets along its excellent cleavage. Hardness 2.0 – 2.5. Occurs in large crystals or fine-grained masses.		as microscopic crystals that color the rock green	as *in situ* crystals
Garnet	Red to black rounded crystals with no cleavage. Very hard (Hardness 7).	Rarely, as *in situ* crystals	as detrital clasts	as *in situ* crystals
Gypsum	Colorless, white, or gray mineral. Easily scratched (Hardness 2.0), even with a fingernail.		as *in situ* crystals	
Halite	Colorless, white, yellow, gray cubes, that break into cubic shapes because they have three excellent cleavages 90 degrees apart. Brittle. Hardness 2.5.		as *in situ* crystals	
Hornblende amphibole	Dark gray to black, hard mineral (Hardness 5.5 – 6.0). Breaks along glossy cleavage surfaces about 56 and 124 degrees apart.	as *in situ* crystals		as *in situ* crystals
Kaolinite	Earthy white, gray or very light brown clayey masses that leave powder on your fingers. Very fine-grained. No visible crystals. Hardness 1 – 2.		as *in situ* earthy masses	
Muscovite mica	Colorless, brown, yellow, or white minerals that easily splits into transparent thin sheets along its excellent cleavage. Hardness 2.0 – 2.5.	as *in situ* crystals	tiny flakes as clasts	as foliated *in situ* crystals
Olivine	Pale to dark olive green or yellow mineral with no cleavage. Very hard (Hardness 7). Crystals may resemble sand grains. Brittle.	as *in situ* crystals		as *in situ* crystals
Plagioclase feldspar	Usually white to pastel gray, but may be colorless or black with iridescent play of colors. Exhibits fracture surfaces and two good cleavages. Cleavage surfaces may have thin striations. Hardness 6.	as *in situ* crystals	as detrital clasts	as *in situ* crystals
Potassium feldspar (orthoclase)	Usually pink-orange or pale brown, may be white. Usually has internal discontinuous streaks (exsolution lamellae). Exhibits fracture surfaces and two good cleavages. Hardness 6.	as *in situ* crystals	as detrital clasts	as *in situ* crystals
Quartz	Usually transparent to translucent gray or milky white, may be colorless. No cleavage. Breaks along uneven fractures or curved conchoidal fractures (like glass). Very hard (Hardness 7).	as *in situ* crystals	as *in situ* crystals and commonly as detrital clasts	as *in situ* crystals
Serpentine	Usually pale to dark green, opaque masses with no visible crystals or cleavage. Usually scratches easily (Hardness 2 – 5).			as *in situ* masses

In situ ("in place") mineral grains are present in the rock where they originally formed. Examples are mineral crystals newly formed from cooling of lava or magma (in igneous rocks), crystals newly formed or recyrstallized in rock or hot watery solutions under conditions of intense heat and pressure or (in metamorphic rocks), or as newly formed crystals precipitated from evaporating surface or ground water (in sedimentary rocks).
Detrital mineral grains are not in situ. They did not form where they are now found, are not intergrown, and do not lock together to form the rock. They were removed from the place or rock where they originally formed and were moved by wind, water, ice, organisms, and/or gravity to a new place. Examples are pebbles and sand grains in sedimentary and metamorphic rocks.
Foliated mineral grains are flat or blade-like crystals that have been aligned and layered, like scales on a fish, during metamorphism.

FIGURE 4.3 Some common rock-forming minerals.

ACTIVITY

4.3 Rock-forming Minerals

THINK About It **What are rocks made of, and where and how do they form?**

OBJECTIVE Analyze and identify samples of some common rock-forming minerals.

PROCEDURES

1. Before you begin, read about Rock Composition (page 116 and FIGURE 4.3). Also, this is **what you will need:**
   ___ pencil with eraser
   ___ Activity 4.3 Worksheet (p. 123)
   ___ optional: a set of mineral samples (obtained as directed by your instructor)
   ___ optional: a set of mineral analysis tools (obtained as directed by your instructor)
2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY

4.4 What Is Rock Texture?

THINK About It **How are a rock's composition and texture used to classify it as igneous, sedimentary, or metamorphic?**

OBJECTIVE Determine textures of rocks and classify them based on their composition and texture.

PROCEDURES

1. **Before you begin**, read about rock textures below, and how rock composition and texture can be used to determine if a rock is igneous, sedimentary, or metamorphic. Also, this is **what you will need:**
   ___ pencil with eraser
   ___ Activity 4.4 Worksheets (pp. 124–126)
   ___ optional: a set of rock samples (obtained as directed by your instructor)
2. **Then follow your instructor's directions** for completing the worksheets.

Rock Texture

Another very important property of rocks is **texture**—a description of the grains and other parts of a rock and their size, shape, and arrangement. Carefully review the textures below. You will need to identify them in rock samples on Worksheet 4.2.

- **Glassy** refers to rocks that have no visible grains, and break along wavy, curved glossy surfaces—just like a broken glass bottle. An example is *obsidian*, a dense dark-colored volcanic glass. Another example is anthracite coal (hard coal), which has a glassy texture but is not really glass. It is made of plant fragments and parts that are so small and compacted together, that rock just looks glassy. Coal is also opaque in hand sample and less dense than true glass.
- **Fine-grained** refers to rocks made mostly of grains that are barely visible and too small to identify even when magnified with a hand lend (grains generally < 1 mm in diameter).
- **Coarse-grained** refers to rocks made mostly of grains that are visible and large enough to identify with either a hand lens or your unaided eyes (grains generally > 1 mm in diameter).
- **Vesicular** refers to rocks with round or oval holes, called *vesicles*, that resemble the holes in a sponge or Swiss cheese. The holes are bubbles of volcanic gases that bubbled through the lava that cooled to make the rock before the bubbles could escape. Some volcanic rocks have just scattered vesicles, but *pumice* is a rock containing so many vesicles that it floats in water. The vesicles in pumice are tiny glassy bubbles with sharp edges where they break, so pumice is used as an abrasive in polishes and as a cosmetic exfoliant bar to soften skin (pumice stones, Lava™ soap).
- **Crystalline** texture refers to fine- and coarse-grained rocks in which the grains are intergrown mineral crystals that glitter when rotated in bright light. (The light reflects off the flat crystal faces or cleavage surfaces like tiny mirrors.) The crystals may be **heterogranular** (a mixture of two or more significantly different sizes) or **equigranular** (all about the same size). The crystals may also be randomly arranged or else *foliated*—a metamorphic texure in which mineral grains have been aligned or layered, causing the rock to break or reflect light in a specific direction like the layered scales on a fish.
- **Clastic** texture means that the rock is mostly made of clasts (fragments; broken pieces) of minerals or other rocks (a rock made mostly of plant fragments or broken or separated bones and shells is called **bioclastic**). The clasts may be **angular**—freshly broken with sharp corners and edges, or **rounded**—having corners and edges worn down from transportation and grain abrasion. Recall that the terms gravel, sand, silt, and clay are also textural terms. **Gravelly** rocks are made mostly of gravel (grains larger than 2 mm; equal to or coarser-grained than aquarium gravel). **Sandy** rocks are mostly made of sand (grains 1/16 to 2 mm in diameter, coarse-grained like sand in a sandbox or a sandy beach). Silty and clayey rocks are fine-grained. The **silty** rocks are mostly made of grains that you

FLOWCHART FOR CLASSIFICATION OF ROCKS AS IGNEOUS, SEDIMENTARY, OR METAMORPHIC

START

		The rock is probably:
The rock has layering.	Layers are flat and soft or crumbly.	sedimentary
	Layers are made of mud, sand, or gravel.	sedimentary
	Layers are made of crystals, which are about the same size in all layers.	metamorphic
	Layers are made of crystals, which are of different sizes in different layers.	sedimentary or igneous
	Layers are folded or otherwise deformed.	metamorphic
No visible grains are present in the rock.	Looks like dry clay or mud	sedimentary
	Looks glassy → Dense and hard, like window glass	igneous
	Looks glassy → Brittle, lightweight, opaque black: i.e., anthracite coal	metamorphic
	Very soft, easily scratched with fingernail	sedimentary
	Very hard	igneous
	Reacts (effervesces) with drop of dilute HCl	sedimentary
Visible grains are present in the rock.	Contains fossils → Whole or fragmented leaves, stems, shells, footprints	sedimentary
	Contains fossils → The fossils are so deformed (sheared, folded, or of changed composition) that they are barely recognizable	metamorphic
	Grains are mostly sand, silt, or gravel (a *clastic* texture).	sedimentary
	Contains rounded grains (like pebbles) (a *clastic* texture)	sedimentary
	Contains grains that are fragments of other rocks (a *clastic* texture)	sedimentary
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are randomly oriented in very hard rock.	igneous or metamorphic
	Grains are mostly mineral crystals (*crystalline* texture). → Large crystals sit in a very hard mass (*groundmass*, *matrix*) with smaller crystals or no visible grains.	igneous
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals can be easily scratched and/or broken apart.	sedimentary
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are flat (e.g., mica) and *foliated*: lay parallel to one another, giving the rock a layered or scaly appearance.	metamorphic
	Grains are mostly mineral crystals (*crystalline* texture). → Long crystals are *foliated*: lay parallel to one another.	metamorphic
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are calcite: they react (effervesce) with dilute HCl. → *Equigranular*: all about same size	metamorphic
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are calcite: they react (effervesce) with dilute HCl. → Have different sizes and/or occur in layers	sedimentary
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are mostly gypsum or halite.	sedimentary
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are mostly olivine, feldspar, or pyroxene.	igneous
	Grains are mostly mineral crystals (*crystalline* texture). → Crystals are mostly garnet, micas (muscovite, biotite), serpentine, graphite, galena, or sphalerite.	metamorphic
The rock has additional features.	Rock looks metallic (silvery, brassy, or copper-like) and scaly or smooth.	metamorphic
	Rock is *vesicular*: has bubble-shaped holes/cavities or looks frothy.	igneous
	Rock is very hard and has ropy, streamlined flow structures.	igneous

FIGURE 4.4 Flowchart for classification of rocks as igneous, sedimentary, or metamorphic.

can barely see and feel but are too small to identify with a hand lens or your unaided eye. **Clayey** rocks are mostly made of clay, which has grains too small to feel or see (even with a hand lens).

- **Layered** texture. Some rocks have grains arranged in layers that can be observed at more than one scale: over a region, in an outcrop, or in a hand sample. Sedimentary rocks generally have **flat layers** made of either clastic grains (gravel, sand, silt, clay, shells, plant fragments) or crystals of gypsum, halite, or calcite. Metamorphic rock layers are generally not flat-lying and **foliated** (a metamorphic texure described above in which mineral grains have been aligned or layered, causing the rock to break or reflect light in a specific direction like the layered scales on a fish). Metamorphic rock layers may also be **folded,** like you would fold a napkin. If the folds are smooth and unbroken, then the rock must have been soft and ductile (due to high thermal energy) when it was folded. The foliation is due to directed pressure and shearing during metamorphism. Brittle rocks do not fold easily. They tend to fracture (break, form a clastic texture) and move apart along faults.

ACTIVITY

4.5 Rocks and the Rock Cycle Model

THINK About It **How are rocks formed, deformed, transformed, melted, and reformed as a result of environmental factors and natural processes of the rock cycle?**

OBJECTIVE Analyze and classify rocks, infer how they formed, and predict how they may change according to the rock cycle.

PROCEDURES

1. Before you begin, read about The Rock Cycle (page 114 and FIGURE 4.2). Also, this is **what you will need:**

   ___ pencil with eraser
   ___ Activity 4.5 Worksheets (pp. 127–128)

2. **Then follow your instructor's directions** for completing the worksheets using Figure 4.5.

Rock Classification

All rocks are classified as igneous, sedimentary, or metamorphic, based on their properties of composition and texture and how they formed. Some properties are characteristic of more than one rock type. For example, igneous, sedimentary, and metamorphic rocks all can be dark, light, or made of mineral particles. Therefore, it is essential to classify a rock based on more than one of its properties.

Igneous Composition and Texture

Recall that igneous rocks form when molten rock (rock liquefied by heat and pressure in the mantle) cools to a solid form (FIGURE 4.1). Molten rock exists both below Earth's surface (where it is called *magma*) and at Earth's surface (where it is called *lava*). Igneous rocks can have various textures, including crystalline (heterogranular), glassy, or vesicular (bubbly). They commonly contain mineral crystals of olivine, pyroxene, or feldspars. Igneous rocks from cooled lava flows may have ropy, streamlined shapes or layers (from repeated flows of lava). Igneous rocks usually lack fossils and organic grains.

Sedimentary Composition and Texture

Recall that sedimentary rocks form in two ways (FIGURE 4.1). **Lithification** is the hardening of sediment—masses of loose Earth materials such as clasts (rock fragments, detrital mineral grains, pebbles, gravel, sand, silt, mud, shells, plant fragments) and products of chemical decay (clay, rust). **Precipitation** produces mineral crystals that collect as *in situ* aggregates, such as the rock salt that remains when ocean water evaporates. The lithification process occurs as layers of sediments are **compacted** (pressure-hardened) or **cemented** (glued together by tiny crystals precipitated from fluids in the pores of sediment).

Thus, most sedimentary rocks are layered and have a **clastic** texture (i.e., are made of grains called *clasts*—fragments of rocks, mineral crystals, shells, and plants—usually rounded into pebbles, gravel, sand, and mud). The sedimentary grains are arranged in layers due to sorting by wind or water. Sedimentary rocks may also include **fossils**—bones, impressions, tracks, or other evidence of ancient life.

The crystalline sedimentary rocks are layered aggregates of crystals precipitated from water. This includes the icicle-shaped stalactites that hang from the roofs of caves. Common minerals of these precipitated sedimentary rocks include calcite, dolomite, gypsum, or halite.

Metamorphic Composition and Textures

Recall that metamorphic rocks are rocks that have been deformed and transformed by intense heat, intense pressure, or the chemical action of hot fluids (FIGURE 4.1). Therefore, metamorphic rocks have textures indicating significant deformation (folds, extensive fractures, faults, and foliation). Fossils, if present, also are deformed (stretched or compressed). Metamorphic rocks often contain garnet, tourmaline, or foliated layers of mica. Serpentine, epidote, graphite, galena, and sphalerite occur only in metamorphic rocks. Metamorphism can occur over large regions, or in thin "contact" zones (like burnt crust on a loaf of bread) where the rock was in contact with magma or other hot fluids.

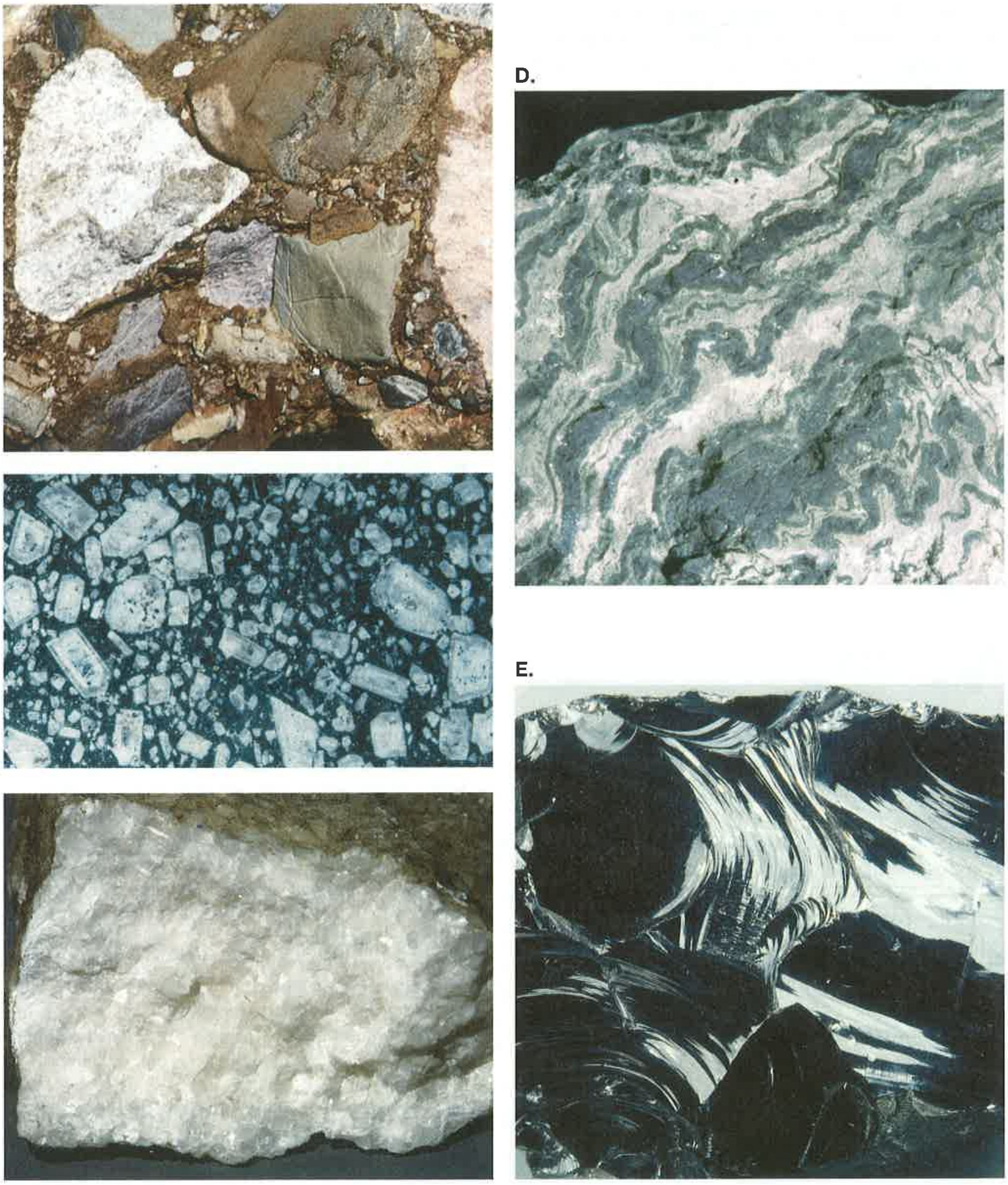
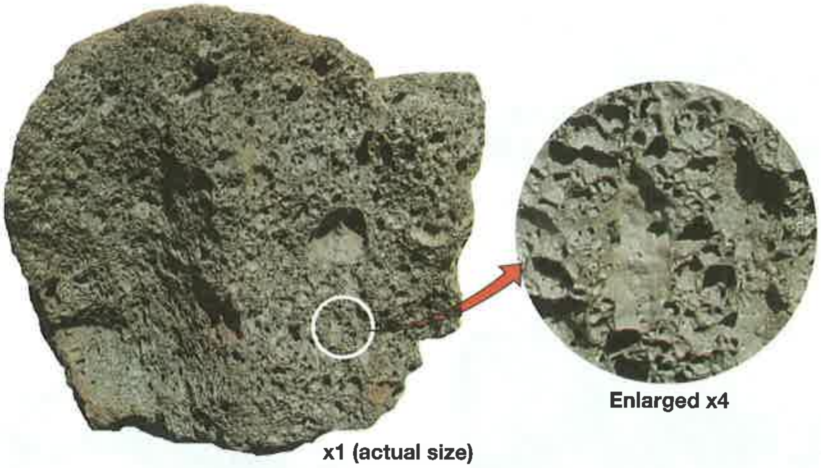


FIGURE 4.5 **Photograph of a rock sample for analysis, classification, and evaluation. (×1.0)**

4.1 Rock Inquiry

Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. **REFLECT & DISCUSS** Describe the rock below, where it may have formed, and how it may have formed.



x1 (actual size)

Enlarged x4

B. **REFLECT & DISCUSS** Describe the rock below, where it may have formed, and how it may have formed.

Enlarged x2

ACTIVITY 4.2 What Are Rocks Made Of?

Name: ____________ **Course/Section:** ____________ **Date:** ____________

A. What is the difference between *in situ* mineral grains and detrital mineral grains?

B. REFLECT & DISCUSS Rocks are made of the materials listed below and described on page 115. Below each sample, write the name of every kind of material it contains from the list below. (All samples are x1.) Be prepared to compare your observations with the observations of the other geologists.

Mineral grains (*in situ*)	Clasts (detrital minerals)	Gravel	Silt	Glass
Mineral grains (detrital)	Clasts (rock fragments)	Sand	Clay	Bioclasts

1


2


3


4


5


6


7


8


9


ACTIVITY 4.3 Rock-forming Minerals

Name: ______________________ **Course/Section:** ______________________ **Date:** __________

A. **REFLECT & DISCUSS** Refer to **FIGURE 4.3** (page 116) and identify each rock-forming mineral below. Write its name below the picture. Be prepared to compare your observations with the observations of the other geologists. (All samples x1.)

1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12


13


14


15


ACTIVITY **4.4** **What Is Rock Texture?**

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Review the following list of textures on page 117. Below each sample, write the name of every one of these textures it contains. Be prepared to compare your observations with the observations of the other geologists. (All samples x1.)

Glassy	Fine-grained	Crystalline (heterogranular)	Clastic (angular)	Layered (flat)
Vesicular	Coarse-grained	Crystalline (equigranular)	Clastic (rounded)	Layered (foliated)
			Bioclastic	Layered (folded)
			Clastic (gravely, sandy, silty, clayey)	

1


2


3


4


5


6


7


8


9


10


11


12


B. REFLECT & DISCUSS Based on the texture(s) and composition of each of the rocks in part A, tell whether you think it is igneous, sedimentary, or metamorphic (in its current state) and why?

1.

2.

3.

4.

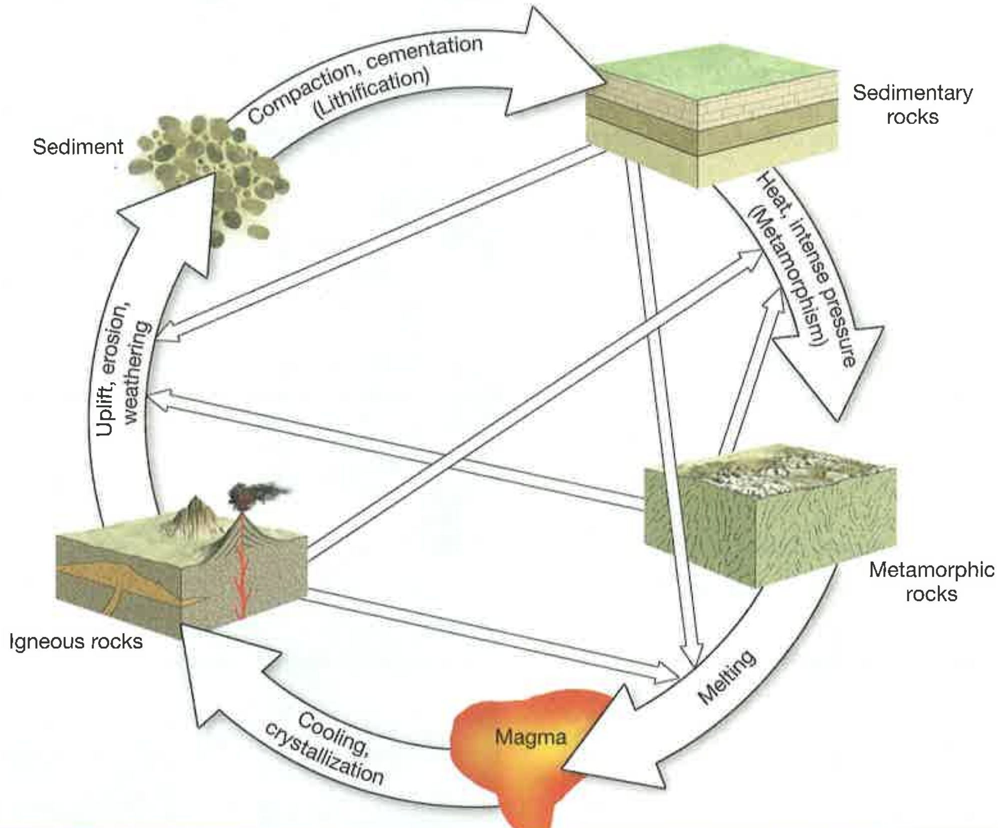
5.

6.

ACTIVITY 4.5 Rocks and the Rock Cycle Model

Name: ______________________ **Course/Section:** ______________ **Date:** __________

A. On the rock cycle below, color arrows orange if they indicate a process leading to formation of igneous rocks, brown if they indicate a process leading to formation of sedimentary rocks, and green if they indicate a process leading to formation of metamorphic rocks. Place check marks in the table to indicate what rock group(s) is/are characterized by each of the processes and rock properties.



Processes and Rock Properties	Igneous	Sedimentary	Metamorphic
lithification of sediment			
intense heating (but no melting)			
crystals precipitate from water			
solidification of magma/lava			
melting of rock			
compaction of sediment			
cementation of grains			
folding of rock			
crystalline			
foliated			
common fossils			

B. FIGURE 4.5 contains photographs of five rocks (**a–e**). For each photograph, record the following information in the chart on the next page:

1. In column one (left-hand column), note the figure number of the rock sample photograph to be analyzed.
2. In column two (blue), list the rock properties that you can observe in the sample.
3. In column three (pink), classify the rock as igneous, sedimentary, or metamorphic.
4. In column four (yellow), describe, as well as you can, how the rock may have formed.
5. On the rock cycle diagram above, write the figure number of the photograph/rock sample to show where it fits in the rock cycle model.
6. In column five (green), predict from the rock cycle (FIGURE 4.2) three different changes that the rock could undergo next if left in a natural setting.

Sample	ROCK PROPERTIES (grain types, textures)	ROCK CLASSIFICATION (igneous, sedimentary, metamorphic) Figure 4.4	HOW DID THE ROCK FORM?	WHAT ARE THREE CHANGES THE ROCK COULD UNDERGO? (according to the rock cycle model, Figure 4.2)
Figure 4.5a				1. 2. 3.
Figure 4.5b				1. 2. 3.
Figure 4.5c				1. 2. 3.
Figure 4.5d				1. 2. 3.
Figure 4.5e				1. 2. 3.

C. **REFLECT & DISCUSS** Starting with a sedimentary rock, describe a series of processes that could transform the rock into each of the other two kinds of rock and back into a sedimentary rock.