TOPIC 11

Igneous Rocks

*A **rock** is any naturally formed solid that is made up of an aggregate of one or more minerals. Rocks are divided into three groups based on how they formed: igneous, sedimentary, and metamorphic. Most rocks are polymineralic (made of more than one mineral), but some are monomineralic (made of only one type of mineral). Some monomineralic rocks can also be considered minerals. In addition to minerals, sedimentary rocks may contain organic materials or pieces of other types of rocks.*

SUBTOPIC A
WHAT ARE IGNEOUS ROCKS?

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.5; A.1, A.2; D.1, D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

VOCABULARY

rock	intrusive
igneous rock	plutonic
molten rock	extrusive
magma	volcanic
lava	noncrystalline
crystallization	vesicular
texture	nonvesicular

The majority of Earth's crust is made of **igneous rocks,** which are rocks that formed as a result of the cooling and solidification of molten rock. **Molten rock** is rock that is in a liquid state. Molten rock inside Earth is known as **magma,** while molten rock found on Earth's surface is referred to as **lava.** As molten rock cools and hardens, the atoms in the rock usually arrange themselves into ordered patterns to form crystals; this process is called crystallization.

Characteristics of Igneous Rocks

Igneous rocks can be recognized by their texture. To a geologist, the **texture** of a rock refers to the size, shape, and arrangement of the materials that make up the rock. Thus, a rock with a coarse texture has large, visible crystals, even though it may not actually feel rough or coarse. A rock with a fine texture has very small crystals. The cores of the continents are made mostly of a light-colored, coarse-grained igneous rock called granite. In contrast, the ocean floor is made almost entirely of basalt, a dark, fine-grained igneous rock. Some igneous rocks lack crystals; these rocks may have a glassy appearance and may contain bubbles.

Intrusive Igneous Rocks

Igneous rocks formed from magma cooling inside Earth are called **intrusive** or **plutonic.** Extremely high temperatures and pressures inside Earth allow magma to cool slowly, which allows the growth of large crystals. The greater the amount of time that is allowed for cooling, the larger are the crystals that form and the coarser the texture is.

Extrusive Igneous Rocks

Igneous rocks formed from lava cooling on Earth's surface are called **extrusive** or **volcanic.** Lava cools very quickly as a result of the lower temperatures and decreased pressure on Earth's surface. Rapid cooling results in rocks with small crystals that may be visible only under a magnifying glass or microscope. Such rocks have a fine texture and may appear to contain sparkles when viewed with the naked eye; these sparkles are the very small mineral crystals present in the rocks. The more rapidly the lava cools, the smaller the crystals are.

When lava cools very quickly, it solidifies before any crystals can form, producing **noncrystalline** igneous rocks. Some noncrystalline igneous rocks, such as obsidian, have a glassy texture. Obsidian is very smooth and shiny. It is also easily identified by its conchoidal fracture (described in Topic 10). Some noncrystalline igneous rocks also contain bubbles and are therefore said to have a **vesicular** texture. The bubbles were produced by gases that became trapped in the lava when it solidified. Pumice has a vesicular texture and often contains so many bubbles that it can float in water. Rocks that do not contain bubbles have a **nonvesicular** texture.

Uses of Igneous Rocks

The properties of igneous rocks, including their strength, texture, and mineral content, allow humans to use igneous rocks in a variety of ways. The interlocking crystals of igneous rocks such as granite make such rocks strong and therefore excellent building materials. In addition, many of the minerals present in igneous rocks are very resistant to weathering, which helps structures made from these rocks last for extended periods of time.

The presence of granite or other strong igneous rocks in bedrock allows large, heavy structures such as skyscrapers to be built with minimal risk of compressing the bedrock. Another strong igneous rock, basalt, is often used in the beds of roads and railroad tracks to increase stability.

Many valuable mineral and metal deposits have been found in or near layers of igneous rocks. Sometimes these deposits occur in veins or pegmatites and may include exquisitely formed crystals used for jewelry and museum exhibits. Gems such as diamonds and deposits of rare elements such as lithium are often mined from igneous intrusions.

Obsidian's conchoidal fracture and glassy texture allow it to be sharpened to a very fine point. Early humans used this rock to make cutting tools, and obsidian is still used today to make extremely sharp scalpels used for cosmetic surgery. Another useful igneous rock is pumice; its vesicular texture makes it useful as an abrasive and for polishing hard materials. In fact, dentists use pumice for polishing teeth.

SUBTOPIC B
CLASSIFYING IGNEOUS ROCKS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.5; A.1, A.2; D.1, D.2

Unifying Concepts and Processes

UCP.1 Systems, order, and organization
UCP.2 Evidence, models, and explanation
UCP.3 Change, constancy, and measurement
UCP.5 Form and function

Science as Inquiry

A.1 Abilities necessary to do scientific inquiry
A.2 Understandings about scientific inquiry

Earth and Space Science

D.1 Energy in the Earth system
D.2 Geochemical cycles

VOCABULARY

felsic	**pegmatite**
mafic	**porphyritic**

Recall that igneous rocks are classified as intrusive or extrusive based on the conditions under which they formed. Geologists further classify igneous rocks based on their mineral composition, density, color, texture, and grain size. The distribution of these characteristics among different types of igneous rocks is shown in Figure 11-1 and in *Scheme for Igneous Rock Identification* in the *Earth Science Tables and Charts.* Observe that the middle section of Figure 11-1, labeled "Characteristics," consists of three double-headed arrows that show the ranges for color, density, and composition of igneous rocks. Light-colored, low-density rocks are listed above the left side of the arrows; dark-colored, high-density rocks are listed above the right side of the arrows; and rocks with intermediate color and density are listed above the middle of the arrows.

Mineral Composition, Density, and Color

Igneous rocks are classified as felsic, mafic, or intermediate based on their mineral composition. A rock's mineral composition, in turn, determines the rock's density and color.

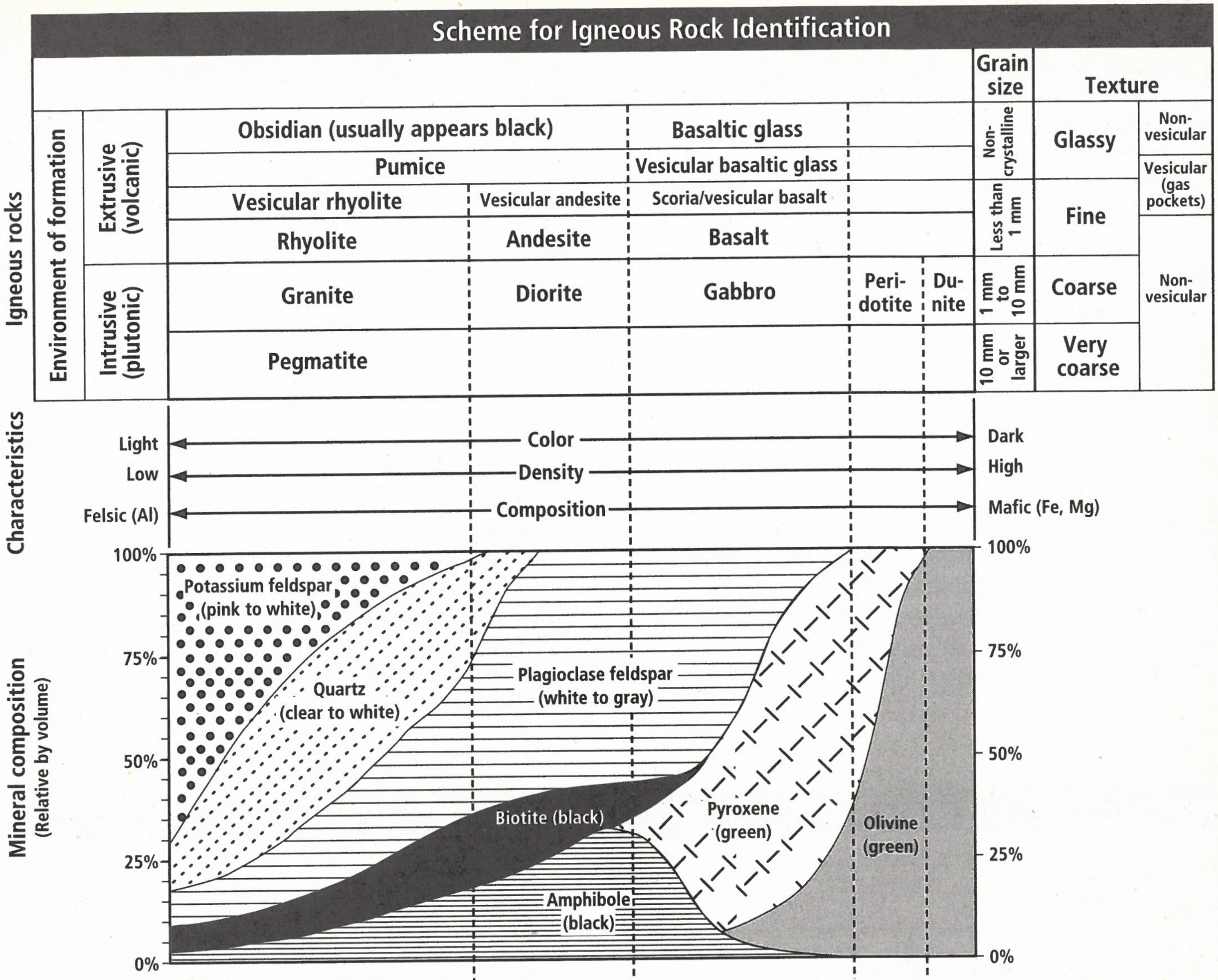


Figure 11-1 Scheme for identifying igneous rocks.

Felsic Rocks

Felsic rocks are composed largely of feldspars; they also contain a high proportion of silica and aluminum. Felsic rocks tend to be light-colored and to have a relatively low density. In Figure 11-1, felsic rocks are listed on the left side of the left dashed line. Notice in Figure 11-1 that the minerals most commonly found in felsic rocks are potassium feldspar, quartz, and plagioclase feldspar, all of which are light colored. Smaller amounts of the dark minerals biotite (a type of mica) and hornblende (a type of amphibole) are also found in felsic rocks. Felsic rocks include granite, rhyolite, pumice, and most types of obsidian. These rocks form from rhyolytic (also called felsic) magma or lava, which is 70 percent silica. The silica content of magma or lava affects its melting temperature and the rate at which it flows. Magma or lava with a high silica content usually is thick (highly viscous) and flows slowly.

Mafic Rocks

Mafic rocks, such as basalt, are made mostly of minerals high in magnesium (Mg) and iron (Fe). Mafic rocks tend to be dark and have a relatively high density. In Figure 11-1, mafic rocks are listed on the right side of the second dashed line from the left. Notice in Figure 11-1 that the minerals commonly found in mafic rocks include pyroxene and olivine, along with smaller amounts of biotite, amphibole, and plagioclase feldspar. Mafic rocks include basalt, gabbro, and scoria, which typically form from basaltic (also called mafic) magma or lava, which is only 50 percent silica. The lower silica content of this magma or lava makes it thinner (less viscous) and faster flowing than felsic magma.

Two rocks listed in Figure 11-1 have a composition referred to as ultramafic: peridotite and dunite. Ultramafic rocks appear very dark and tend to be the densest igneous rocks. Peridotite is made primarily of dark pyroxene and olivine, while dunite is made exclusively of dark green olivine.

Intermediate Rocks

Rocks with an intermediate composition are made of a combination of light and dark minerals. In Figure 11-1, intermediate rocks are listed between the two dashed lines that are farthest to the left. These rocks are usually made of plagioclase feldspar with smaller amounts of biotite, amphibole, quartz, and pyroxene. Plagioclase feldspar is usually gray, so most intermediate rocks take on this color. As Figure 11-1 shows, intermediate rocks include andesite, diorite, and some types of pumice and obsidian. Intermediate rocks form from andesitic magma, which is about 60 percent silica.

Texture and Grain Size

Recall that the texture of an igneous rock refers to the rock's grain size and is determined by the environment in which the rock formed. As Figure 11-1 shows, the intrusive rocks granite, diorite, gabbro, peridotite, and dunite have a coarse texture, with crystals ranging from 1 mm to 10 mm in diameter. Mineral grains in coarse-textured igneous rocks are often so large that you can easily identify them as a particular mineral. Although minerals forced to grow in tight spaces often cannot take on their usual crystal shapes, you can use other characteristics to identify minerals within igneous rocks. The most useful tests for this purpose are tests for color, streak, cleavage, and luster. See Topic 10 for a description of mineral tests.

Intrusive rocks with extremely large crystals (10 mm or larger in diameter) are referred to as **pegmatites** in Figure 11-1, and their texture is very coarse. Pegmatites cooled from magma deep in the ground over a very long time. The minerals in this type of rock often take on their usual crystal shapes because the crystals grow very slowly in fractures and veins around the margins of large plutons. Coarse and very coarse rocks can never have a vesicular texture because bubbles form only when molten rock cools very quickly.

Extrusive igneous rocks often have a fine texture, with crystals generally less than 1 mm in diameter, as shown in Figure 11-1. Igneous rocks can be fine-grained and vesicular (such as vesicular rhyolite), or they can be fine-grained and non-vesicular (such as rhyolite). As explained in subtopic A, rocks that cool extremely quickly do not develop crystals at all. Noncrystalline rocks can be glassy and vesicular, like vesicular basaltic glass, or glassy and nonvesicular like obsidian.

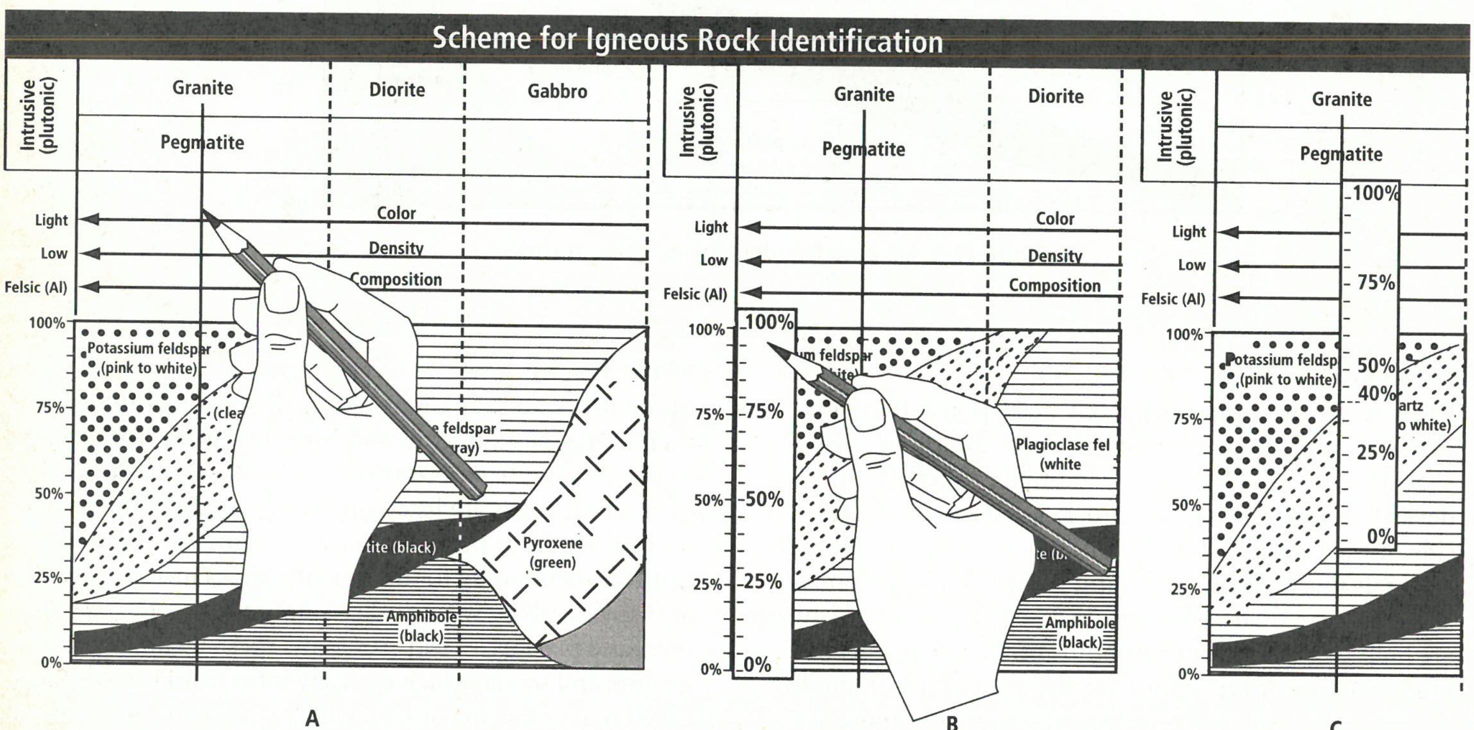


Figure 11-2 To estimate the percentage of quartz in a typical piece of granite, draw a vertical line from the center of "Granite" in the chart titled *Scheme for Igneous Rock Identification* in the *Earth Science Tables and Charts*. Extend the line to the bottom of the chart (A). Then copy the percentage scale at the left side of the chart onto a strip of paper (B). Finally, position the strip of paper alongside the line you drew in the first step. The 0% mark on the strip should line up with the bottom of the stippled section representing quartz on the chart. The mark that lines up with the top of the stippled section (40%) indicates the percentage of quartz in granite.

One texture not included in Figure 11-1 is **porphyritic.** Rocks with a porphyritic texture have large crystals surrounded by finer crystals, often of the same mineral. Such rocks form when slowly cooling magma or lava suddenly begins to cool quickly. This often happens when magma inside a volcano is thrust to Earth's surface during an eruption. The large crystals that have already formed in the magma are incorporated into the fine-grained rocks that form on or near the surface.

Using the *Scheme for Igneous Rock Identification*

The *Scheme for Igneous Rock Identification* (Figure 11-1) can be used to answer many types of questions about igneous rocks. You have already learned that you can read vertically down this chart to determine the color, density, and composition of igneous rocks. You have also learned that you can read across this chart to see which igneous rocks are intrusive or extrusive and to determine rock texture and grain size.

The *Scheme for Igneous Rock Identification* can also be used to classify igneous rocks based on just their color and texture. For example, suppose you found a rock that has a color midway between light and dark and it has a coarse texture. First, locate the column on the chart that includes the middle of the double-headed "Color" arrow. Then locate the row that lists rocks with a coarse texture. The place where that column and row intersect shows the name of the rock you found: diorite.

Finally, the *Scheme for Igneous Rock Identification* can be used to determine the percentage composition of any mineral shown on the chart in any igneous rock. As an example, Figure 11-2 explains how to estimate the percentage of quartz in a typical piece of granite.

QUESTIONS FOR SUBTOPIC A

Some questions may require the use of the *Earth Science Tables and Charts.*

Type A

1. The rock andesite forms as a result of
- **a.** cooling and solidification of molten material on the surface of Earth.
- **b.** compaction and cementation of sediments.
- **c.** precipitation of minerals out of seawater.
- **d.** cooling and solidification of molten material beneath Earth's surface.

2. Which observation about a rock would lead you to identify it as igneous?
- **a.** The rock has well-defined layers.
- **b.** The rock has a glassy texture.
- **c.** The rock contains pebbles.
- **d.** The rock is made of calcite.

3. Granite is composed of large crystals because it
- **a.** is relatively dense.
- **b.** is composed of felsic minerals.
- **c.** cooled slowly, deep underground.
- **d.** contains pebbles of various compositions.

4. Large crystal grains in an igneous rock are an indication that the crystals formed
- **a.** over a long period of time.
- **b.** under low pressure.
- **c.** near the surface of Earth.
- **d.** at a low temperature.

5. The bedrock of the flat areas on the Moon is mostly basalt. This fine-grained igneous rock was most likely formed by the
- **a.** cementing and compacting of sediments.
- **b.** changes caused by heat and pressure on pre-existing rocks.
- **c.** slow cooling of molten material deep under the Moon's surface.
- **d.** rapid cooling of molten rock on the Moon's surface.

6. Obsidian's glassy texture indicates that it formed from molten material that cooled
- **a.** slowly, deep below Earth's surface.
- **b.** slowly, on Earth's surface.
- **c.** quickly, deep below Earth's surface.
- **d.** quickly, on Earth's surface.

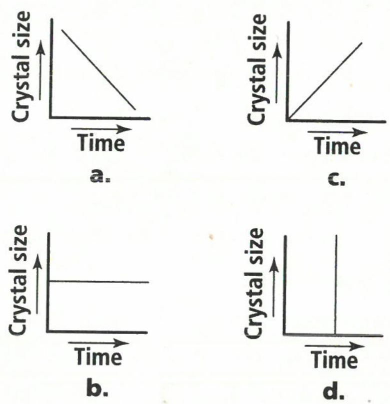
7. A student found a light-colored rock with many air holes. Which word best describes the texture of this rock?

a. felsic
b. coarse
c. vesicular
d. foliated

Type B

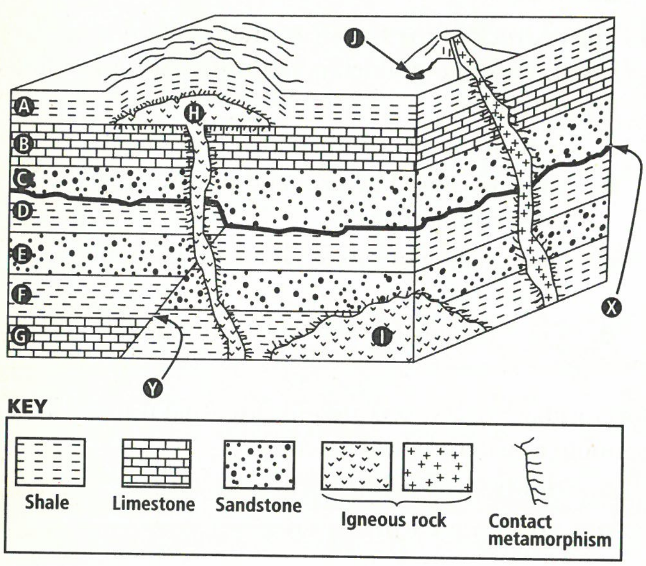
Some questions may require the use of the *Earth Science Tables and Charts.*

8. Which graph below best represents the relationship between the length of time molten material beneath Earth's surface takes to cool and the size of the crystals in the rock formed by the molten material?



9. Where do coarse-grained igneous rocks usually form? Why do they form there?

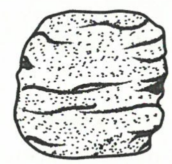
Base your answers to questions 10–12 on the block diagram below. Letters A–J represent rock units. An unconformity is shown at X. A fault is shown at Y.



10. Rock units A–H all contain

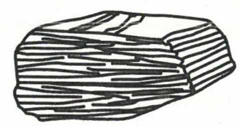
a. intergrown crystals.
b. sediments.
c. fossils.
d. minerals.

11. Rock J in the diagram represents molten rock that has cooled rapidly at the surface of Earth. Of the diagrams and descriptions below, which best represents rock J ?



Bands of alternating light and dark minerals
a.

Glassy black rock that breaks with a shell-shape fracture
c.



Easily split layers of 0.0001-cm diameter particles cemented together
b.

Interlocking 0.5-cm diameter crystals of various colors
d.

12. How would the characteristics of rock H differ from the characteristics of rock J ? Why?

13. Which rock took the longest time to solidify from molten material deep within Earth?

a. gneiss
b. obsidian
c. shale
d. gabbro

Type C

14. What is the relationship between the cooling rate of magma or lava and crystal size in the rocks that result?

15. Describe the characteristics of a rock that formed from molten material cooling on Earth's surface. Give the name of a rock that forms in this way.

16. What characteristic of pumice allows it to float in water? What happened during the formation of pumice to give it this characteristic?

17. Name an igneous rock and state one possible use for this rock. What characteristics of this rock make it good for the purpose you selected?

QUESTIONS FOR SUBTOPIC B

Type A

Some questions may require the use of the *Earth Science Tables and Charts.*

18. The table below provides information about the mineral composition of a sample of beach sand from Hawaii.

Mineral	Composition (%)
Pyroxene	50
Plagioclase feldspar	40
Olivine	3
Amphibole	5
Unidentified minerals	2

If the sand deposited on this beach recently weathered from only one type of igneous rock, the rock was most likely

a. granite.
b. peridotite.
c. diorite.
d. basalt.

19. Which two igneous rocks could have the same mineral composition?

a. rhyolite and diorite
b. pumice and scoria
c. peridotite and andesite
d. gabbro and basalt

20. Which three minerals are usually found in gabbro?

a. potassium feldspar, olivine, and amphibole
b. quartz, pyroxene, and olivine
c. potassium feldspar, quartz, and hornblende
d. plagioclase feldspar, biotite, and pyroxene

21. Which mineral can be found in granite and andesite?

a. calcite
b. pyroxene
c. olivine
d. quartz

22. Some Moon rock samples have coarse, intergrown crystals composed of plagioclase feldspar, hornblende, and olivine. These Moon rock samples are most similar to Earth rock samples of

a. gabbro.
b. rhyolite.
c. diorite
d. dunite.

23. Which relative concentration of elements is found in a felsic rock?

a. a high concentration of carbon and a low concentration of iron
b. a high concentration of iron and a low concentration of aluminum
c. a high concentration of aluminum and a low concentration of iron
d. a high concentration of aluminum and a low concentration of magnesium

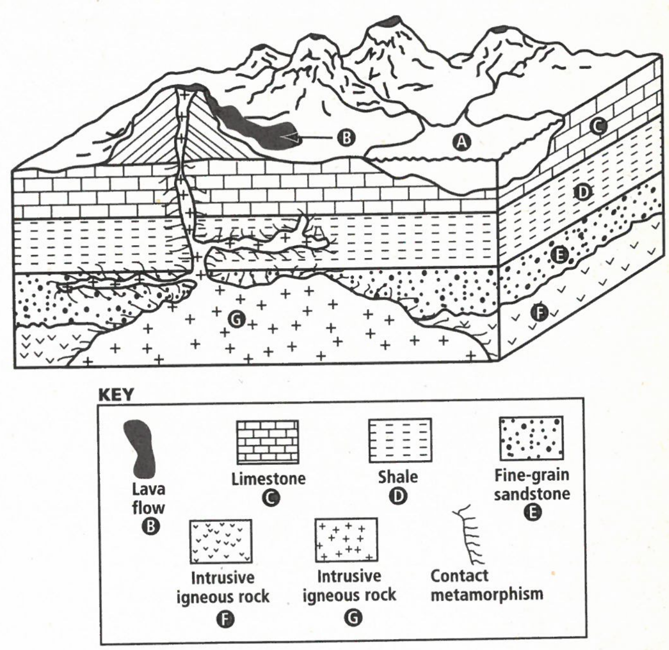
24. The end product of the weathering of gabbro or basalt rocks is a solution that most likely would contain high concentrations of

a. iron and magnesium.
b. magnesium and potassium.
c. aluminum and iron.
d. aluminum and potassium.

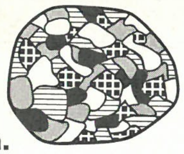
Type B

Some questions may require the use of the *Earth Science Tables and Charts.*

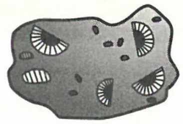
Base your answers to questions 25 and 26 on the block diagram below, which shows a cross section of Earth's crust. Letter A identifies a lake, letter B represents a lava flow, and letters C–G represent different types of bedrock.



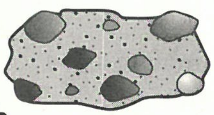
25. Which diagram best represents a sample of rock G?



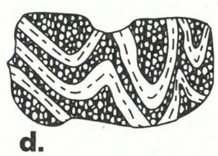
a.



c.



b.

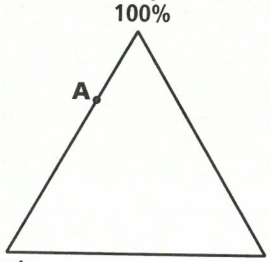


d.

26. Rock B is a dark-colored, crystalline rock that formed when molten material cooled and solidified quickly on the surface of Earth. Rock B is classified as an

a. extrusive igneous rock with a coarse texture and felsic composition.
b. extrusive igneous rock with a fine texture and a mafic composition.
c. intrusive igneous rock with a coarse texture and a felsic composition.
d. intrusive igneous rock with a fine texture and a mafic composition.

27. In the diagram below, each point of the triangle represents 100% composition of the mineral named at that point. The percentage of that mineral decreases toward 0% as you move along a side of the triangle toward either of the other points of the triangle. Letter A represents the mineral composition of an igneous rock.



Rock A is a coarse-grained igneous rock that can best be identified as

a. rhyolite. **c.** granite.
b. pumice. **d.** gabbro.

28. According to the *Earth Science Tables and Charts*, what is the percentage of the mineral quartz in a typical rhyolite?

a. 5% **c.** 35%
b. 10% **d.** 75%

29. A rock formed deep underground that is composed of 70% pyroxene, 15% plagioclase feldspar, 10% olivine, and 5% amphibole should be classified as

a. granite. **c.** rhyolite.
b. gabbro. **d.** basalt.

30. Which statement best describes the percentage of plagioclase feldspar in a sample of gabbro?

a. The percentage of plagioclase feldspar in gabbro can vary.
b. Gabbro always contains less plagioclase feldspar than pyroxene.
c. Plagioclase feldspar always makes up 25% of a gabbro sample.
d. Gabbro contains no plagioclase feldspar.

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*

31. A student finds a rock with mostly medium-colored mineral crystals that are as large as 3 mm across. Describe the conditions under which this rock most likely formed. What is the name this rock?

32. What characteristics of an igneous rock are most useful for identification?

33. Draw a bar graph that shows the relative grain sizes of the minerals in basalt, granite, and rhyolite.

Base your answers to questions 34 and 35 on the table below, which provides data about the texture and mineral composition of four different igneous rock samples with the same volume.

34. Describe the evidence that indicates that rock D is probably basalt.

35. Describe how the rock with the lowest density can be determined based solely on the information in the table. Which rock has the lowest density?

Rock	Texture	Potassium feldspar	Quartz	Plagioclase feldspar	Biotite	Amphibole	Pyroxene
A	coarse	62%	20%	7%	7%	4%	0%
B	coarse	0%	0%	55%	6%	27%	12%
C	fine	6%	16%	41%	14%	23%	0%
D	fine	0%	0%	50%	0%	6%	44%

TOPIC 12

Sedimentary and Metamorphic Rocks

In Topic 11, you learned that igneous rocks form when molten rock cools, but rocks can form in other ways, too. Sedimentary rocks form when rock fragments, organic materials, or minerals that have fallen (precipitated) out of solution are compacted and/or cemented together. Metamorphic rocks form when heat and/or pressure change existing rocks without melting them. The rock cycle describes how igneous, sedimentary, and metamorphic rocks can change from one type to another.

SUBTOPIC A FORMATION OF SEDIMENTARY ROCKS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.5; A.1, A.2; D.1, D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

VOCABULARY

weathering
sediments
erosion
deposition
clastic sedimentary rock
lithification
organic
organic sedimentary rock
compaction
cementation
chemical sedimentary rocks
precipitate
saturated
evaporites

The formation of a sedimentary rock requires several processes. First, rocks of any type are weathered and eroded, and their fragments are deposited as sediments. These sediments are buried under additional layers of sediment, causing the sediments to compact and cement together to form a sedimentary rock. **Weathering** is the chemical or mechanical breaking down of any type of rock into smaller pieces called fragments or **sediments. Erosion** is the process by which weathered particles are transported to a new location. **Deposition** occurs when particles are deposited or dropped in a new location. Additional information on weathering, erosion, and deposition can be found in Topic 7.

Gravity, wind, glaciers, waves, or running water may move fragments of weathered rock over great distances. While floating in or being pushed by running water or another agent of erosion, the fragments may become smoother and rounder. When they are finally deposited (often in layers), they may form into a **clastic sedimentary rock,** by the process of **lithification.** Lithification is the process by which sediments are transformed into sedimentary rocks; this process is further explained later. If the transported particles are very small and water soluble, they may get dissolved in water and eventually could become part of a chemical sedimentary rock. If the fragments are **organic** (made from or by organisms), they can form an **organic sedimentary rock.** The processes that change sediments into sedimentary rocks include compaction, cementation, chemical processes, and organic processes. Conditions that existed when a rock formed can be inferred from the rock's mineral content and texture.

Although the majority of the rocks in Earth's crust are igneous or metamorphic, many rocks exposed on Earth's surface are sedimentary. Sedimentary rocks are usually found on the surface because the processes that form them occur closer to the surface than the processes that form most igneous and metamorphic rocks. Rocks are classified by their origin, mineral content, and texture.

Compaction

As layers of sediment are deposited one on top of the other, the weight of the overlying layers of sediment and water compresses these particles together. This process is called **compaction.** Rocks made of sticky sediments such as mud or clay may form purely by compaction, but most rocks also require cementation to "glue" their particles together. Compaction forces sediments closer together and squeezes water out of the spaces between sediments. Some sediments, such as sand, are resistant to compaction and retain their pore spaces. These spaces can then hold water or other fluids in the future.

Cementation

When water gets between sediments as they are forming into a rock, **cementation** usually follows. Most water on Earth contains dissolved minerals, so as water evaporates or is squeezed out of the sediments, the minerals it was carrying may be left behind. These minerals then serve as a glue or cement that holds the sediments together to form a clastic rock. The cements in most sedimentary rocks are either calcite or quartz cements.

Chemical Processes

Sometimes entire rocks form by a method similar to the way the cement of clastic rocks forms. **Chemical sedimentary rocks** form when water containing dissolved minerals evaporates, leaving the minerals behind. These minerals then get compacted together by the weight of overlying sediments to form rock.

Dissolved minerals **precipitate** out of solution when water is **saturated** with minerals. Saturated water contains as many dissolved minerals as it possibly can hold. When water is saturated, the addition of any more minerals will cause some of the minerals currently dissolved in the water to fall out of the solution and settle on the bottom.

Another situation in which chemical sedimentary rocks can form happens when the temperature of or pressure on a body of water changes. This makes the water unable to hold all of its dissolved minerals, forcing some of them to settle out of the water. Rocks formed when the minerals in water come out of solution, or precipitate, are called **evaporites.** Notice how evapor*ite* looks like evapor*ate*. This should help you remember how chemical sedimentary rocks (also known as evaporites) form.

Organic Processes

Substances that are or once were alive, or that were created naturally by living things are called organic. Sedimentary rocks consisting of organic materials are called organic sedimentary rocks. Limestone, an organic sedimentary rock, forms when animal skeletal or shell remains are compacted and cemented together. Coal, another organic rock, forms in hot, moist areas such as swamps and tropical coastlines with a high concentration of life. The hot, moist climate that speeds up decay, combined with the large quantity of life, results in thick layers of decaying organic material that gets compacted together to form coal.

SUBTOPIC B
TYPES OF SEDIMENTARY ROCKS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.5; A.1, A.2; D.1, D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.5	Form and function

Science as Inquiry

A.1	Abilities necessary to do scientific inquiry
A.2	Understandings about scientific inquiry

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

VOCABULARY

bedding	**bioclastic**
graded bedding	**fossil**

There are three distinctive types of sedimentary rocks: clastic, chemical, and organic. They are classified based on how they formed. Clastic rocks form by compaction and/or cementation of sediments, while chemical rocks form by chemical processes (such as evaporation), and organic rocks form by organic processes (such as the compaction of decayed plant remains).

Clastic Rocks

Most sedimentary rocks are clastic. This type of sedimentary rock is made of mainly inorganic, land-derived sediments or fragments. The fragments of other rocks that were compacted and cemented together to make a clastic rock are often visible to the naked eye.

Characteristics of Clastic Rocks

When fragments of other rocks or minerals are seen in a rock, that rock is identified as clastic. Some clastic sedimentary rocks exhibit **bedding** (parallel layers of sediments in rocks). Bedding is sometimes the result of the vertical sorting that happens when sediments settle in quiet (nonflowing or slowly flowing) water. Because larger, denser particles settle more rapidly than smaller particles, the bottom layer of a sedimentary rock that formed in quiet water will generally consist of larger particles. The next layer will contain smaller particles. These layers often alternate in sedimentary rocks. This division of particles creates a type of bedding (called **graded bedding**) that can be used to identify some clastic rocks. Bedding also may occur as a result of repeated depositional events. If a stream floods periodically, resulting in the deposition of a layer of sediments in the surrounding area, these layers may be visible in the rocks that form. Figure 12-1A shows an example of graded bedding in a clastic rock.

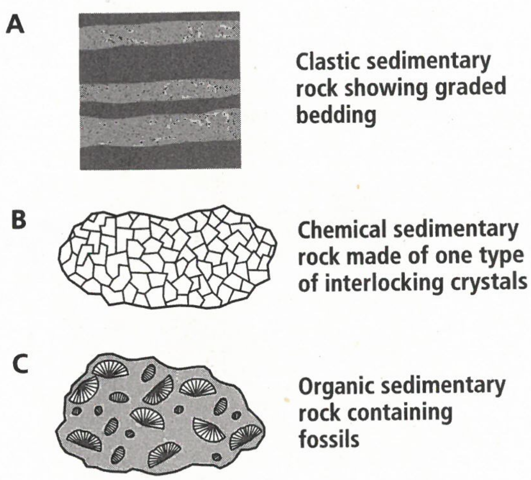


Figure 12-1 Diagrams of clastic, chemical, and organic, sedimentary rocks. Notice the graded bedding of the clastic rock, the mineral crystals in the chemical rock, and the fossils in the organic rock.

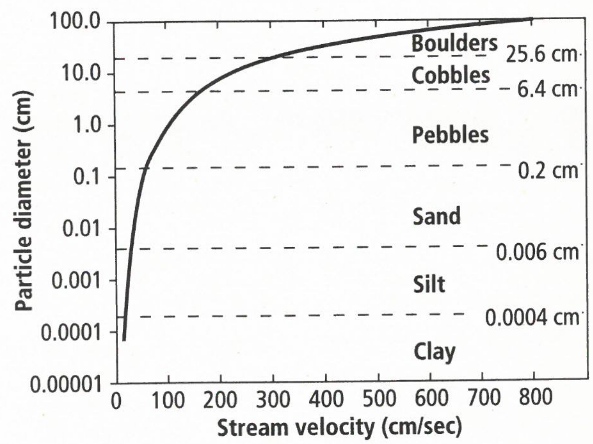
Identifying Clastic Rocks

All clastic rocks are made mostly of quartz, feldspar, and clay minerals. However, the particles that make up clastic rocks can range in size from less than 0.0004 cm in diameter (clay) to more than 25.6 cm in diameter (boulders). Therefore, clastic rocks are named based on their grain size and shape.

Conglomerate and breccia have the same composition and range of fragment sizes (0.2 cm to 25.6 cm in diameter), so they are differentiated by their particle shape. Conglomerate is made up of rounded fragments, while breccia is made up of angular fragments. Because particles become rounder the longer they are transported, the rounded particles found in conglomerate indicate that these particles were carried great distances before being deposited. On the other hand, the angular fragments of breccia indicate a very short period of transport. Sand-sized particles (0.006 cm to 0.2 cm in diameter) make up sandstone, which looks and feels like sand and may exhibit bedding. Clay-sized particles (less than 0.0004 cm in diameter) make up shale, which tends to be very smooth and is easily split into flat layers.

Two parts of the *Earth Science Tables and Charts* can be used to determine particle size and thus the name of clastic rocks. The ruler on the edge of the first page of the tables and charts can be used to measure the diameter of particles in a sample or diagram drawn to scale (except for those particles that are extremely small). In addition, the *Relationship of Transported Particle Size to Water Velocity* on page 6 of the *Earth Science Tables and Charts* shows ranges of particle sizes on the right side. This graph, which is duplicated in Figure 12-2, shows that cobbles range in diameter from 6.4 cm to 25.6 cm. You can use this graph to determine the particle size of a particular type of sediment (such as cobble, pebble, or silt) and to determine the name of a type of sediment based on its particle size.

Relationship of Transported Particle Size to Water Velocity



***This generalized graph shows the water velocity needed to maintain, but not start, movement. Variations occur due to differences in particle density and shape.**

Figure 12-2 Graph relating particle diameter to stream velocity, found in the *Earth Science Tables and Charts.*

Chemical Rocks

When minerals dissolved in water precipitate and are then compacted and cemented together, the result is a chemical sedimentary rock.

Characteristics of Chemical Rocks

Chemical sedimentary rocks, formed by chemical processes, have a crystalline texture and can be recognized because they are usually monomineralllic (consisting of only one mineral) and consist of interconnected mineral crystals. Refer to Figure 12-1B for an example of this texture. Some chemical sedimentary rocks are soft enough to be scratched with a fingernail.

Identifying Chemical Rocks

Chemical sedimentary rocks are named based on their common composition. Because chemical rocks are commonly comprised of a single compound, they can often be identified using mineral tests (see Topic 10). For example, rock salt is made entirely of the mineral halite, so it tastes salty and forms cubic crystals. **CAUTION: Never taste any rocks or minerals in the lab.** Rock gypsum is made of the mineral gypsum. Rock salt and rock gypsum are also known as evaporites. Limestone formed by chemical processes is made of calcite, which fizzes in the presence of a weak acid. Calcite is usually tested with diluted hydrochloric acid.

Organic Rocks

Organic rocks tend to be monominerallic and have a bioclastic texture. Most bioclastic rocks are made of compacted and cemented organic material, such as animal shells or decayed plant remains. Biological processes contribute to the formation of organic rocks.

Characteristics of Organic Rocks

Recall that the fragments that make up clastic sedimentary rocks are often visible with the naked eye. If the visible fragments appear to be organic, such as bones or shells, then the texture is said to be **bioclastic,** and the rock is organic. Also, any rock containing a fossil is most likely an organic sedimentary rock. However, fossils can also be found in clastic sedimentary rocks, such as shale and sandstone. A **fossil** is any evidence of previous life preserved in a rock. See Figure 12-1C for an example of an organic sedimentary rock.

Identifying Organic Rocks

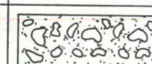
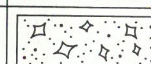
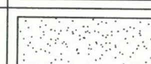
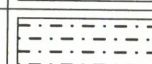
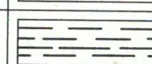
An organic rock consisting of visible shell fragments is a type of limestone, sometimes called coquina or fossiliferous limestone. Coal is an organic rock composed of carbon that is made from decayed plant and animal remains. Coal can be recognized by its black color and fine-grained texture.

Using the *Scheme for Sedimentary Rock Identification*

The *Scheme for Sedimentary Rock Identification,* found on page 7 of the *Earth Science Tables and Charts* and in Figure 12-3, can be used to name, classify, and describe sedimentary rocks. This chart is divided into two sections. The top section lists clastic sedimentary rocks and is titled *Inorganic Land-Derived Sedimentary Rocks.* This title should help you remember that clastic rocks do *not* contain organic materials (they are inorganic), and that they are formed from sediments found on land (they are land-derived).

Scheme for Sedimentary Rock Identification

Inorganic Land-Derived Sedimentary Rocks

Texture	Grain size	Composition	Comments	Rock name	Map symbol
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate	
			Angular fragments	Breccia	
	Sand (0.2 to 0.006 cm)		Fine to coarse	Sandstone	
	Silt (0.006 to 0.0004 cm)		Very fine grain	Siltstone	
	Clay (less than 0.0004 cm)		Compact; may split easily	Shale	

Chemically and/or Organically Formed Sedimentary Rocks

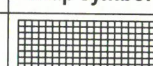
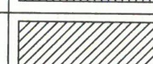
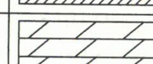
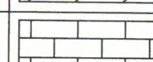
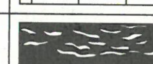
Texture	Grain size	Composition	Comments	Rock name	Map symbol
Crystalline	Varied	Halite	Crystals from chemical precipitates and evaporites	Rock salt	
	Varied	Gypsum		Rock gypsum	
	Varied	Dolomite		Dolostone	
Bioclastic	Microscopic to coarse	Calcite	Cemented shell fragments or precipitates of biologic origin	Limestone	
	Varied	Carbon	From plant remains	Coal	

Figure 12-3 Scheme for identifying sedimentary rocks.

The bottom section of the chart lists chemical and organic sedimentary rocks.

The leftmost column of this chart indicates *Texture.* This column should help remind you that all land-derived sedimentary rocks have a clastic (fragmental) texture. On the other hand, chemically formed rocks have a crystalline texture, and organically formed rocks have a bioclastic texture.

The next column lists *Grain Size,* which is very important for classifying clastic rocks. Because grain size is usually variable for chemical and organic rocks, it is less useful for classifying those types of rocks. The *Composition* column tells you what makes up the various sedimentary rocks. Notice that the composition of all clastic rocks is roughly the same (mostly quartz, feldspar, and clay minerals), so composition is not as useful for classifying clastic rocks as it is for classifying chemical and organic sedimentary rocks. Because most chemical and organic rocks are made of only one mineral, composition is very useful for classifying those kinds of rocks. Clastic rocks are polymineralic, consisting of more than one type of mineral, and chemical and organic rocks are monomineralic, consisting of only one type of mineral.

The *Comments* column gives additional information about the texture of clastic rocks and the formation of chemical and organic rocks. The symbols for each rock type given in the last column are standard symbols and are used consistently by both geologists and test-makers.

Uses of Sedimentary Rocks

Sedimentary rocks such as sandstone, limestone, and conglomerate are used as building stones. Limestone is also used for making cement, sidewalks, and concrete. Chemical sedimentary rocks such as rock gypsum, limestone, and rock salt are often mined for the minerals they contain. The halite found in rock salt, for example, is used for making table salt as well as the salt that is spread on icy roads. Coal is another useful sedimentary rock. It is mined for the heat energy it releases when burned.

Shale weathers easily, so regions where shale forms the bedrock often have a topography consisting of low rolling hills that are easy to build on. Limestone is made of calcite (calcium carbonate), which is chemically a base (pH>7), so it serves as a good buffer to counteract the effects of acid precipitation. Acid precipitation tends to acidify soil, making it unfit for growing crops, but the presence of limestone in the bedrock allows areas that would normally be unable to support farming due to acidic soil to be used for growing crops. However, because calcite dissolves with even a weak acid, areas with a limestone bedrock also tend to experience a great deal of erosion.

Clastic sedimentary rocks are especially valuable to geologists because of the fossils, imprints of raindrops, certain types of bedding, and ripple marks they may contain. These features provide scientists with information about surface conditions, life-forms, and climates of the distant past. In addition, some geologists work to locate deposits of groundwater, oil, and natural gas found in the pores of sedimentary rocks such as sandstone.

SUBTOPIC C
METAMORPHIC ROCKS

Covers National Science Content Standards UCP.1, UCP.2, UCP.3, UCP.4, UCP.5; B.6; D.1, D.2

Unifying Concepts and Processes

UCP.1	Systems, order, and organization
UCP.2	Evidence, models, and explanation
UCP.3	Change, constancy, and measurement
UCP.4	Evolution and equilibrium
UCP.5	Form and function

Physical Science

B.6	Interactions of energy and matter

Earth and Space Science

D.1	Energy in the Earth system
D.2	Geochemical cycles

VOCABULARY

recrystallization	**nonfoliated**
metamorphism	**slaty foliation**
regional metamorphism	**schistose foliation (schistosity)**
contact metamorphism	**gneissic foliation (banding)**
foliation	**rock cycle**
parent rock	

Metamorphic rocks form when igneous, metamorphic, or sedimentary rocks are changed by heat and/or pressure. The heat that creates metamorphic rocks is not intense enough to cause melting, but it allows atoms in the rocks to rearrange themselves in response to pressure changes, temperature changes, or chemical reactions.

Formation of Metamorphic Rocks

Metamorphic rocks form when the composition of preexisting rocks is changed by heat and/or pressure, but without melting. When heat, pressure, and hot fluids cause atoms to rearrange, forming a new rock, the process is called **recrystallization** or **metamorphism.** As temperature and pressure increase, some minerals that were previously stable become unstable. In other words, because some minerals can exist (are stable) only at a narrow range of temperatures and pressures, when heat and/or pressure increases during metamorphism, these minerals can no longer exist. These minerals are said to be unstable. During metamorphism, unstable minerals are changed into minerals that are stable under the new conditions. Metamorphic rocks can form from any preexisting rock (igneous, sedimentary, or metamorphic). There are two types of metamorphism that occur: regional metamorphism and contact metamorphism. Rocks are classified as contact metamorphic or regional metamorphic based on how they were formed.

Regional Metamorphism

Most metamorphic rocks form deep underground by regional metamorphism. **Regional metamorphism** occurs when large areas of rock are changed by heat and pressure. The heat involved in this type of transformation is usually radiated from Earth's core or is the result of the friction between moving tectonic plates (see Topic 5). This heat combines with intense pressure caused by compressive forces within Earth and/or pressure from overlying rock layers to metamorphose rocks. The heat and pressure change the molecular arrangement, and thus the chemical composition, of existing rocks.

Contact Metamorphism

Contact metamorphism is less common than regional metamorphism. When existing rock is contacted by molten rock, the heat of and chemicals in the molten rock can cause recrystallization of the existing rock without melting. This process is called **contact metamorphism,** as shown in Figure 12-4. An example of contact metamorphism is the sedimentary rock limestone being metamorphosed into the metamorphic rock marble. In addition, contact metamorphic rocks such as hornfels are found in a narrow zone between igneous rock layers and nonigneous rock layers.

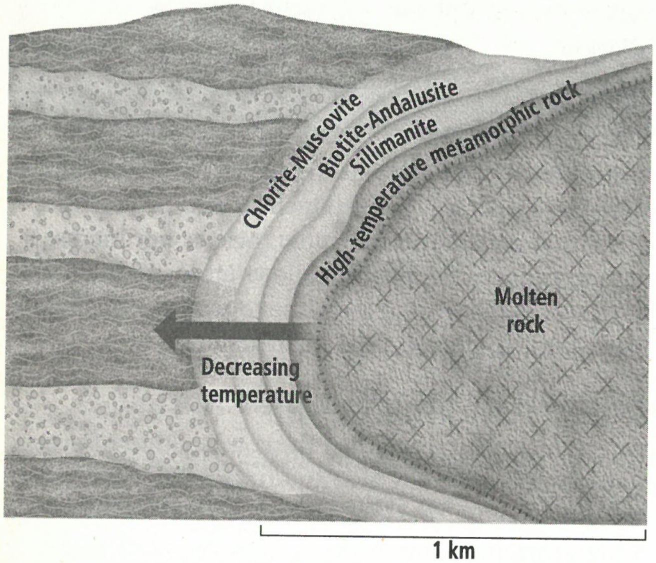


Figure 12-4 Contact metamorphism results in large-scale mineral changes with little deformation. Geologists can follow the occurrence of metamorphic minerals to locate igneous intrusions.

They are commonly seen on the sides of intrusions and the bottoms of extrusions (see Topic 11). Because rocks formed by contact metamorphism experience great heat with little pressure, they are usually less dense than regional metamorphic rocks. Also, contact metamorphic rocks rarely have the **foliation** (banding) common to most regional metamorphic rocks.

Characteristics of Metamorphic Rocks

You can often identify metamorphic rocks by banding, distortion, or resemblance to other rock types. The rock from which a metamorphic rock formed is called its **parent rock** or protolith. Metamorphic rocks generally resemble their parent rock and sometimes have the same chemical composition, but they may show increased distortion and have a higher density as a result of the increased pressure.

The banding seen in many types of metamorphic rocks is called foliation. Foliation is different from the bedding seen in sedimentary rocks because the bands in metamorphic rocks are of different types of minerals. Foliation occurs when mineral crystals (like those found in igneous rocks) are flattened into bands by the increasing pressure of regional metamorphism. Crystals or fragments in metamorphic rocks often get distorted by pressure, and occasionally distorted fossils can even be found. However, fossils are very rare in metamorphic rocks because intense pressure and heat tend to destroy them.

Classifying Metamorphic Rocks

In addition to being classified by the way they formed, metamorphic rocks can be classified by their texture. Metamorphic rocks may be foliated (have layers) or **nonfoliated** (have no layers).

Foliated metamorphic rocks have visible bands of crystals that may be arranged in different ways. This allows further classification and identification of metamorphic rocks based on their type of foliation. Refer to Figure 12-5 as you read this section to see examples of the three types of foliation. Rocks with flat, even layers containing very small crystals have a **slaty foliation.** This type of foliation is named for the metamorphic rock slate, since it often shows these flat layers clearly. A rock with medium-sized crystals arranged in uneven layers has a **schistose foliation,** or **schistosity.** This type of foliation is named for the metamorphic rock schist. Metamorphic rocks with alternating bands of light and dark minerals have **gneissic foliation,** or banding. This type of foliation may also be referred to as apparent layering. The metamorphic rock gneiss often has black and white or black and pink bands, making it unique and easily recognizable. The bands in a gneissic rock may be straight or distorted (curved).

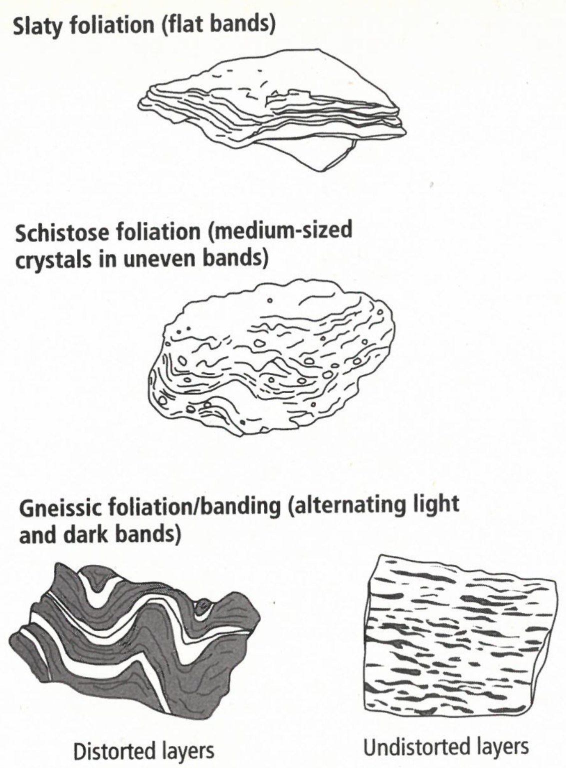


Figure 12-5 Slaty, schistose, and gneissic foliation.

Nonfoliated metamorphic rocks may exhibit some amount of distortion (stretching or scrunching) of their crystals or fragments, but do not exhibit layering. Contact metamorphism tends to create nonfoliated metamorphic rocks that are often difficult to classify. Nonfoliated metamorphic rocks can best be identified if they are located right next to what is clearly their parent rock. For example, if an igneous rock intruded into a layer of limestone, the limestone close to the intrusion would have been changed into nonfoliated marble as a result of contact metamorphism.

Using the *Scheme for Metamorphic Rock Identification*

The *Scheme for Metamorphic Rock Identification* can be found on page 7 of the *Earth Science Tables and Charts* and in Figure 12-6. Recall that metamorphic rocks can be first identified based on their texture (foliated or nonfoliated). Notice that the composition of the foliated rocks listed in the top half of the chart is mostly the same. All are made of a combination (different percentages) of mica, quartz, feldspar, amphibole, garnet, and pyroxene. Therefore, foliated rocks cannot be identified easily by their composition, so their type of foliation and their grain sizes are used to classify them instead.

Scheme for Metamorphic Rock Identification

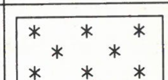
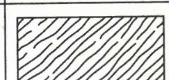
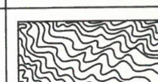
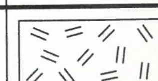
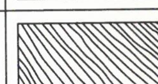
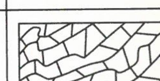
Texture		Grain size	Composition	Type of metamorphism	Comments	Rock name	Map symbol
Foliated	Mineral alignment	Fine	Mica	Regional	Low-grade metamorphism of shale	Slate	
Foliated	Mineral alignment	Fine to medium	Mica, Quartz, Feldspar, Amphibole, Garnet	(Heat and pressure increase with depth) ↓	Foliation surfaces shiny from microscopic mica crystals	Phyllite	
Foliated	Mineral alignment	Fine to medium	Mica, Quartz, Feldspar, Amphibole, Garnet, Pyroxene		Platy mica crystals visible from metamorphism of clay or feldspars	Schist	
Foliated	Banding	Medium to coarse	Mica, Quartz, Feldspar, Amphibole, Garnet, Pyroxene		High-grade metamorphism; some mica changed to feldspar; segregated by mineral type into bands	Gneiss	
Nonfoliated		Fine	Variable	Contact (Heat)	Various rocks changed by heat from nearby magma/lava	Hornfels	
Nonfoliated		Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	Quartzite	
Nonfoliated		Fine to coarse	Calcite and/or dolomite	Regional or contact	Metamorphism of limesone or dolostone	Marble	
Nonfoliated		Coarse	Various minerals in particles and matrix	Regional or contact	Pebbles may be distorted or stretched	Metaconglomerate	

Figure 12-6 Scheme for identifying metamorphic rocks.

Nonfoliated metamorphic rocks, listed in the bottom half of the chart, are best identified based on their mineral composition and resemblance to (or location near) their parent rock. For example, quartzite, metamorphosed from sandstone, looks very much like sandstone, but is denser and does not feel gritty. Marble is made up of the minerals calcite or dolomite, which react with acids such as hydrochloric acid. Therefore, marble also bubbles when it is exposed to acid. However, marble that contains a large amount of dolomite must be crushed into a powder before this effect is visible. Hornfels, a fine-grained metamorphic rock with randomly oriented grains, is difficult to identify unless it is found on the sides of an intrusion or the bottom of an extrusion.

Starting from the left side of the chart, notice that the texture (foliated or nonfoliated) is listed. The second column lists grain size, which is not usually as useful for identifying metamorphic rocks, although it may be used to describe them. The next column is *Composition*, which was discussed earlier. The *Type of Metamorphism* column tells whether a particular metamorphic rock forms by contact metamorphism or regional metamorphism. Notice that for foliated rocks it is indicated that heat and pressure increase with depth. This is a reminder of an important fact and also indicates that gneiss has experienced greater heat and pressure and thus more intense metamorphism than slate. In fact, if slate is subjected to increasing amounts of heat and pressure, it changes from slate to phyllite to schist to gneiss. The *Comments* column of this chart often indicates the parent rock.

Uses of Metamorphic Rocks

Since slate breaks into hard, thin sheets, it is often used in roofing and has been used in the making of chalkboards. Marble is used as a building stone and for making sculptures because it is durable and attractive. Quartzite is very strong and resistant to weathering, so it is also useful as a building stone. Valuable minerals such as garnet, gold, copper, zinc, tungsten, and lead are often found in or near metamorphic rocks.

Gneiss and other regional metamorphic rocks are very strong and dense as a result of forming under great pressure. This strength makes areas with metamorphic bedrock good places to build very tall or heavy buildings because the ground underneath the buildings can support a great deal of weight.

The Rock Cycle

Recall that the three main types of rocks are igneous, sedimentary, and metamorphic. Rocks are categorized and placed in these groups based on the way they formed. The *Rock Cycle in Earth's Crust*, which is found on page 6 of the *Earth Science Tables and Charts* and in Figure 12-7, can be used to help remind you how each class of rock forms, and how rocks can be transformed from one type to another. These transformations are driven by sunlight (which drives the water cycle that causes erosion—see Topic 7), heat from Earth's core (which drives plate movements—see Topic 5), and gravity (which drives erosion and causes compaction). These factors cause uplift, weathering, erosion, pressure, and melting that are responsible for rock formation. The **rock cycle** is the continuous changing and remaking of rocks.

You should remember that the rock cycle is a continuous process with no definite beginning or end, and that all rock types can be changed into all other rock types over time. By following the arrows in Figure 12-7, you can see that one way igneous rocks form is when metamorphic rocks are melted into magma, which then solidifies to form igneous rock. A sedimentary rock may be exposed to heat and/or pressure, creating a metamorphic rock. This rock can then be weathered and eroded back into sediments that can then be compacted and cemented, creating yet another sedimentary rock. Follow the other arrows in the figure to see how each of the other types of rocks can form. Be sure to note the many alternative pathways that may be taken through the middle of the diagram, in addition to those around the outside.

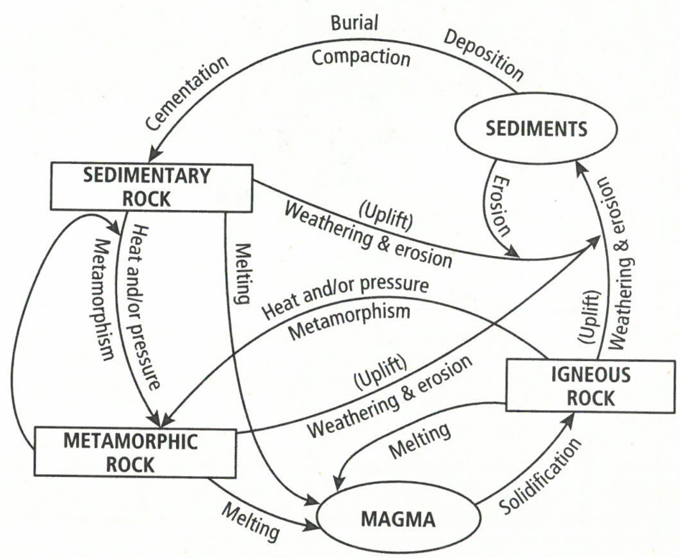


Figure 12-7 Diagram of the rock cycle.

QUESTIONS FOR SUBTOPIC A

Some questions may require the use of the *Earth Science Tables and Charts.*

Type A

1. Which of the following can change sediments into sedimentary rocks?

a. melting
b. extrusion and intrusion
c. compaction and cementation
d. recrystallization

2. Which processes are necessary for sedimentary rocks to form?

a. weathering and erosion
b. intrusion and extrusion
c. melting and solidification
d. recrystallization

3. Most sedimentary rocks are formed by

a. uplifting and melting.
b. compaction and cementation.
c. eruption of volcanoes.
d. changes deep within Earth.

4. Which process would form a sedimentary rock?

a. cooling of molten magma within Earth's crust
b. recrystallization of unmelted material within Earth's crust
c. cooling of a lava flow on Earth's surface
d. precipitation of minerals as seawater evaporates

5. A rock made of the shells of marine organisms should be classified as which of the following?

a. chemical sedimentary rock
b. metamorphic rock
c. organic sedimentary rock
d. clastic sedimentary rock

Type B

Some questions may require the use of the *Earth Science Tables and Charts.*

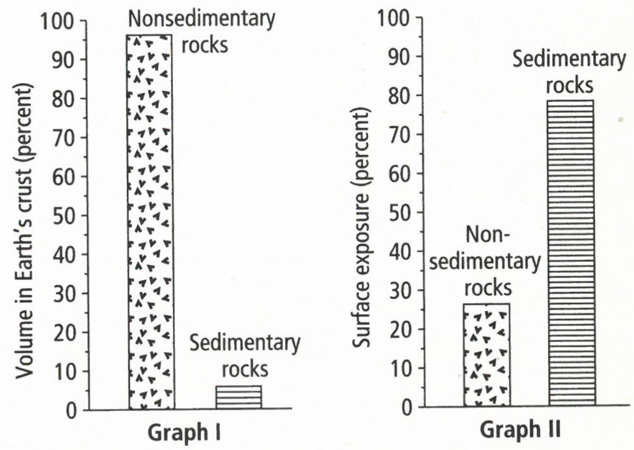
6. Which type(s) of rock can be the source of deposited sediments?

a. igneous and metamorphic rocks only
b. metamorphic and sedimentary rocks only
c. sedimentary rocks only
d. igneous, metamorphic, and sedimentary rocks

7. Rocks made directly from sediments usually contain

a. rounded particles in layers.
b. hard, intergrown crystals.
c. banded zones of minerals.
d. distorted structures.

Base your answers to questions 8 and 9 on your knowledge of Earth science and the two graphs below. Graph I represents the percentages by volume of sedimentary and nonsedimetary rocks that make up Earth's crust. Graph II represents the percentages of sedimentary and nonsedimentary rocks in rocks that are exposed at Earth's surface.



8. Approximately what percentage of Earth's crust is composed of sedimentary rocks?

a. 5%
b. 25%
c. 75%
d. 95%

9. Compare the percentage of sedimentary rocks exposed at Earth's surface with the percentage of sedimentary rocks found in Earth's crust.

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*

10. What causes the compaction of sediments?

11. How does cementation of sediments occur?

12. A geologist discovers a large deposit of rock salt in the middle of a desert. Describe how this deposit may have formed.

QUESTIONS FOR SUBTOPIC B

Type A

Some questions may require the use of the *Earth Science Tables and Charts.*

13. Which sedimentary rock is formed by the compaction and cementation of pebble-sized particles?
- **a.** shale
- **b.** sandstone
- **c.** conglomerate
- **d.** siltstone

14. Which sedimentary rock may most likely form as a result of biological processes?
- **a.** conglomerate
- **b.** siltstone
- **c.** limestone
- **d.** breccia

Base your answers to questions 15–17 on the diagram below, which represents a scheme for classifying rocks. Letters A, B, C, X, Y, and Z represent missing labels.

15. Which process would form the type of rock that is represented by circle B?
- **a.** deposition and compaction
- **b.** weathering and erosion
- **c.** melting and solidification
- **d.** faulting and folding

16. If the rock in circle C formed from limestone, it would be called
- **a.** schist.
- **b.** coal.
- **c.** marble.
- **d.** slate.

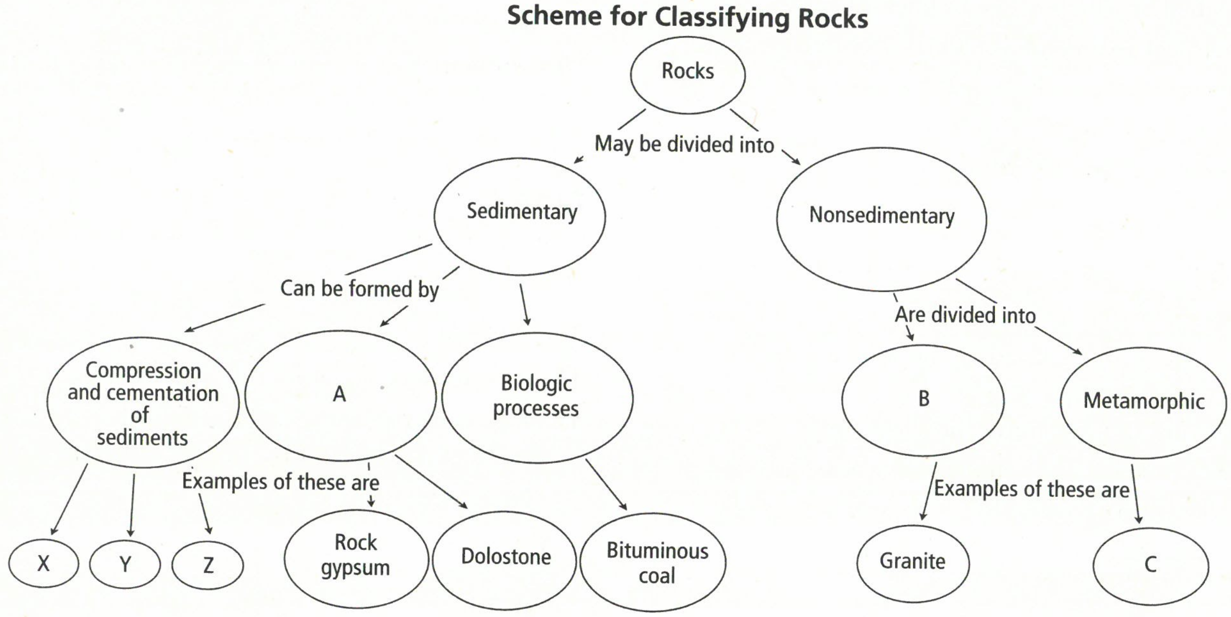
17. Which rocks could be represented by circles X, Y, and Z?
- **a.** shale, slate, and schist
- **b.** sandstone, shale, and siltstone
- **c.** coal, metaconglomerate, and rock salt
- **d.** breccia, gneiss, and rhyolite

Type B

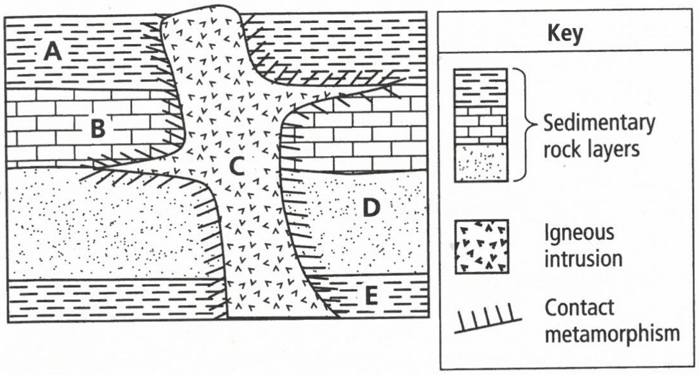
Some questions may require the use of the *Earth Science Tables and Charts.*

18. Which sedimentary rocks are clastic and consist of particles that have diameters smaller than 0.006 cm?
- **a.** conglomerate and sandstone
- **b.** siltstone and shale
- **c.** coal and breccia
- **d.** fossiliferous limestone and coal

Scheme for Classifying Rocks



Base your answers to questions 19 and 20 on the geologic cross section below. The cross section shows an outcrop in which the layers have not been overturned. Rock units are labeled A–E.



19. State the name of the sediment that was compacted to form rock unit A.

20. Describe one way in which rock unit B could have formed.

21. Which rock type is most likely to be monominerallic?

a. rock salt
b. rhyolite
c. basalt
d. conglomerate

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*

Base your answers to questions 22 and 23 on the description of the different rock samples A–E in the table below and your knowledge of Earth science.

Rock Sample	Description
A	a gray rock consisting of particles of uniform size (0.05 cm in diameter) cemented together
B	a light-colored, felsic rock consisting of coarse-grained, intergrown crystals (pink, white, and black) evenly distributed throughout the sample
C	a rock consisting of light and dark, intergrown crystals with the crystals aligned in alternating light and dark, wavy bands
D	a black, mafic rock consisting of fine-grained, dark, intergrown crystals evenly distributed throughout the sample
E	a soft, white rock consisting of one uniform material containing fossil shells

22. Describe the information in the table that indicates some of the samples in the table are most likely sedimentary rocks. Indicate the samples of sedimentary rocks.

23. Which part of the description of rock sample A can be used to identify the sample?

24. Describe the three types of sedimentary rocks and state how they are different from one another.

QUESTIONS FOR SUBTOPIC C

Type A

25. Metamorphic rocks are formed by

a. erosion of weathered rock.
b. recrystallization of heated rock.
c. cooling and solidification of magma.
d. compaction and cementation of sediments.

26. Which rock forms from the recrystallization of unmelted rock material under conditions of high temperature and pressure?

a. granite
b. gneiss
c. rock gypsum
d. coal

27. Heat and pressure due to magma intrusions may result in

a. vertical sorting.
b. graded bedding.
c. contact metamorphism.
d. chemical evaporites.

28. The diagram below represents a sample of a rock.

This rock would be classified as metamorphic because it shows

a. distorted banding.
b. an organic composition.
c. a mixture of minerals.
d. crystals from precipitation.

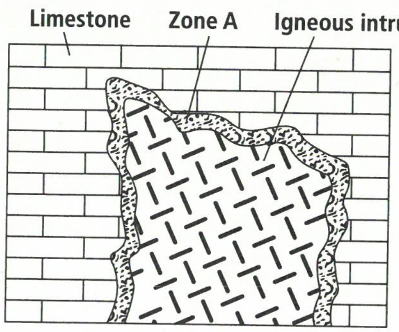
29. The minerals of many metamorphic rocks are aligned in bands as a result of

a. earthquake faulting.
b. cooling and solidification.
c. mechanical weathering.
d. heat and pressure.

Type B

Some questions may require the use of the *Earth Science Tables and Charts.*

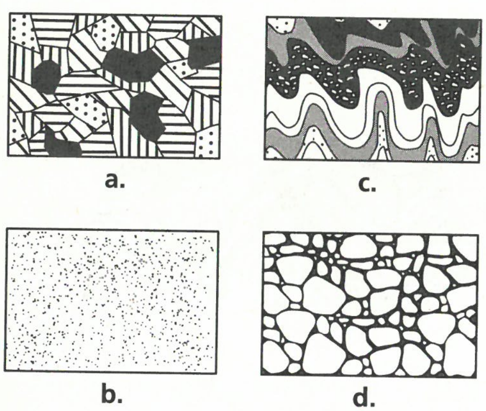
30. The geologic cross section below shows limestone that was intruded by an igneous body. Part of the limestone (zone A) was heated intensely but was not melted.



Which type of rock most likely formed in zone A?

a. gneiss
b. slate
c. marble
d. obsidian

31. The diagrams below represent actual-size rock samples. Which diagram represents the metamorphic rock gneiss? What two features allow you to determine this?



32. What is one difference between the metamorphic rocks quartzite and hornfels?

a. Hornfels is foliated; quartzite is nonfoliated.
b. Hornfels is nonfoliated; quartzite is foliated.
c. Hornfels is produced by metamorphism of various rocks; quartzite is produced by metamorphism or quartz sandstone.
d. Hornfels is coarse grained; quartzite is fine grained.

Type C

Some questions may require the use of the *Earth Science Tables and Charts.*

33. Explain the difference between regional metamorphism and contact metamorphism. Which type of metamorphism would generally produce a denser rock? Why?

34. How would you distinguish between quartzite and marble if you were a geologist in the field? The tools you have are a magnifying glass, a piece of glass, a rock hammer, and a streak plate. What other material would make your identification positive? Why?

35. What characteristics would you look for to determine if a rock was igneous, sedimentary, or metamorphic? Do *not* describe how each type of rock is formed or simply define the words *igneous, sedimentary,* and *metamorphic.*