Section 5.1

1 FOCUS

Section Objectives

5.1 **Define** mechanical weathering.
5.2 **Explain** chemical weathering.
5.3 **Identify** the factors that affect the rate of weathering.

Reading Focus

Build Vocabulary L2

Vocabulary Rating Chart Have each student construct a chart with four columns labeled Term, Can Define or Use It, Heard or Seen It, and Don't Know. Students should then write the vocabulary terms *mechanical weathering, frost wedging, talus, exfoliation,* and *chemical weathering* in column 1 and rate their knowledge of each term by putting a check in one of the other columns. Before reading the text, ask questions that help students anticipate the meaning of the terms based on prior knowledge. For example, ask: **What is a wedge used for?** *(to force objects apart)* After students have read the section, have them revise their charts.

Reading Strategy L2

a. process in which physical forces break rock into pieces without changing the rock's mineral composition
b. process in which water enters cracks in a rock, enlarges the cracks by freezing and expanding, and breaks the rock
c. large piles of rock fragments that usually form at the base of cliffs
d. process in which slabs of outer rock separate and break loose
e. the transformation of rock into one or more new compounds

5.1 Weathering

Reading Focus

Key Concepts

- What is mechanical weathering?
- What is chemical weathering?
- What factors affect the rate of weathering?

Vocabulary

- mechanical weathering
- frost wedging
- talus
- exfoliation
- chemical weathering

Reading Strategy

Building Vocabulary Copy the table. As you read the section, define each vocabulary term.

Vocabulary Term	Definition
Mechanical weathering	a. ___?___
Frost wedging	b. ___?___
Talus	c. ___?___
Exfoliation	d. ___?___
Chemical weathering	e. ___?___

Figure 1 Weathering Ice, rain, and wind are slowly breaking down the rock in this mountain. The rock fragments accumulate in sloped deposits at the base of the mountain.

Earth's surface is constantly changing. Internal forces gradually raise some parts of the surface through mountain building and volcanic activity. At the same time, external processes continually break rock apart and move the debris to lower elevations, as shown in Figure 1. The breaking down and changing of rocks at or near Earth's surface is called weathering. Weathering is a basic part of the rock cycle and a key process in the Earth system. There are two types of weathering—mechanical and chemical. Though these processes are different, they are at work at the same time.

Mechanical Weathering

Mechanical weathering occurs when physical forces break rock into smaller and smaller pieces without changing the rock's mineral composition. Each piece has the same characteristics as the original rock. Breaking a rock into smaller pieces increases the total surface area of the rock. Look at Figure 2. When rock is broken apart, more surface area is exposed to chemical weathering. **In nature, three physical processes are especially important causes of mechanical weathering: frost wedging, unloading, and biological activity.**

Mechanical Weathering and Surface Area

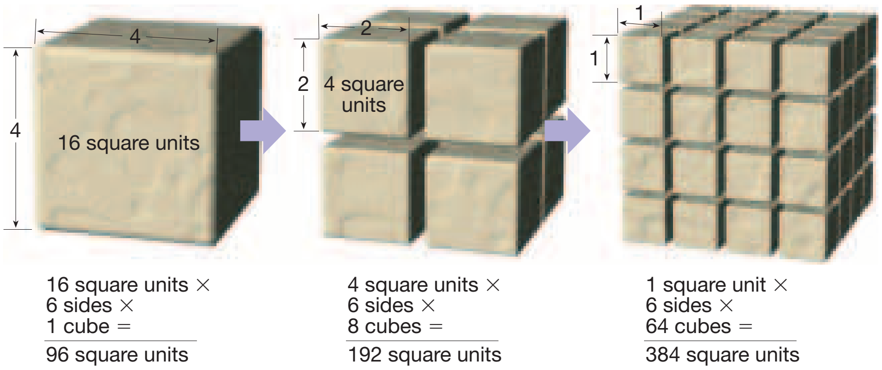


Figure 2 By breaking a rock into smaller pieces, mechanical weathering increases the rock's surface area that can be exposed to chemical weathering. **Calculating** ***Calculate the total surface area if each of the 64 cubes shown in the right diagram were broken into 8 equal-sized cubes.***

Frost Wedging When liquid water freezes, it expands by about 9 percent, exerting a tremendous outward force. This force is great enough to burst water pipes during the winter. In nature, water works its way into every crack in rock. When water freezes and expands, it enlarges the cracks. After many freeze-thaw cycles, the rock breaks into pieces. This process, which is shown in Figure 3, is called **frost wedging.** Frost wedging is most common in mountainous regions in the middle latitudes. Here daily freezing and thawing often occur. Sections of rock that are wedged loose may tumble into large piles called **talus,** which typically form at the base of steep, rocky cliffs.

Reading Checkpoint *Explain how water can cause mechanical weathering.*

Figure 3 Frost Wedging Rainwater entered cracks in this boulder. Each time the water froze, it expanded. Eventually, the boulder split.

2 INSTRUCT

Mechanical Weathering

Build Reading Literacy L1

Refer to **p. 334D** in **Chapter 12**, which provides the guidelines for outlining.

Outline Have students create an outline of Section 5.1 (pp. 126–132). Outlines should follow the head structure used in the text. Major headings are shown in green, and subheadings are shown in blue. Ask: **Based on your outlines, what do you expect to learn about in this section?** *(mechanical weathering, chemical weathering, and rates of weathering)* **Verbal**

Use Visuals L1

Figure 2 Ask: **Which of the three diagrams has the most exposed surface area?** *(the third one)* **If the diagrams were actual rocks, which one would experience the least chemical weathering?** *(the first one)* **Visual**

Build Science Skills L2

Designing Experiments ACTIVITY Have students work in small groups to design experiments showing how water expands when frozen. Students should write down each step of their procedures, listing materials used and safety measures. A sample experiment might involve pouring water into a container, placing the container in a freezer overnight, then observing the effect of the frozen water on the container. If time permits, allow students to perform their experiments. Be sure to approve all procedures beforehand. **Logical, Group**

Customize for English Language Learners

Tailor your presentation by speaking directly and simplifying the terms and sentence structures used to explain key concepts. For example, split a cause-and-effect sentence into two sentences labeled Cause and Effect. A sample cause sentence might be *Water expands when it freezes*. A sample effect sentence might be *The frozen water enlarges cracks in rocks*. Other techniques include using visual aids and body language when appropriate to emphasize important concepts. For example, you can clasp your hands together, then move them apart when discussing how water expands when it freezes.

Answer to . . .

Figure 2 *64 cubes × 8 = 512 cubes; 1 square unit/side × 6 sides/cube × 512 cubes = 768 square units*

Reading Checkpoint *Water works its way into cracks in rock. When water freezes, it expands, enlarging the cracks. After many freeze-thaw cycles, the rock breaks.*

Section 5.1 (continued)

Use Community Resources L2

Arrange for students to take a walking tour of your community to look for signs of mechanical weathering. If possible, bring along a camera or camcorder to document the field trip. Have students attempt to classify each example of mechanical weathering as frost wedging, unloading, or biological activity.
Visual

Teacher Demo

Modeling Exfoliation L2

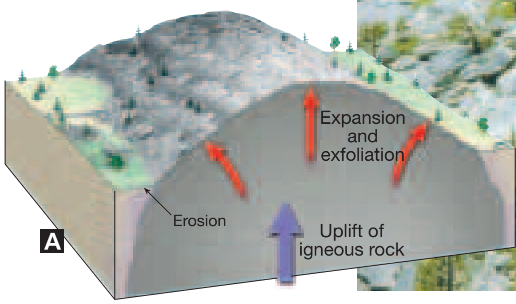
Purpose Students will observe a model of the process of exfoliation.

Materials large onion, small kitchen knife

Procedure Stand before the class and hold up a large, unpeeled onion. Cut off the top of the onion and show students its inner layers. Peel the onion, layer by layer. Wash your hands afterwards.

Expected Outcomes Have students relate the activity to Figure 4, which shows an example of exfoliation. Have them point out the onionlike layers of the Half Dome in Yosemite National Park.
Visual

Figure 4 Unloading and Exfoliation A Uplift and erosion expose a buried mass of igneous rock. Reduced pressure on the rock, called unloading, causes the outer rock layers to expand. They separate from the rest of the rock mass. This process is called exfoliation. **B** The granite layers of Half Dome in Yosemite National Park, California, are undergoing exfoliation.



Unloading Large masses of igneous rock may be exposed through uplift and erosion of overlying rocks. When that happens, the pressure exerted on the igneous rock is reduced. This is known as unloading. As illustrated in Figure 4A, unloading causes the outer layers of the rock to expand more than the rock below. Slabs of outer rock separate like the layers of an onion and break loose in a process called **exfoliation.** Exfoliation is especially common in rock masses made of granite. It often produces large, dome-shaped rock formations. Figure 4B shows one of these formations. Other important exfoliation domes are Stone Mountain, Georgia, and Liberty Cap also in Yosemite National Park.

A striking example of the weathering effects of unloading is shown in deep underground mining. Newly cut mine tunnels suddenly reduce the pressure on the surrounding rock. As a result, large rock slabs sometimes explode off the walls of the tunnels.

Biological Activity The activities of organisms, including plants, burrowing animals, and humans, can also cause mechanical weathering. As Figure 5 shows, plant roots grow into cracks in rock, wedging the rock apart as they grow. Burrowing animals move rocks to the surface, where weathering is more rapid. Decaying organisms produce compounds called acids that cause chemical weathering.

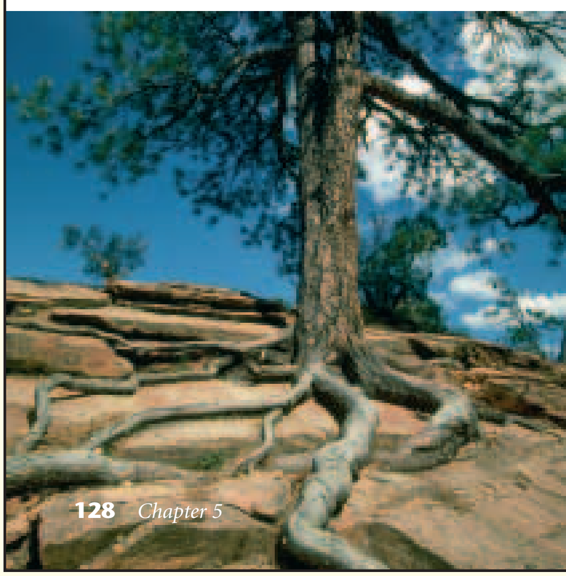


Figure 5 The roots of this tree are causing mechanical weathering by widening the cracks in the rock.

Humans accelerate mechanical weathering through deforestation and blasting in search of minerals or in the creation of new roads.

Chemical Weathering

Chemical weathering is the transformation of rock into one or more new compounds. The new compounds remain mostly unchanged as long as the environment in which they formed does not change. You can contrast chemical weathering and mechanical weathering with a sheet of paper. Tearing the paper into small pieces is like mechanical weathering of rock. Burning the paper, which changes it into carbon dioxide and water, is like chemical weathering.

Water Water is the most important agent of chemical weathering. Water promotes chemical weathering by absorbing gases from the atmosphere and the ground. These dissolved substances then chemically react with various minerals. Oxygen dissolved in water reacts easily with certain minerals, forming oxides. For example, iron-rich minerals get a yellow to reddish-brown coating of iron oxide when they react with oxygen. Iron oxide is the rust that forms when iron-containing objects are exposed to water. Figure 6A shows this rust on barrels.

Water absorbs carbon dioxide when rain falls through the atmosphere. Water that seeps through the ground also picks up carbon dioxide from decaying organic matter. The carbon dioxide dissolved in water forms carbonic acid. This is the weak acid in carbonated soft drinks. Carbonic acid reacts with many common minerals.

Reading Checkpoint *How are water, oxygen, and carbon dioxide involved in chemical weathering?*

Figure 6 **A** Oxygen reacted with the iron in these barrels, forming iron oxide, or rust. **B** This granite gravestone, placed in 1868, shows little evidence of chemical weathering. **C** The inscription date (1872) on this marble gravestone is nearly illegible due to chemical weathering.

Chemical Weathering

Build Science Skills L2

Observing Obtain a new, unrusted nail and a thoroughly rusted nail. Allow students to carefully examine both. Break the rusted nail into two pieces to emphasize how weak it is. Ask: **How do the two nails differ?** *(They differ in strength, appearance, and color.)* Have students relate their observations to chemical weathering. Ask: **What could you infer about the minerals in a rock that had the same color as the rusted nail?** *(The minerals likely contain iron that reacted with oxygen and water.)*
Visual, Kinesthetic

Facts and Figures

Weathering creates many important mineral deposits by concentrating minor amounts of metals that are scattered throughout unweathered rock into economically valuable concentrations. Such a transformation can take place in two ways. In one situation, chemical weathering coupled with downward-percolating water removes undesired materials from decomposing rock, leaving the desired elements enriched in the upper zones of the soil. The second way is basically the reverse of the first. The desirable elements that are found in low concentrations near the surface are removed and carried to lower zones, where they are redeposited and become more concentrated.

Answer to . . .

Reading Checkpoint *Water dissolves some of the minerals in rock. Oxygen dissolved in water reacts with certain minerals, forming oxides. Carbon dioxide dissolved in water forms carbonic acid, which reacts with many common minerals.*

Address Misconceptions L2

During a student's education, a good deal of emphasis is placed on the scientific method and proper investigation techniques. For this reason, many students mistakenly think that scientific knowledge advances mainly through experimentation. In fact, in several fields, including geology, observation is the key to understanding natural processes. This section offers an excellent opportunity to point out the role of observation in science. Challenge students to brainstorm other fields where observation is crucial to understanding natural processes. *(astronomy, biology, ecology)*
Verbal

Integrate Chemistry L2

Weathering of Granite The weathering of the potassium feldspar component of granite takes place as follows:

$2KAlSi_3O_8 + 2(H^+ + HCO_3^-) + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 2HCO_3^- + 4SiO_2$.

In this reaction, the hydrogen ions (H^+) attack and replace potassium ions (K^+) in the feldspar structure, thereby disrupting the crystalline network. Once removed, the potassium is available as a nutrient for plants or becomes the soluble salt potassium bicarbonate ($KHCO_3$), which may be incorporated into other minerals or carried to the ocean in dissolved form by streams. Have students summarize the chemical reaction in their own words. *(Potassium feldspar reacts with carbonic acid and water to produce mainly clay minerals.)*
Logical

Figure 7 One Effect of Acid Precipitation Acid precipitation contributed to the chemical weathering of this stone building facade in Leipzig, Germany.

Water in the atmosphere also absorbs sulfur oxides and nitrogen oxides. These oxides are produced by the burning of coal and petroleum. Through a series of chemical reactions, these pollutants are converted into acids that are the major cause of acid precipitation. Acid precipitation accelerates the chemical weathering of stone monuments and structures, such as the one shown in Figure 7.

Chemical Weathering of Granite To illustrate how chemical weathering can change the properties of rock, let's consider granite. Recall that granite consists mainly of the minerals feldspar and quartz. When granite is exposed to water containing carbonic acid, the feldspar is converted mostly to clay minerals. Quartz, in contrast, is much more resistant to carbonic acid and remains unchanged. As the feldspar slowly changes to clay, the quartz grains are released from the granite. Rivers transport some of this weathered debris to the sea. The tiny clay particles may be carried far from shore. The quartz grains are deposited near the shore where they become the main component of beaches and sand dunes.

Chemical Weathering of Silicate Minerals Recall that silicate minerals make up most of Earth's crust and are composed largely of just eight elements. When silicate minerals undergo chemical weathering, the sodium, calcium, potassium, and magnesium they contain dissolve and are carried away by groundwater. Iron reacts with oxygen, producing iron oxide. The three remaining elements are aluminum, silicon, and oxygen. These elements usually combine with water and produce clay minerals. See Table 1 for a list of products of weathering.

Table 1 Products of Weathering

Mineral	Residual Products	Materials in Solution
Quartz	Quartz grains	Silica
Feldspars	Clay minerals	Silica K^+, Na^+, Ca^{2+}
Amphibole (hornblende)	Clay minerals Limonite Hematite	Silica Ca^{2+}, Mg^{2+}
Olivine	Limonite Hematite	Silica Mg^{2+}

Spheroidal Weathering Chemical weathering can change the physical shape of rock as well as its chemical composition. For example, when water enters along the joints in a rock, it weathers the corners and edges most rapidly. These parts of the rock have a greater surface area than the faces have. As a result, the corners and edges become more rounded. The rock takes on a spherical shape, as shown in Figure 8A. This process is called spheroidal weathering.

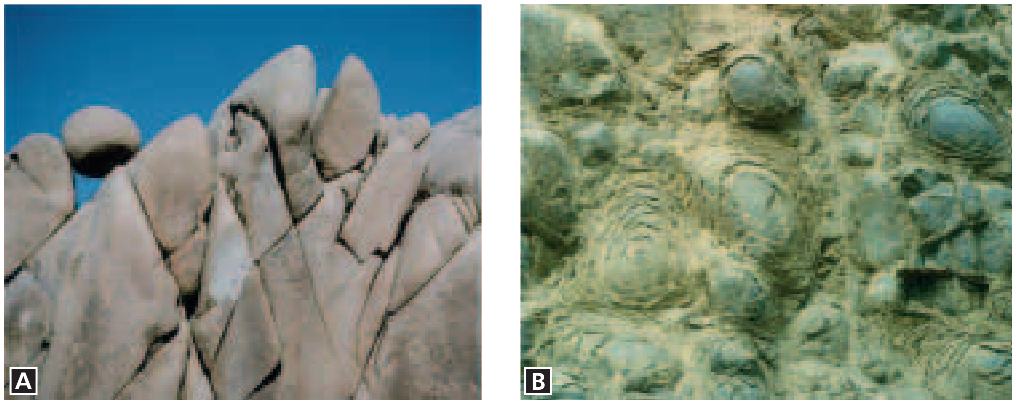


Figure 8 Spheroidal Weathering A The edges of these granite rocks in California's Joshua Tree National Monument were rounded through spheroidal weathering. **B** Spheroidal weathering has caused the outer layers of this rock to loosen and separate.

As Figure 8B shows, spheroidal weathering sometimes causes the outer layers of a rock to separate from the rock's main body. This can happen when the minerals in the rock turn to clay, which swells by adding water. The swelling exerts a force that causes the layers to break loose and fall off. This allows chemical weathering to penetrate deeper into the boulder. Although the effects of this type of spheroidal weathering resemble exfoliation, the two processes are different. Spheroidal weathering is a form of chemical weathering. Exfoliation is caused by unloading. The layers that separate from the rock are not chemically changed.

Rate of Weathering

Mechanical weathering affects the rate of chemical weathering. By breaking rock into smaller pieces, mechanical weathering accelerates chemical weathering by increasing the surface area of exposed rock. **Two other factors that affect the rate of weathering are rock characteristics and climate.**

Rock Characteristics

Physical characteristics of rock, such as cracks, are important in weathering because they influence the ability of water to penetrate rock. However, a rock's mineral composition also dramatically affects its rate of weathering. You can see this by visiting a cemetery and comparing old gravestones made from different rock types. Gravestones made of granite, like the one in Figure 6B on page 129, are relatively resistant to chemical weathering. You can easily read the inscriptions on a granite gravestone that is over 100 years old. In contrast, marble gravestones undergo much more rapid chemical weathering, as shown in Figure 6C on page 129. Marble is composed of calcite (calcium carbonate), which easily dissolves even in weak acids.

Use Visuals L1

Figure 8 Have students compare Figure 8 to Figure 4 on p. 128. Have them discuss the similarities and differences between spheroidal weathering and exfoliation. *(Both are types of weathering that give rock a layered appearance. Spheroidal weathering is a form of chemical weathering. Thus, the composition of the rock changes. Exfoliation is a type of mechanical weathering; the composition of the rock does not change.)*
Visual, Verbal

Rate of Weathering

Build Science Skills L2

Inferring Hold up an atlas in front of the class. Select an area and briefly describe its climate in terms of hot and wet, cold and dry, hot and dry, and so on. Have students infer rates of weathering for each location. *(In general, areas that are hot and wet have higher rates of weathering than do areas that are cooler and drier.)*
Logical, Visual

Section 5.1 (continued)

Build Science Skills L2

Communicating Results Show students a copy or transparency of Bowen's reaction series. Have them note the order of crystallization of minerals. Students can then use the series to sequence the resistance of silicates to weathering, starting with the least resistant mineral. *(olivine, pyroxene, amphibole, biotite mica, potassium feldspar, muscovite mica, and quartz)*
Verbal

3 ASSESS

Evaluate Understanding L2

Have students describe the relationship between burning coal and chemical weathering. *(Oxides produced by burning coal react with water in the atmosphere to create acid precipitation. Acid precipitation, in turn, accelerates rates of chemical weathering.)*

Reteach L1

Give students examples of different types of weathering, such as unloading and spheroidal weathering, and have them classify the examples as mechanical or chemical.

Math Practice

Solutions L2

7. diameter = 2 m; radius = 1 m; area of sphere = $4\pi(1\ m)^2 = 4\pi\ m^2$ = 12.57 m^2; area of two hemispheres = area of sphere + (2 × area of circle) = $4\pi\ m^2 + [2 \times \pi(1\ m)^2] = 4\pi\ m^2 + 2\pi\ m^2 = 6\pi\ m^2 = 18.85\ m^2$

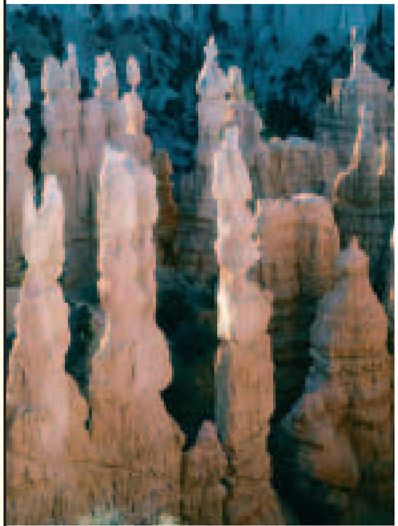


Figure 9 These boldly sculpted pinnacles in Bryce Canyon National Park show differential weathering. **Drawing Conclusions** ***In which parts of these formations is weathering happening most rapidly?***

Silicates are the most abundant mineral group. Silicates weather in the same sequence as their order of crystallization. Olivine crystallizes first and weathers most rapidly. Quartz, which crystallizes last, is the most resistant to weathering.

Climate Climatic factors, especially temperature and moisture, have a strong effect on the rate of weathering. For example, these factors control the frequency of freeze-thaw cycles, which affect the amount of frost wedging. Temperature and moisture also affect the rate of chemical weathering. They influence the kind of vegetation and how much is present. Regions with lush vegetation generally have a thick layer of soil rich in decaying organic matter that releases acids into the water.

The climate most favorable for chemical weathering has high temperatures and abundant moisture. So, chemical weathering is very slow in arid regions. It is also slow in polar regions because the low temperatures there keep moisture locked up as ice.

Differential Weathering Different parts of a rock mass often weather at different rates. This process, called differential weathering, has several causes. Differences in mineral composition are one cause. More resistant rock protrudes as pinnacles, or high peaks, such as those shown in Figure 9. Another cause is the variations in the number and spacing of cracks in different parts of a rock mass.

Section 5.1 Assessment

Reviewing Concepts

1. What happens to a rock's mineral composition during mechanical weathering?
2. What is unloading? How does it contribute to weathering?
3. How does chemical weathering affect the compounds in rock?
4. Name two rock characteristics and two climatic factors that affect the rate of weathering.

Critical Thinking

5. **Using Analogies** Think about the following processes: dissolving a piece of rock salt in a pan of water and grinding a peach pit in a garbage disposal. Which process is more like mechanical weathering, and which is more like chemical weathering?
6. **Applying Concepts** The level of carbon dioxide in the atmosphere is increasing. How might this affect the rate of chemical weathering of Earth's surface rocks? Explain your reasoning.

Math Practice

7. Suppose frost wedging splits a spherical rock 2 m in diameter into two equal-sized hemispheres. Calculate the total surface area of the original rock and of the two hemispheres. (The area of a circle = πr^2, and the surface area of a sphere = $4\pi r^2$, where r is the radius.)

Section 5.1 Assessment

1. It does not change.
2. Unloading is the reduction in pressure that happens when a mass of rock is exposed. It causes the outer layers of the rock to expand, which makes slabs of outer rock separate and break loose.
3. It transforms them into one or more new compounds.
4. Rock characteristics include cracks and mineral composition; climatic factors include temperature and moisture.
5. mechanical weathering—grinding a peach pit in a garbage disposal; chemical weathering—dissolving a piece of rock in a pan of vinegar
6. An increased level of carbon dioxide should result in higher levels of carbonic acid, which reacts with many common minerals. Therefore, the rate of chemical weathering should increase.

Answer to . . .

Figure 9 *The parts where the formations are thinnest weather most rapidly.*