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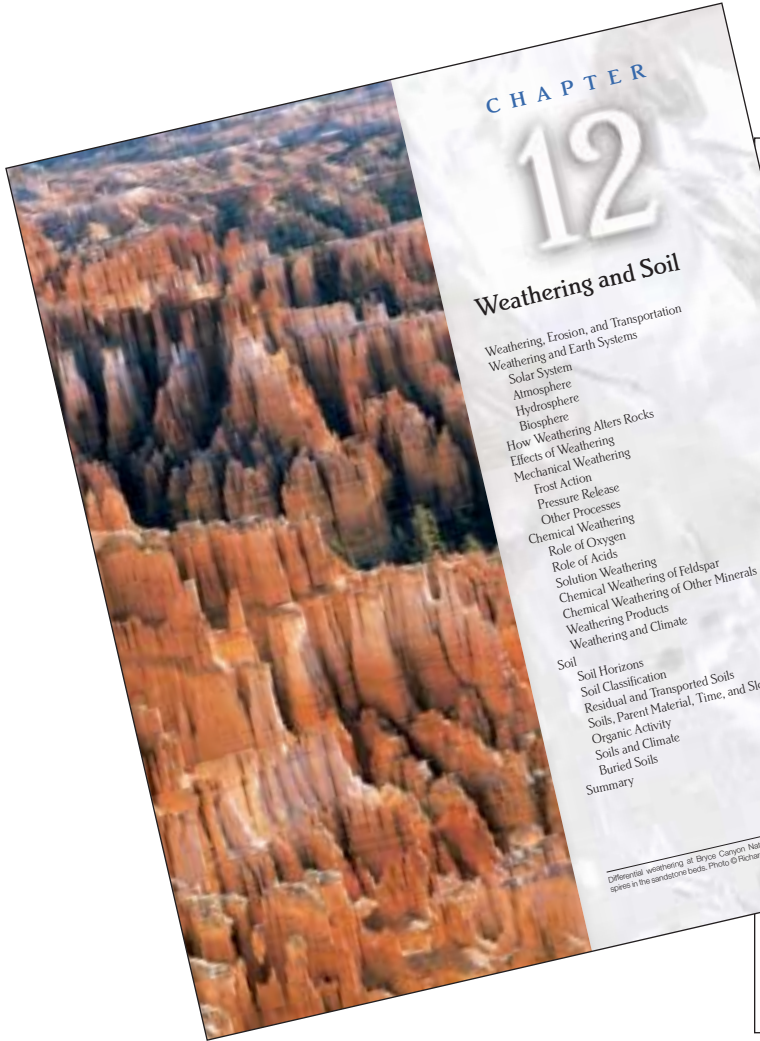
- The Earth in Space 550
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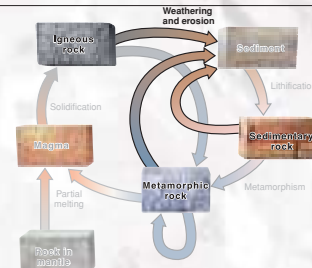
Glossary G-1

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In this chapter, you will study several visible signs of weathering in the world around you, including the cliffs and slopes of the Grand Canyon and the rounded edges of boulders. As you study these features, keep in mind that weathering processes made the planet suitable for human habitation. From the weathering of rock eventually came the development of soil, upon which the world's food supply depends.

How does rock weather? You learned in chapters 10 and 11 that the minerals making up igneous rocks crystallize at relatively high temperatures and sometimes at high pressures as magma and lava cool. Although these minerals are stable when formed, most of them are not stable during prolonged exposure at the surface. In this chapter, you see how minerals and change when they are subjected to the physical and chemical conditions existing at the surface. Rocks undergo mechanical weathering (physical disintegration) and chemical weathering (decomposition) as they are attacked by air, water, microorganisms. Your knowledge of the chemical composition and atomic structure of minerals will help you understand the processes that occur during chemical weathering. Weathering processes create sediments (primarily mud and silt) and soil. Sedimentary rocks, which form from sediments, are discussed in chapter 14. In a general sense, weathering is the process for erosion and is a fundamental part of the rock cycle, transforming rocks into the raw material that



eventually becomes sedimentary rocks. Through weathering, there are important links between the rock cycle and the atmosphere and biosphere.

### WEATHERING, EROSION, AND TRANSPORTATION

The Earth's surface is constantly being changed by weathering, erosion, and transportation. Temperature, other environmental factors, and time can decompose and disintegrate into smaller particles that alter rock weathering, erosion, and transportation.

Weathering refers to the group of destructive physical and chemical character of rock. For example, if you abandon a car, particularly the paint will flake off and the metal will rust. Similarly, the tightly bound particles of a rock are loosened and altered to new minerals during weathering. Weathering occurs on rocks that are either stationary or moving.

**Erosion** is the picking up or physical removal of rock particles by an agent such as running water or glaciers. Weathering helps break down a solid rock into loose particles that are easily eroded. Rainwater flowing down a cliff or hillside removes the loose particles produced by weathering. Similarly, if you sandblast rust off of a car, erosion takes place.

After a rock fragment is picked up (eroded), it is transported. **Transportation** is the movement of eroded particles by agents such as rivers, waves, glaciers, or wind. Weathering processes continue during transportation. A boulder being transported by a stream can be physically worn down and chemically altered as it is carried along by the water. In the car analogy, transportation would take place when a stream of rust-bearing water flows away from a car in which rust is being hoisted off.

### WEATHERING AND EARTH SYSTEMS

#### Solar System

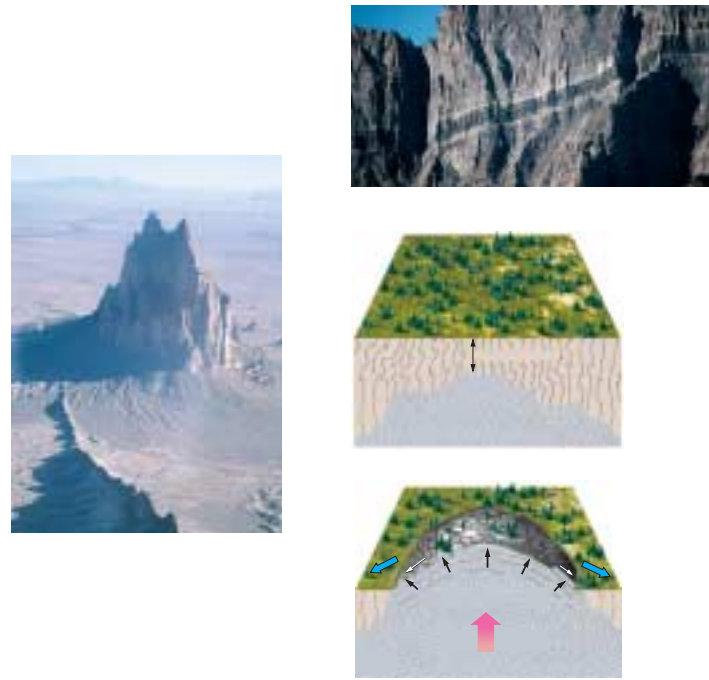
Weathering, as we know it on Earth, does not take place on any other body in the solar system. It takes place on Earth because of our atmosphere (which contains oxygen and carbon dioxide) and the abundance of water. Mars has features that indicate water flowed there in the distant past (see box 16.3). Although Mars no longer has surface water, it does have an atmosphere. Winds on Mars, sometimes several times faster than hurricanes on Earth, transport fine-grained material and erode by sandblasting the barren surface (see box 18.3).

- In the earthquake chapter (chapter 7), we have a discussion and photo of the November, 2002, Denali earthquake in Alaska. We have added new information on how an earthquake-triggered submarine landslide may have increased the size of the 1998 Papua, New Guinea, tsunami. The earthquake prediction section was substantially rewritten.
- Some of the descriptions of the geologic occurrence of geologic resources have been moved from chapter 21 (geologic resources) to appropriate chapters. For instance, the portion on ore deposits associated with hydrothermal activity has been moved to chapter 15. This is in response to many instructors who don't have time to cover chapter 21 but nevertheless want important resources to be part of their courses.

## KEY FEATURES

Features that will capture and maintain a student's attention include:

- Each chapter begins with a statement of the purpose of the chapter and its relationship with other chapters. This is usually followed by a section showing how the chapter's material relates to Earth systems.
- Geology is a visually oriented science. The book contains four hundred fifty-seven photographs and four hundred fifty illustrations. The art pieces are vital to understanding the concepts being discussed, so they must be straightforward and uncluttered yet visually appealing. We strive to have the best photographs possible so they are the next best thing to seeing geology on a field trip.



- “In Greater Depth” boxes discuss phenomena that are not necessarily covered in a geology course (e.g., *Precious Gems*) or present material in greater depth (e.g., *Calculating the Age of a Rock*).

## 15.3 IN GREATER DEPTH

### Metamorphic Facies and the Relationship to Plate Tectonics

**D**uring the early part of the twentieth century, geologists in Scandinavia introduced the concept of metamorphic facies. They noted that metamorphosed basalts contained a particular set of minerals in some parts of Scandinavia, but in other regions, the minerals in metabasalts were quite different. As these rocks were chemically similar, the different mineral assemblages were regarded as indicating significantly different pressure and temperature conditions during metamorphism. Rocks having the same mineral assemblage are regarded as belonging to the same **metamorphic facies**, implying that they formed under broadly similar pressure and temperature conditions. The name for each facies is based on the assemblage of minerals or the name of a rock common to that facies. For instance, a metabasalt composed mostly of the minerals chlorite, actinolite, and epidote (all of which are green minerals) belongs to the *greenschist facies*. On the other hand, rocks of the same chemical composition (metabasalts) belonging to the *amphibolite facies* are largely made up of hornblende and garnet. (Do not try to remember the names of the facies or their compositions; your aim should be to understand the concept.)

Based on the geologic setting, early workers inferred that the temperature conditions during metamorphism were lower for the greenschist facies than for the amphibolite facies. Laboratory work has since confirmed this as well as determined the pressure and temperature *stability fields* for each of the facies (box figure 1).

The concept of metamorphic facies is analogous to defining climatic zones by the combinations of plants found in each zone. A place where ferns, palm trees, and vines flourish corresponds to a climate with warm temperatures and abundant rainfall. On the other hand, a combination of palm trees, cactus, and sagebrush implies a hot, dry climate.

By identifying the metamorphic facies of rocks presently cropping out on the surface, geologists can infer, within broad limits, the depth at which metamorphism took place. They may also (again, within broad limits) be able to determine the corresponding temperature.

The concept of metamorphic facies preceded plate-tectonic theory by several decades. Although earlier geologists were able to relate the individual facies to pressure and temperature combinations, they had no satisfactory explanation for the environments that produced the various combinations. Figure 15.15, which relates the temperatures of regional metamorphism to plate tectonics, may be used to infer the environment for each of the metamorphic facies shown in box figure 1. Box figure 2 shows the likely distribution of metamorphic facies across the same convergent boundary as in figure 15.15.

If one were to determine the geothermal gradient represented by the three vertical lines marked A, B, and C in figure 15.15 and box figure 2, the temperatures for particular depths should plot on the corresponding arrows shown in box figure 1.

**BOX 15.3 — Figure 1**  
The metamorphic facies. Facies are named after minerals (prehnite, zeolite, pumpellyite) or rock types (e.g., blueschist, granulite). Boundaries between facies are approximate. The arrows represent increases in temperature with depth for the three lines labeled A, B, C in figure 2 and in figure 15.15. From W. G. Ernst, *Metamorphism and Plate Tectonic Regimes*. Stony Brook, Pa.: Dowden, Hutchinson & Ross, 1975, p. 428. Reprinted by permission of the publisher.

**BOX 15.3 — Figure 2**  
Schematic representation of the distribution of facies across a convergent plate boundary. From W. G. Ernst, *Metamorphism and Plate Tectonic Regimes*. Stony Brook, Pa.: Dowden, Hutchinson & Ross, 1975, p. 428. Reprinted by permission of the publisher.

- “Environmental Geology” boxes discuss topics that relate the chapter material to environmental issues, including impact on humans (e.g., *Radon—A Radioactive Health Hazard*).

## 10.1 ENVIRONMENTAL GEOLOGY

### Mount St. Helens Blows Up

**B**efore 1980, Mount St. Helens, in southern Washington, had not erupted since 1857. On March 27, 1980, ash and steam eruptions began and continued for the next six weeks. These were minor eruptions in which magma was not erupted. Rather, they were due to exploding gas blasting out the volcano's previously formed rock. However, the steam and the pattern of earthquakes indicated magma was working its way upward beneath the volcano.

After several weeks, the peak began swelling—like a balloon being inflated—indicating magma was now inside the volcano. The northern flank of the volcano bulged outward at a rate of 1.5 meters per day. Bulging continued until the surface of the northern slope was displaced outward over a hundred meters from its original position. The bulge was too steep to be stable, and the U.S. Geological Survey warned of another hazard—a mammoth landslide.

On May 18, a monumental blast destroyed the summit and north flank of Mount St. Helens (see figure 10.1). Seconds after the eruption began, an area extending northward 10 kilometers was stripped of all vegetation and soil.

Although the sequence of events was exceedingly rapid, it is now clear what happened (box figure 1). A fairly strong earthquake loosened the bulging north slope, triggering a landslide. The landslide, known as a *debris avalanche*, moved at speeds of over 160 kilometers per hour (100 mph). It was one of the largest landslides ever to occur, but it was eclipsed by the huge eruption that followed. The landslide stripped away the lid on the magma chamber, and because of the reduced pressure, the previously dissolved gases in the magma exploded (figure 10.1A). The violent froth of gas and magma blasted away the mountain's north flank and roared outward at up to 1,000 kilometers per hour (600 mph). The huge

lateral blast of hot gas and volcanic rock debris killed everything near the volcano and, beyond the 10-kilometer scorched zone knocked down every tree in the forest.

For the next 30 hours, exploding gases propelled frothing magma and volcanic ash vertically into the high atmosphere. The mushroom-shaped cloud of ash was blown northwesterward by winds. A rain of ash went on for days, causing damage as far away as Montana. Volcanic mudflows also caused damage during and after the eruption. The mudflows resulted from water from melted snow and glacier ice mixing with volcanic debris to form a slurry having the consistency of wet cement. Mudflows flowed down river valleys, carrying away steel bridges and other structures.

Damage was in the hundreds of millions of dollars, and 63 people were killed. The death toll might have been much worse had not scientists warned public officials about the potential hazards causing them to evacuate the danger zone before the eruption. For comparison, 29,000 people were killed during an eruption of Mount Pelée (described later in this chapter), and 23,000 lives were lost in a 1985 volcanic mudflow in Colombia.

Perhaps Mount St. Helens will remain quiescent for decades or a century. Other volcanoes in the Pacific Northwest, however, could erupt and be disastrous to nearby cities. Seattle and Tacoma are close to Mount Rainier. Mount Hood is practically in Portland, Oregon's suburbs. Vancouver, British Columbia, could be in danger if either Mount Garibaldi to the north or Mount Baker in Washington to the south erupt.

**Additional Resource**  
Mount St. Helens Home Page  
[www.volcanoworld.org/vwdocs/msh/msh.html](http://www.volcanoworld.org/vwdocs/msh/msh.html)

**BOX 10.1 — Figure 1**  
Sequence of events at Mount St. Helens, May 18, 1980. (A) Just before the eruption. (B) The landslide relieves the pressure on the underlying magma. (C) Magma blasts outward.

- “Planetary Geology” boxes compare features elsewhere in the solar system to their Earthly counterparts (e.g., *Stream Features on the Planet Mars*).

## PLANETARY GEOLOGY 14.2

### Sedimentary Rocks: The Key To Mars' Past

**S**edimentary rocks on Mars will provide the historical record to help geologists unravel the planet's past. The latest images from the Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor spacecraft reveal thin (a few to about 200 meters thick) repeated layers of horizontal sediment. The most extensive exposures of the layered deposits on Mars are in the western Candor Chasma (box figure 1), where exposures of horizontal layers have been exposed through erosion. These laterally continuous layers are similar to sedimentary beds that were deposited in shallow seas on Earth and are now exposed in places like the Grand Canyon. The widespread occurrence of the sedimentary layers in craters and low-lying areas on Mars suggests that the sediment may have been deposited by water. Deep seas or oceans usually deposit thick layers of sediment, whereas lakes and shallow seas typically deposit relatively thin horizontal layers, such as those observed in the western Candor Chasma area. There are other processes, however, that could deposit layered sediments, such as explosive volcanic eruptions and dust storms.

Violent volcanic eruptions of pyroclastic material can produce horizontally layered deposits of repeated beds, however, it is unlikely that this type of deposition is responsible for the widespread uniformly thick layers observed on Mars because pyroclastic deposits are usually quite thick near the vent and much thinner away from the volcano. Also, no volcanic vents have been observed nearby that would have been capable of such a large eruption.

Large dust storms occur on Mars today and undoubtedly occurred in the past. If the layered sediments were deposited by the

wind, the layers should contain cross-bedding structures similar to those shown in figure 14.27. The fact that cross-bedding has not been observed and that wind usually does not deposit laterally continuous, regularly repeated layers of sediment argue for deposition in water.

Scientists are excited by these latest images of layered sedimentary rocks from Mars that are similar to sediments deposited in lakes or shallow seas on Earth. Was there once water and life on Mars? Because most of the evidence of past life, such as fossils, is found in sedimentary rocks that formed in lakes and shallow seas on Earth, the Candor Chasma area may be the best place to look for evidence that life once existed on Mars.

**Additional Resources**  
M. C. Malin and K. S. Edgett. 2000. Sedimentary rocks of early Mars. *Science* 290 (5498): 1927–37.  
<http://science.nasa.gov/headlines>  
Information about the Mars Global Surveyor and the latest images from the Mars Orbiter Camera are available at the Jet Propulsion Laboratory/NASA website.  
<http://mars.jpl.nasa.gov/mgs/>  
Visit the Main Space Science Systems website for an extensive collection of archived Mars Orbiter Camera images.  
[www.msss.com](http://www.msss.com)

**BOX 14.2—Figure 1**  
Layered sedimentary rock exposed in the Candor Chasma. Each layer is approximately 10 meters thick. Photo by NASA/JPL/Malin Space Systems

- “Earth Systems” boxes are new in the sixth edition and highlight the interrelationships between the geosphere, the atmosphere, and other Earth systems (e.g., *Oxygen Isotopes and Climate Change*).

## 8.1 EARTH SYSTEMS

### Highlights Of The Evolution Of Life Through Time

**T**he history of the biosphere is preserved in the fossil record. Through fossils, we can determine their place in the evolution of plants and animals as well as get clues as to how extinct creatures lived. The oldest readily identifiable fossils found are prokaryotes—microscopic, single-celled organisms that lack a nucleus. These date back to around 3.5 billion years (b.y.) ago, so life on Earth is at least that old. It is likely that even more primitive organisms date back further in time but are not preserved in the fossil record. Fossils of much more complex, single-celled organisms that contained a nucleus (eukaryotes) are found in rocks as old as 1.4 b.y. These are the earliest living creatures to have reproduced sexually. Colonies of unicellular organisms likely evolved into multicellular organisms. Multicellular algae fossils date back at least a billion years.

Imprints of larger multicellular creatures appear in rocks of late Precambrian age, about 700 to 550 million years ago (m.y.). These resemble jellyfish and worms.

Sedimentary rocks from the Paleozoic, Mesozoic, and Cenozoic Eras have abundant fossils. Large numbers of fossils appeared early in the Cambrian Period. Trilobites (figure 8.19) evolved into many species and were particularly abundant during the Cambrian. Trilobites were arthropods that crawled on muddy sea floors and are the oldest fossils with eyes. They became less significant later in the Paleozoic, and finally, all trilobites became extinct by the end of the Paleozoic.

The most primitive fish, the first vertebrates, date back to late in the Cambrian. Fish similar to presently living species (including sharks) flourished during the Devonian (named after Devonshire, England). The Devonian is often called the “age of fish.” Amphibians evolved from fish that had developed lungs late in the Devonian. These were the first land vertebrates. However, invertebrate land animals date back to the latest Cambrian, and land plants first appeared in the Ordovician. Reptiles and early ancestors of mammals evolved from amphibians in Pennsylvania time or perhaps earlier.

The Paleozoic ended with the greatest mass extinction ever to occur on Earth. Over 95% of species that existed died out.

During the Mesozoic, new creatures evolved to occupy ecological domains left vacant by extinct creatures. Dinosaurs and mammals evolved from the animal species that survived the great extinction. Dinosaurs became the dominant group of land animals. Birds likely evolved from dinosaurs in the Mesozoic. Large, now extinct, marine reptiles lived in Mesozoic seas. Ichthyosaurs, for example, were up to 20 meters long, had dolphinlike bodies, and were probably fast swimmers. Flying reptiles, pterosaurs, some of which had wingspans of almost 10 meters, soared through the air.

The Cretaceous Period (and Mesozoic Era) ended with the second-largest mass extinction (around 75% of species were wiped out).

The Cenozoic is often called the age of mammals. Mammals, which were small, insignificant creatures during the Mesozoic, evolved into the many groups of mammals (whales, bats, canines, cats, elephants, primates, and so forth) that occupy Earth at present. Many species of mammals evolved and became extinct throughout the Cenozoic. Hominids (modern humans and our extinct ancestors) have a fossil record dating back 4 m.y. and likely evolved from a now extinct ancestor common to hominids, chimps, and other apes.

We tend to think of mammals' evolution as being the great success story (because we are mammals); mammals, however, pale in comparison to insects. Insects have been around far longer than mammals and now account for an estimated 1 million species.

**Additional Resource**  
University of California Museum of Paleontology  
Find the fossils mentioned here.  
[www.ucmp.berkeley.edu](http://www.ucmp.berkeley.edu)

**Paleontologists**, specialists in the study of fossils, have patiently and meticulously over the years identified many thousands of species of fossils and determined the time sequence in which they existed. Therefore, sedimentary rock layers anywhere in the world can be assigned to their correct place in geologic history by identifying the fossils they contain.

Ideally, a geologist hopes to find an **index fossil**, a fossil from a very short-lived, geographically widespread species known to exist during a specific period of geologic time. A single index fossil allows the geologist to correlate the rock in which it is found with all other rock layers in the world containing that fossil.

Many fossils are of little use in time determination because the species thrived during too large a portion of geologic time. Sharks, for instance, have been in the oceans for a long time, so discovering a shark's tooth in a rock is not very helpful in determining the rock's relative age.

A geologist is likely to find a **fossil assemblage**, several different fossil species in a rock layer. A fossil assemblage is generally more useful for dating rocks than a single fossil is, because the sediment must have been deposited at a time when all the species represented existed (figure 8.18).

Some fossils are restricted to geographic occurrence, representing organisms adapted to special environments. But many former organisms apparently lived over most of the Earth, and fossil assemblages from these may be used for worldwide correlation. Fossils in the lowermost horizontal layers of the Grand Canyon are comparable to ones collected in Wales, Great Britain, and many other places in the world (the trilobites in figure 8.19 are an

- “Web” boxes summarize material that is further explained on the book’s Online Learning Center.


## WEB BOX

# 9.7

## On Time with Quartz

Ever wonder why your watch has “quartz” printed on it? A small slice of quartz in the watch works to keep incredibly accurate time. This is because a small electric current applied to the quartz causes it to vibrate at a very precise rate (close to 100,000 vibrations per second).

**For the full story, go to:**  
[www.mhhe.com/plummer10e](http://www.mhhe.com/plummer10e)

- The Internet has revolutionized the way we obtain knowledge, and this book makes full use of its potential to help students learn. We have URLs for appropriate websites throughout the book—within the main body of text, at the end of many boxes, and at the end of chapters. We have made the process student-friendly by having all websites that we mention in the book posted as links in this book’s Online Learning Center website. (We also include all URLs in the textbook for those who wish to go directly to a site.)
- Internet exercises are located on the text’s Online Learning Center and allow students to investigate appropriate sites as well as raise interest for further, independent exploration on a topic. The Online Learning Center also includes additional readings and video resources. By placing these on the website, we can update them after the book has been published. We expect to add more sites and exercises to our website as we discover new ones after the book has gone to press. The Online Learning Center also features online quizzes, flashcards, animations, and other interactive items to help a student succeed in a geology course.
- Chapter resources include: *Summary*, which brings together and summarizes the major concepts of the chapter; *Terms to Remember*, which has all of the boldfaced terms covered in the chapter so that students can verify their understanding of the concepts behind each term; *Testing Your Knowledge*, a quiz that students can use to gauge their understanding of the chapter (The answers to the multiple choice portions are posted on the website.); *Expanding Your Knowledge*, which is intended to stimulate a student’s critical thinking by asking questions with answers that are not found in the textbook; and *Exploring Web Resources*, which describes some of the best sites on the web that relate to the chapter.
- *Animations* list the animations that were created for the chapter and are accessible on the Online Learning Center. A special animation icon  has been placed beside every figure that has a corresponding animation on the Online Learning Center.

## SUPPLEMENTS

The sixth edition provides a complete physical geology package for the student and instructor.

### For the Student

- *Student Interactive CD-ROM*

This interactive CD-ROM can be packaged with every new copy of McGeary: *Earth Revealed*, 6th edition. This CD-ROM features chapter-based quizzes, chapter-based text web exercises, student tutorial, animations and PowerPoints of all the images found in the textbook.

- *Online Learning Center* at [www.mhhe.com/mcgeary6e/](http://www.mhhe.com/mcgeary6e/).

This comprehensive site gives you the opportunity to further explore topics presented in the book using the Internet. The site contains several types of interactive quizzes with immediate feedback, animations, flashcards, Internet activities, additional readings, answers to selected end-of-chapter questions, and a career center. We’ve integrated *PowerWeb: Geology’s* information and timely world news, web links, and much more into the site to make these valuable resources easily accessible to students.



### For the Instructor

- *Online Learning Center* at [www.mhhe.com/mcgeary6e/](http://www.mhhe.com/mcgeary6e/).

Included in the password-protected Instructor’s Edition is an Instructor’s Manual that contains a chapter overview, a list of changes, learning objectives, a list of boxes, discussion and essay questions, and selected readings. The Online Learning Center also contains PowerPoint Lecture Outlines, as well as the list of slides and transparencies that accompany the sixth edition.

- *Digital Content Manager CD-ROM*



This CD-ROM contains every illustration, photograph, and table from the text, sixty-nine animations, active art, lecture outlines, and two hundred additional photos. The software makes customizing your multimedia presentation easy. You can organize figures in any order you want; add labels, lines, and your own artwork; integrate material from other sources; edit and annotate lecture notes; and have the option of placing your multimedia lecture into another presentation program such as PowerPoint.

- *Instructor's Testing and Resource CD-ROM*

This cross-platform CD-ROM provides a wealth of resources for the instructor. Supplements featured on this CD-ROM include a computerized test bank using Brownstone Diploma testing software to quickly create customized exams. This user-friendly program allows instructors to search for questions by topic, format, or difficulty level; edit existing questions or add new ones; and scramble questions and answer keys for multiple versions of the same test.

Other assets on the Instructor's Testing and Resource CD-ROM are grouped within easy-to-use folders. The Instructor's Manual and Test Item File are available in both Word and PDF formats. Word files of the test bank are included for those instructors who prefer to work outside of the test-generator software.

- *250 Transparencies*

Included are two hundred and fifty illustrations from the text, all enlarged for excellent visibility in the classroom.

- *100 Slides*

One hundred slides include illustrations and photographs from the text.

- New edition of *Laboratory Manual for Physical Geology*, 12th ed., by Zumberge, Rutherford, and Carter, ISBN 0-07-282689-4

- *Laboratory Manual for Physical Geology*, 4th ed., by Jones and Jones, ISBN 0-07-243655-7
- *Course Management Systems*

The Online Learning Center can be easily loaded into course management systems such as:

- Blackboard
- WebCT
- eCollege
- PageOut

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