Preface

Physical Geology: Earth Revealed is a classic in introductory geology classes that has evolved into a market-leading text read by thousands of students. In keeping with this long-standing tradition, the sixth edition has been updated to include the most current information from the various subdisciplines that comprise physical geology.

APPROACH

Our purpose is to clearly present the various aspects of physical geology so that students can understand the logic of what scientists have discovered as well as the elegant way the parts are interrelated to explain how Earth, as a whole, works. This approach is epitomized by our treatment of plate tectonics. In the first chapter, we present an overview of plate tectonics. In appropriate subsequent chapters, we show how the topic fits into plate-tectonic theory. (For instance, in chapter 11 on igneous activity, we describe in detail how magmas are generated at plate boundaries.) We reserve our comprehensive treatment of plate tectonics for a chapter near the end of the book. By this time, the student who retains the information from the earlier chapters can see how the pieces fit together for a very elegant explanation of how the Earth works.

ORGANIZATION

This book contains the same text and illustrations as the tenth edition of *Physical Geology* by Plummer, McGeary, and Carlson. The chapter order has been changed so that internal processes (plate tectonics, earthquakes, etc.) are covered in the first part of the book and external processes (rivers, glaciers, etc.) are described toward the end of the book. This ordering is favored by many geology instructors. *Physical Geology: Earth Revealed* is featured as the companion text to *Earth Revealed Introductory Geology,* PBS television course and video resource produced in collaboration with the Annenberg/CPB project. *Earth Revealed* is a series of twenty-six half-hour video programs organized around the chapters of this text. The television programs document evidence of geologic principles at geographically diverse sites, often using a case study approach. Videocassettes can be purchased individually or as a thirteen-tape set. A *Study Guide* and *Faculty Guide* are also available to supplement the programs. For information regarding the use of *Earth Revealed Introductory Geology* as a television course, or to purchase videocassettes for institutional or classroom use, contact the Annenberg/CPB Multimedia Collection at 1-800-LEARNER.

We recognize that many instructors organize their courses in different ways. Therefore, we have made groups of chapters and individual chapters as self-contained as possible, allowing for customization. Those chapters on surficial processes can be covered earlier or later in a course. Many instructors prefer covering geologic time at the start of a course. If you would like to customize this text to fit your course needs or provide an online text for your students, please contact your McGraw-Hill representative.

NEW IN THE SIXTH EDITION

Although we retain the basic framework of the book from previous editions, we are excited to introduce new features, which include changes or additions to each chapter as well as a few more substantial changes, in response to feedback from reviewers and students. We have integrated more websites into the text, boxes, and the end-of-chapter web exploration section.

New Planetary Geology Chapter

On the advice of our reviewers, we have added a chapter on planetary geology (chapter 22), whose material is entirely new to the book. This chapter was written by Tom Arny, Professor Emeritus of the University of Massachusetts and author of the successful McGraw-Hill *Explorations* astronomy textbooks.

CHAPTER

22

The Earth's Companions

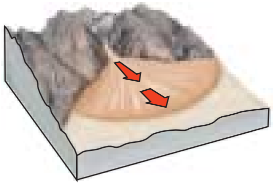
by Tom Arny

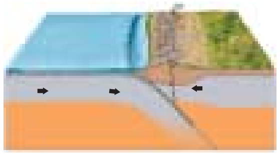
- The Earth in Space
  - The Sun
  - The Solar System
  - The Milky Way and the Universe
- Origin of the Planets
  - The Solar Nebula
  - Formation of the Planets
  - Formation of Moons
  - Final Stages of Planet Formation
  - Formation of Atmospheres
  - Other Planetary Systems
- Portraits of the Planets
  - Our Moon
  - Description of the Moon
    - General Features
    - Surface Features
    - Origin of Lunar Surface Features
  - Structure of the Moon
    - Crust and Interior
    - The Absence of a Lunar Atmosphere
  - Origin and History of the Moon
  - Mercury
    - Mercury's Temperature and Atmosphere
    - Mercury's Interior
    - Mercury's Rotation
  - Venus
    - The Venusian Atmosphere
    - Venus's Surface Temperature and the Greenhouse Effect
    - The Surface of Venus
    - The Interior of Venus

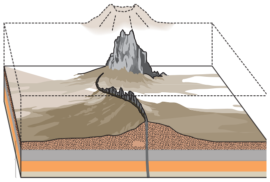
Jupiter's moon Io seen against the cloud tops of the giant planet by the Cassini spacecraft. It is about the same size as our moon—about one quarter the size of earth. Photo by NASA/JPL/University of Arizona

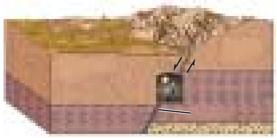
Exceptional Illustrations

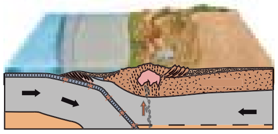
Every illustration and photo has been evaluated for accuracy, currency, and visual appeal, and has either been replaced, updated, or otherwise revised where necessary. This sixth edition features ninety-five new illustrations and seventy new photos. In addition, one hundred fifty-six illustrations have been revised and redrawn. The new illustrations were created in consultation with Dr. Abhijit Basu of Indiana University and thoroughly reviewed by a panel of nine advisors to contribute to a visually spectacular and pedagogically sound art program.







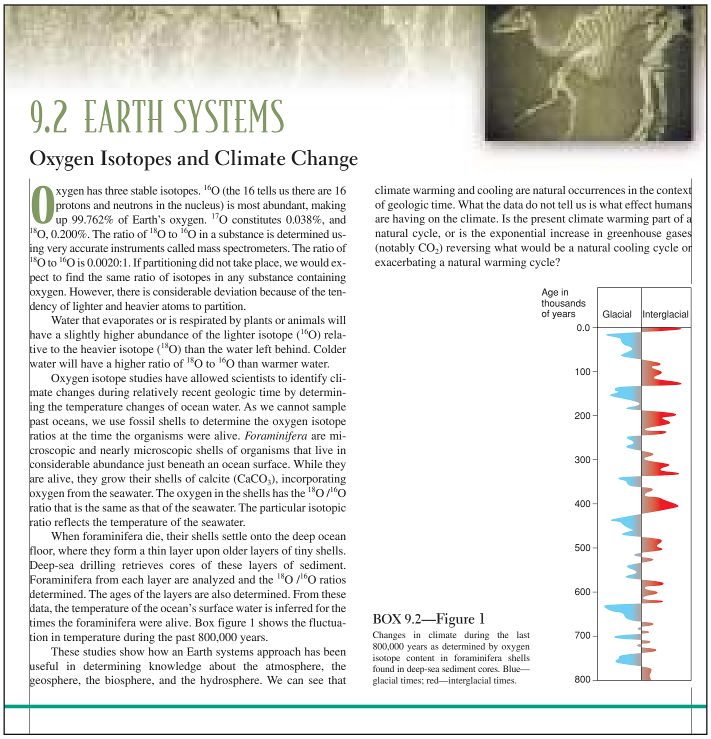




Content Changes

Some of the significant content changes include:

- An integration of the Earth systems approach to geology is introduced in chapter 1, and subsequent chapters include a section relating chapter material to Earth systems. The hydrologic cycle in chapter 16 has been rewritten to reflect Earth systems.
- Earth systems are discussed in new boxed readings. For example, in chapter 3, we discuss the effect of tides on shallow earthquakes along the Juan de Fuca Ridge.
- Astrogeology boxes have been retitled "Planetary Geology." There are fewer boxes throughout as many topics are now covered in the new planetary geology chapter (chapter 22). We have retained those boxes that are particularly appropriate to the topic at hand. We have also added a box on wind features on Mars.
- The importance and use of stable isotopes in geology is described in chapter 9 and includes a new Earth systems box on oxygen isotopes and global climate change.
- A section has been added to the chapter on volcanism (chapter 10) on the influence of volcanoes on religious or supernatural beliefs in cultures that live with volcanoes.
- In chapter 8 on geologic time, we introduce the new technique of cosmogenic exposure dating, which uses isotopes to determine how long a surface has been exposed to bombardment from solar radiation.
- A section on underwater landslides has been added to the chapter on mass wasting (chapter 13).



9.2 EARTH SYSTEMS

Oxygen Isotopes and Climate Change

Oxygen has three stable isotopes. ^{16}O (the 16 tells us there are 16 protons and neutrons in the nucleus) is most abundant, making up 99.762% of Earth's oxygen. ^{17}O constitutes 0.038%, and ^{18}O, 0.200%. The ratio of ^{18}O to ^{16}O in a substance is determined using very accurate instruments called mass spectrometers. The ratio of ^{18}O to ^{16}O is 0.0020:1. If partitioning did not take place, we would expect to find the same ratio of isotopes in any substance containing oxygen. However, there is considerable deviation because of the tendency of lighter and heavier atoms to partition.

Water that evaporates or is respirated by plants or animals will have a slightly higher abundance of the lighter isotope (^{16}O) relative to the heavier isotope (^{18}O) than the water left behind. Colder water will have a higher ratio of ^{18}O to ^{16}O than warmer water.

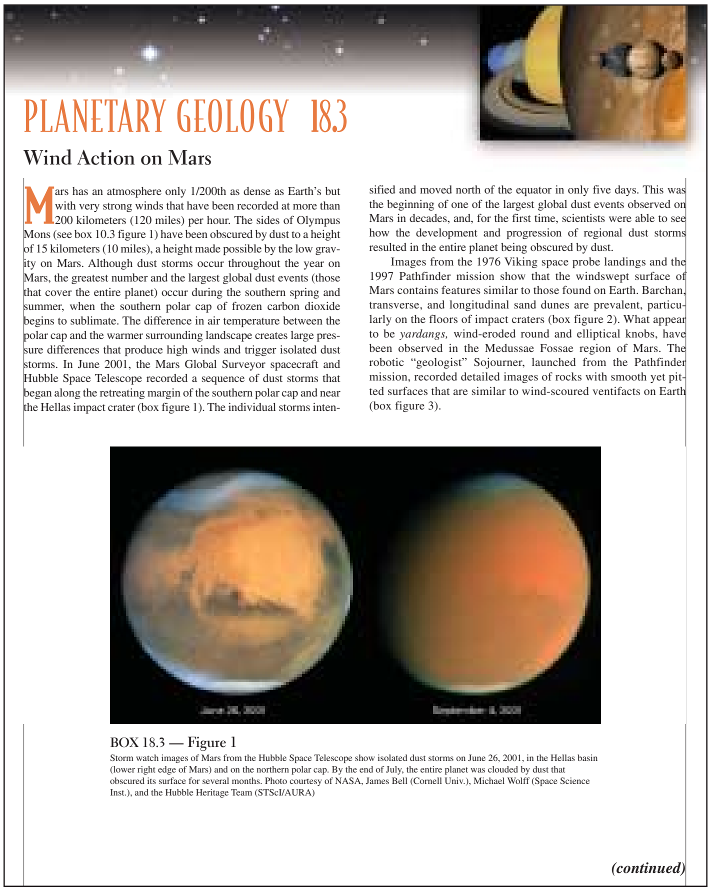
Oxygen isotope studies have allowed scientists to identify climate changes during relatively recent geologic time by determining the temperature changes of ocean water. As we cannot sample past oceans, we use fossil shells to determine the oxygen isotope ratios at the time the organisms were alive. *Foraminifera* are microscopic and nearly microscopic shells of organisms that live in considerable abundance just beneath an ocean surface. While they are alive, they grow their shells of calcite ($CaCO_3$), incorporating oxygen from the seawater. The oxygen in the shells has the $^{18}O/^{16}O$ ratio that is the same as that of the seawater. The particular isotopic ratio reflects the temperature of the seawater.

When foraminifera die, their shells settle onto the deep ocean floor, where they form a thin layer upon older layers of tiny shells. Deep-sea drilling retrieves cores of these layers of sediment. Foraminifera from each layer are analyzed and the $^{18}O/^{16}O$ ratios determined. The ages of the layers are also determined. From these data, the temperature of the ocean's surface water is inferred for the times the foraminifera were alive. Box figure 1 shows the fluctuation in temperature during the past 800,000 years.

These studies show how an Earth systems approach has been useful in determining knowledge about the atmosphere, the geosphere, the biosphere, and the hydrosphere. We can see that climate warming and cooling are natural occurrences in the context of geologic time. What the data do not tell us is what effect humans are having on the climate. Is the present climate warming part of a natural cycle, or is the exponential increase in greenhouse gases (notably CO_2) reversing what would be a natural cooling cycle or exacerbating a natural warming cycle?

BOX 9.2—Figure 1

Changes in climate during the last 800,000 years as determined by oxygen isotope content in foraminifera shells found in deep-sea sediment cores. Blue—glacial times; red—interglacial times.



PLANETARY GEOLOGY 18.3

Wind Action on Mars

Mars has an atmosphere only 1/200th as dense as Earth's but with very strong winds that have been recorded at more than 200 kilometers (120 miles) per hour. The sides of Olympus Mons (see box 10.3 figure 1) have been obscured by dust to a height of 15 kilometers (10 miles), a height made possible by the low gravity on Mars. Although dust storms occur throughout the year on Mars, the greatest number and the largest global dust events (those that cover the entire planet) occur during the southern spring and summer, when the southern polar cap of frozen carbon dioxide begins to sublimate. The difference in air temperature between the polar cap and the warmer surrounding landscape creates large pressure differences that produce high winds and trigger isolated dust storms. In June 2001, the Mars Global Surveyor spacecraft and Hubble Space Telescope recorded a sequence of dust storms that began along the retreating margin of the southern polar cap and near the Hellas impact crater (box figure 1). The individual storms intensified and moved north of the equator in only five days. This was the beginning of one of the largest global dust events observed on Mars in decades, and, for the first time, scientists were able to see how the development and progression of regional dust storms resulted in the entire planet being obscured by dust.

Images from the 1976 Viking space probe landings and the 1997 Pathfinder mission show that the windswept surface of Mars contains features similar to those found on Earth. Barchan, transverse, and longitudinal sand dunes are prevalent, particularly on the floors of impact craters (box figure 2). What appear to be *yardangs,* wind-eroded round and elliptical knobs, have been observed in the Medussae Fossae region of Mars. The robotic "geologist" Sojourner, launched from the Pathfinder mission, recorded detailed images of rocks with smooth yet pitted surfaces that are similar to wind-scoured ventifacts on Earth (box figure 3).

BOX 18.3 — Figure 1

Storm watch images of Mars from the Hubble Space Telescope show isolated dust storms on June 26, 2001, in the Hellas basin (lower right edge of Mars) and on the northern polar cap. By the end of July, the entire planet was clouded by dust that obscured its surface for several months. Photo courtesy of NASA, James Bell (Cornell Univ.), Michael Wolff (Space Science Inst.), and the Hubble Heritage Team (STScI/AURA)

(continued)

CHAPTER 12

Weathering and Soil

Weathering, Erosion, and Transportation
Weathering and Earth Systems
  Solar System
  Atmosphere
  Hydrosphere
  Biosphere
How Weathering Alters Rocks
Effects of Weathering
Mechanical Weathering
  Frost Action
  Pressure Release
  Other Processes
Chemical Weathering
  Role of Oxygen
  Role of Acids
  Solution Weathering
  Chemical Weathering of Feldspar
  Chemical Weathering of Other Minerals
  Weathering Products
  Weathering and Climate
Soil
  Soil Horizons
  Soil Classification
  Residual and Transported Soils
  Soils, Parent Material, Time, and Slope
  Organic Activity
  Soils and Climate
  Buried Soils
Summary

Differential weathering at Bryce Canyon National Park in Utah has produced spires in the sandstone beds. Photo © Richard J. Green/Photo Researchers, Inc.

300 CHAPTER 12 Weathering and Soil

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 at the minerals making up igneous rocks crystallize at relaely high temperatures and sometimes at high pressures as gma and lava cool. Although these minerals are stable when form, most of them are not stable during prolonged expoat the surface. In this chapter, you see how minerals and change when they are subjected to the physical and chemonditions existing at the surface. Rocks undergo mechanweathering (physical disintegration) and chemical ring (decomposition) as they are attacked by air, water, roorganisms. Your knowledge of the chemical compod atomic structure of minerals will help you understand ons that occur during chemical weathering.

hering processes create sediments (primarily mud and soil. Sedimentary rocks, which form from sed discussed in chapter 14. In a general sense, weathres rocks for erosion and is a fundamental part of le, 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.

RING, EROSION,
NSPORTATION

rth's surface are constantly being changed temperature, and other environmental facn indestructible, but given time and expoit can decompose and disintegrate into alter rock are *weathering, erosion,* and

ng refers to the group of destructive physical and chemical character of rock example, if you abandon a car, particntually the paint will flake off and the eathers. Similarly, the tightly bound oosened and altered to new minerals water during weathering. Weathering 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.

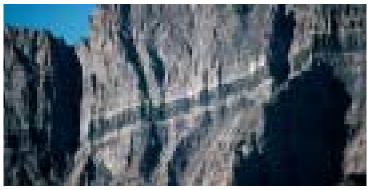
After a rock fragment is picked up (eroded), it is transported. **Transportation** is the movement of eroded particles by agents such as rivers, waves, glaciers, or wind. Weathering processes continue during transportation. A boulder being transported by a stream can be physically worn down and chemically 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 hosed off.

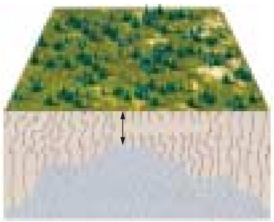
WEATHERING AND EARTH SYSTEMS

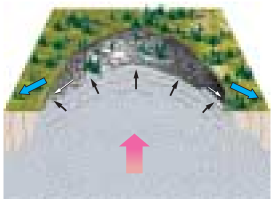
Solar System

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.





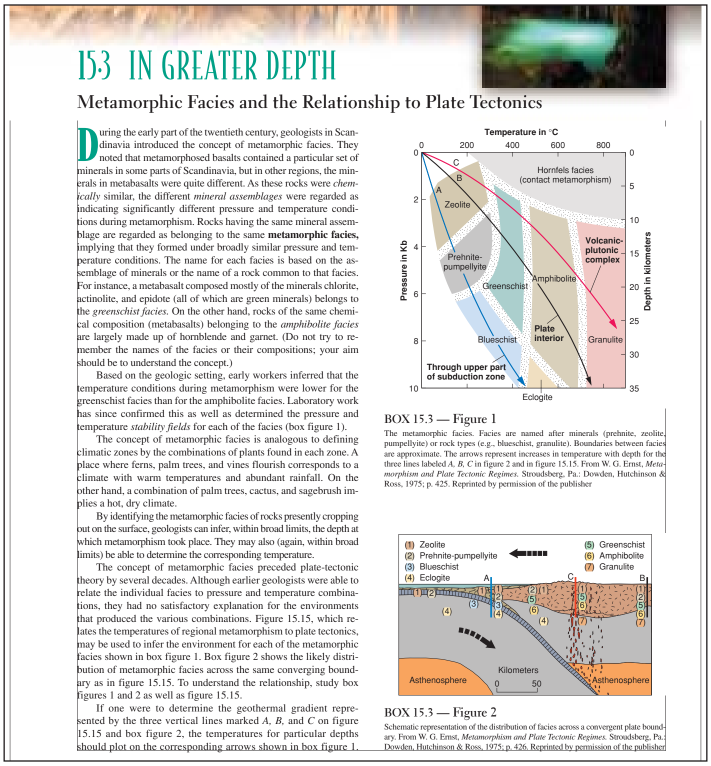


KEY FEATURES

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

During 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 converging boundary as in figure 15.15. To understand the relationship, study box figures 1 and 2 as well as figure 15.15.

If one were to determine the geothermal gradient represented by the three vertical lines marked *A, B,* and *C* on 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.* Stroudsberg, Pa.: Dowden, Hutchinson & Ross, 1975; p. 425. 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.* Stroudsberg, Pa.: Dowden, Hutchinson & Ross, 1975; p. 426. Reprinted by permission of the publisher

- "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

Sedimentary 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.

Visit the NASA Science News headlines website for the latest information and images from Mars.
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 Malin Space Science Systems website for an extensive collection of archived Mars Orbiter Camera images.
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

- "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

Before 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 10.1*A*). 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 northeastward 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

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.

- "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

The 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 Pennsylvanian 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. Ichtyosaurs, 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, chimpanzees, 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/

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 in 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

- 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/.**

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.

Introducing Geology and an Overview of Important Concepts

For the Instructor

- *Online Learning Center* at **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, Rutford, 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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