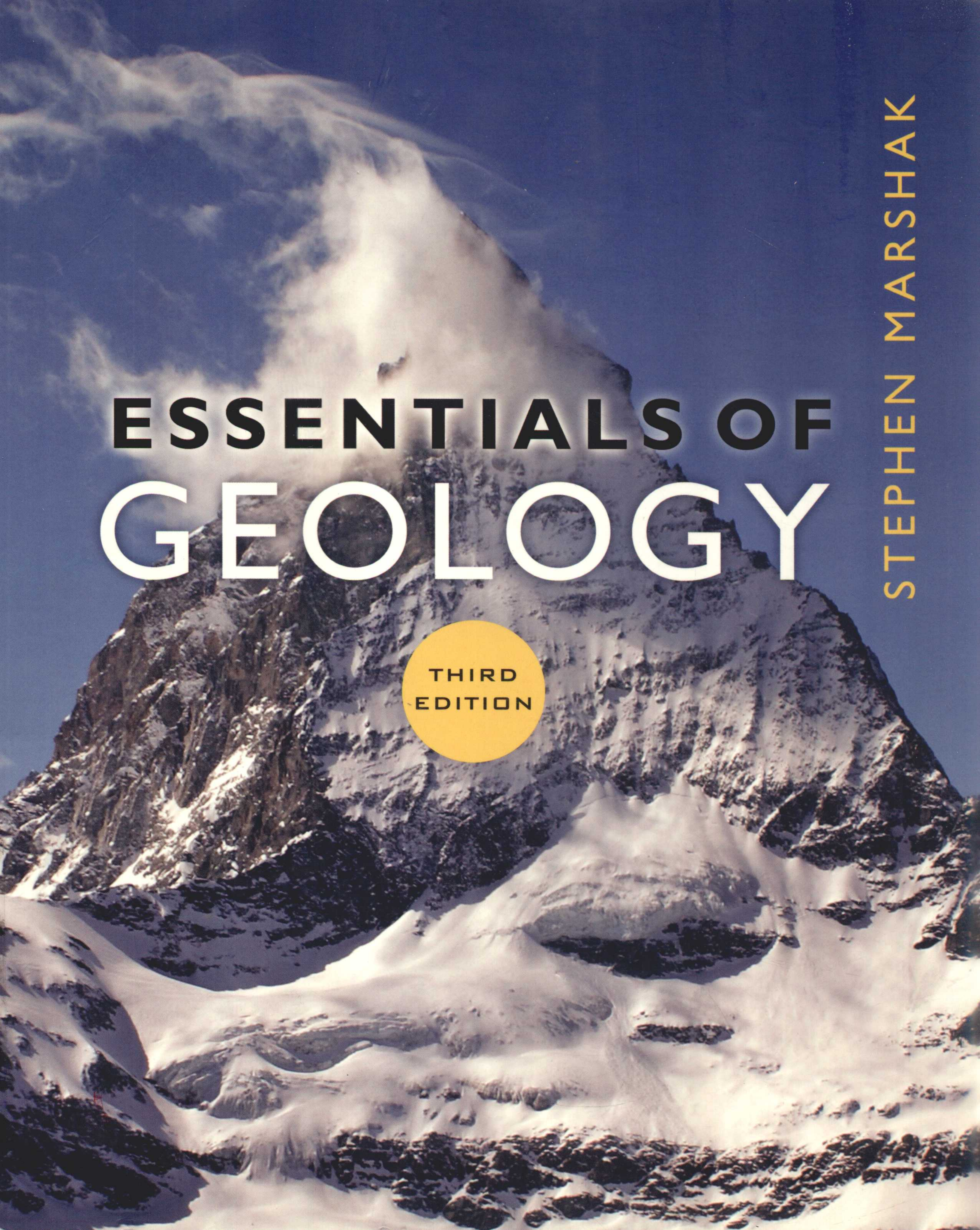
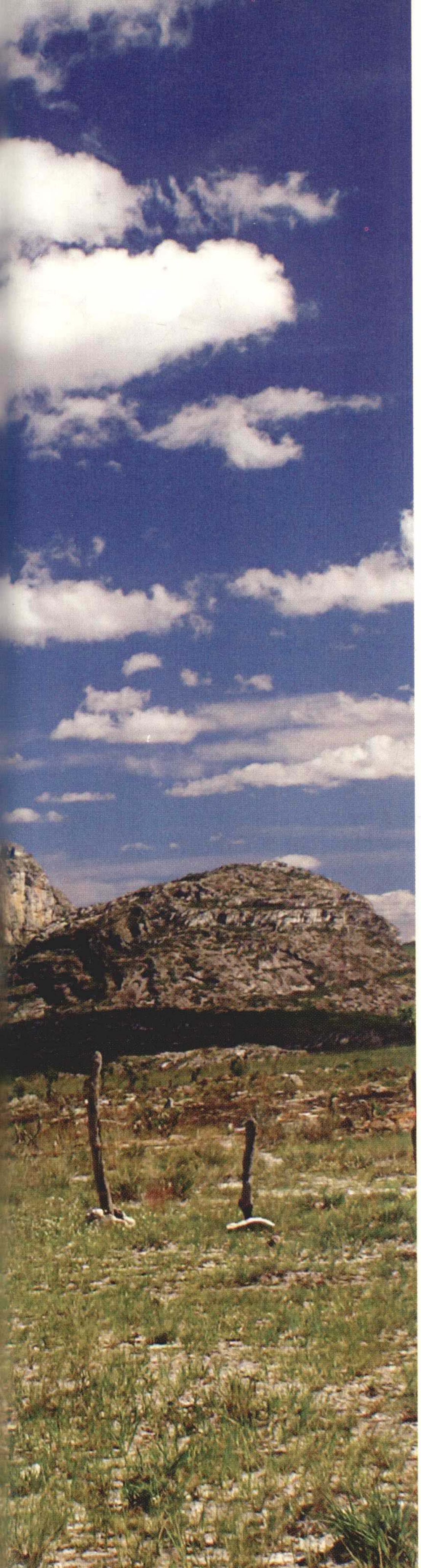
ESSENTIALS OF GEOLOGY

THIRD EDITION

STEPHEN MARSHAK





Essentials of Geology

THIRD EDITION

Stephen Marshak
UNIVERSITY OF ILLINOIS

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Welcome to Geology in the 21st Century!

The Third Edition of Stephen Marshak's *Essentials of Geology* achieves the ideal "crystallization" of narrative, illustrations, and electronic media for today's students and instructors.

What our student readers are saying—

"If you have an interest in geology or the earth sciences, then this is the book to have. The author has performed extensive fieldwork in geology. The clarity of his illustrations goes beyond any text that I have seen. His descriptions are easily understood. You must get a copy! Excellent, Excellent, Excellent! And, no, I am not related to the author, nor have I ever met him."

—Student from Brooklyn, from Amazon.com

"This book serves as an excellent introduction to geology. It is extremely well written and explains difficult concepts well. Among the best parts of the book are the illustrations, which are beautiful to look at and supplement the text expertly, again reinforcing the concepts. I appreciate the way the author has integrated the broad theory of plate tectonics throughout all sections of the book. In particular, he has expertly woven the theory of plate tectonics into the history of earth's evolution and how that in turn has led to the evolution of life. This book is a great introduction for college students to better appreciate and understand this wonderful place we call earth."

—Student from Virginia, from Amazon.com

"I originally chose to take a geology class because I had a relatively small interest in earth science and it was an interesting way to satisfy my lab credit requirement. Upon starting the class, and reading into your textbook, I have decided to make geology my life's work. Without your textbook, I am not sure if I would have found my calling."

—From a student to the author

What instructors using the Marshak texts are saying—

"It is incredibly well-organized and well-written with the best graphics that I have ever seen in any intro text. Students respond very positively to the book."

—Julie Baldwin, University of Montana

"I was impressed by the illustrations, the Interludes, the boxed inserts, and the clear, simple way in which the text is written. I think that you have a great book."

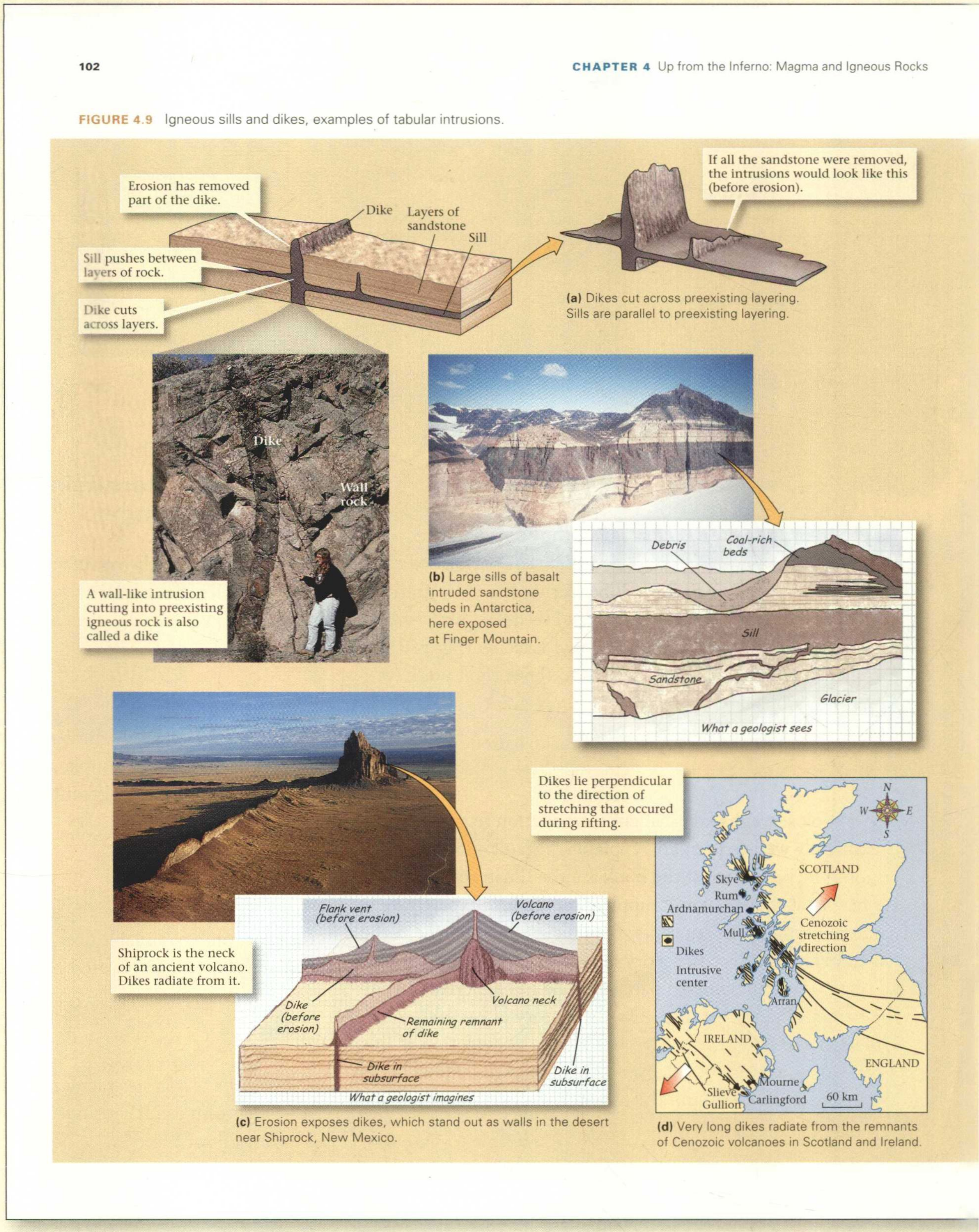
—Norma Small-Warren, Howard University

"Marshak's delivery is really good. He makes very important concepts understandable even for a non-science major. The explanations of complicated concepts are wonderful."

—David Stetty, Jacksonville State University

"Marshak's text is spectacular. In general, it is his figures that have wowed me and continue to wow me . . . they are the best I have seen bar none."

—Dori Farthing, SUNY-Geneseo

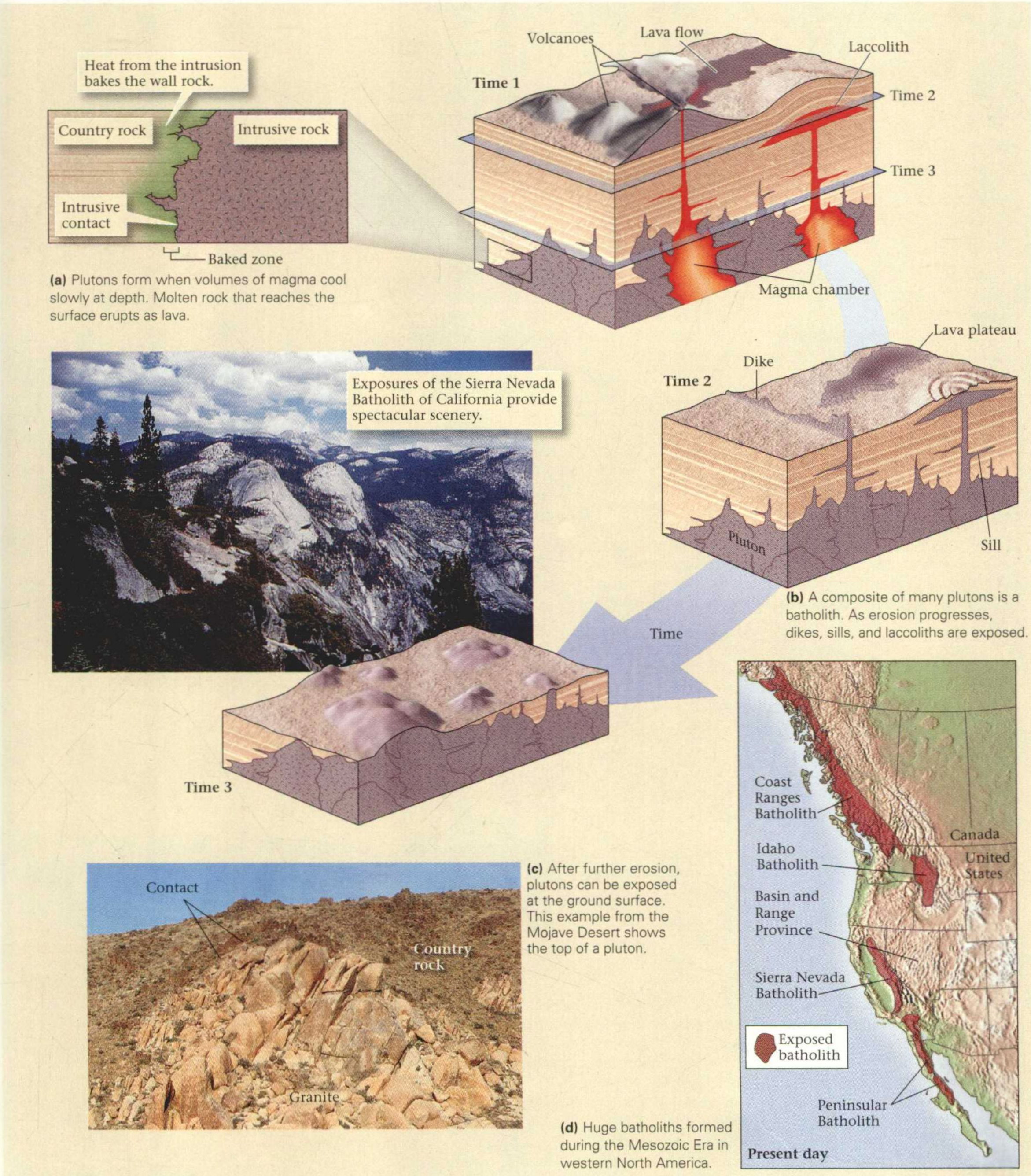


What a Geologist Sees

The untrained eye, when looking at a photograph of a geologic feature, may see only a pretty picture—a geologist looking at the same picture sees a page of Earth history. The **What a Geologist Sees** art in *Essentials of Geology*, Third Edition, provides a simple sketch that conveys what a trained geologist sees when viewing a photograph of a landscape. Adopters of previous editions have raved about how effective the **What a Geologist Sees** art is for helping students understand the geologic concepts illustrated by a photograph.

4.6 How Do Extrusive and Intrusive Environments Differ? 103

FIGURE 4.10 Igneous plutons, "blob-shaped" intrusions.



Narrative Figures

Pictures tell stories. *Essentials of Geology*, Third Edition, takes this concept to heart by arranging related figures into visual narratives—combining figures, photographs, satellite imagery, and concise bubble captions—that help students see the dynamics behind how geologic processes occur through time.

GEOTOUR 5

See for yourself . . .

Volcanic Features

There are more than 1,500 active volcanoes on Earth and thousands more volcanic landscapes. The thumbnail images provided on this page are only to help identify tour sites. Go to wwnorton.com/studyspace to experience this flyover tour.

Yellowstone Falls (Lat 44°43'4.96"N, Long 110°29'45.44"W)

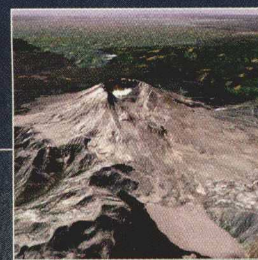
At these coordinates, hover above the Grand Canyon of the Yellowstone from an elevation of 5 km (3 miles). The canyon walls expose bright yellow tuffs deposited during cataclysmic eruptions that occurred during the past 2 million years. Drop to an elevation of 3 km (2 miles), look downstream, and tilt to get a better view (**Image G5.1**).

G5.1

Mt. Saint Helens, Washington (Lat 46°12'1.24"N, Long 122°11'20.73"W)

Box 5.1 discussed the explosion of Mt. Saint Helens. To see the damage for yourself, fly to the coordinates and zoom to 30 km (18.5 miles). The breached crater, the blowdown zone, the slumps, and the lahars are all visible (**Image G5.2**). To get a better sense of the devastation, descend to 13 km (8 miles), tilt your image, and fly around the mountain (**Image G5.3**).

G5.2



G5.3

Smoking Volcano, Ecuador (Lat 1°27'58.96"S, Long 78°26'58.24"W)

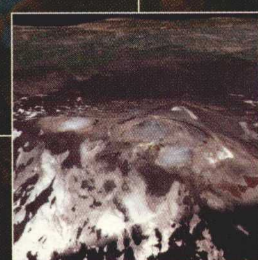
Fly to this locality and zoom to 75 km (46.5 miles). You are looking at the Andean Volcanic Arc in Ecuador, a consequence of subduction of Pacific Ocean floor beneath South America. Here, you see four volcanoes (**Image G5.4**). When this image was taken, Tungurahua was erupting, producing a plume of ash that winds blew to the southwest. The largest volcano in view is Chimborazo, the snow-covered peak at the western edge of the image.

G5.4

Mt. Etna, Sicily (Lat 37°45'5.49"N, Long 14°59'38.41"E)

At these coordinates, from an elevation of 50 km (31 miles), you can see Mt. Etna, which dominates the landscape of eastern Sicily (**Image G5.5**). This volcano erupts fairly frequently—in this image small clouds of volcanic smoke rise from the 3200 m-high summit. Note the numerous lava flows on its flanks. Zoom to 5 km (3 miles), rotate the image, and tilt it so you are looking east. You can see calderas on the summit (**Image G5.6**).

G5.5



G5.6

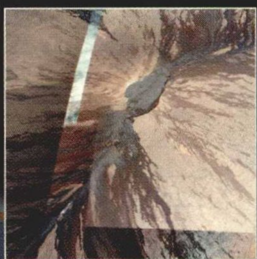
Geotours

Each chapter of *Essentials of Geology*, Third Edition has an accompanying Geotour, which provides a portal through which students can take a virtual field trip and see for themselves what geology looks like in the real world. Through the magic of *Google Earth*™ geology comes alive. Want to understand the eruptive force of the Mt. Saint Helens explosion? With Geotours, you can take a guided flight around the volcano at just the click of a button.

G5.7

Mt. Vesuvius, Italy (Lat 40°49'18.24"N, Long 14°25'32.04"E)

Eruption of Mt. Vesuvius in 79 C.E. destroyed Herculaneum and Pompeii. Fly to the coordinates provided and you'll be hovering over the volcano's crater. Zoom to 50 km (31 miles), and you can see the entire bay of Naples—several volcanic calderas lie on the west side of Naples. In fact, the entire bay is a caldera. Zoom to 15 km (9 miles), tilt the view, and fly around Vesuvius (**Image G5.7**). The central peak of the volcano lies within a larger caldera (Somma) that formed 17,000 years ago.



G5.8

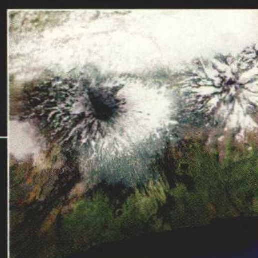
G5.9

Hawaiian Volcanoes (Lat 19°28'20.47"N, Long 155°35'32.82"W)

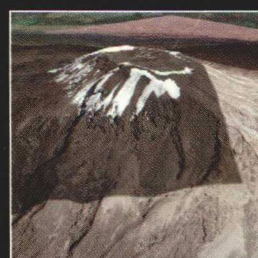
At these coordinates, you'll be above the caldera of Mauna Loa, one of the shield volcanoes on Hawaii. From 25 km (15.5 miles) , you can see that the caldera is elliptical, and that other, smaller calderas occur to the SW. Tilt the image, and you can see a large fissure cutting the frozen lava lake in the Caldera. Distinctive lava flows spilled out of the ends of the caldera (**Image G5.8**). Fly about 33 km (20.5 miles) ESE to find the caldera of Kilauea (**Image G5.9**). From here, fly 41 km (25.5 miles) to the NNE to cross Mauna Kea, home to an observatory (white buildings).

Mt. Shishildan, Alaska (Lat 54°45'36.59"N, Long 163°58'28.65"W)

Unimak Island, in the Aleutian chain, hosts a large stratovolcano, Mt. Shishildan. From an elevation of 35 km (22 miles), you'll note that the snowline starts halfway up the mountain, but that the peak itself is black (**Image G5.10**). That's because the volcano is active, and recent eruptions have buried and melted snow at the peak. From an elevation of 10 km (6 miles), you can see a red glow at the peak. Note that another, smaller volcano lies to the east.



G5.10

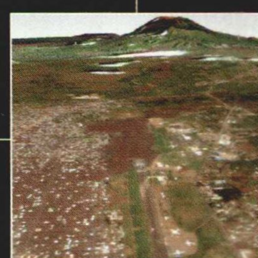


G5.11

East African Rift (Two Locations)

To understand volcanism in the East African rift, it is necessary to visit several locations. Here we provide two: (1) Mt. Kilimanjaro (Lat 3°3'53.63"S, Long 37°21'31.02"E): From a height of 10 km, you can see the caldera at the top of Africa's highest volcano (**Image G5.11**). The glaciers on the summit have been shrinking rapidly and may be gone in 20 years. Slumping has produced steep cliffs. Fly 45 km NE to find a long chain of cinder cones marking eruptions along a fault in the rift. (2) Goma region (Lat 1°39'27.40"S Long 29°14'15.27"E): At these coordinates, zoom to 80 km (50 miles), and tilt your view to look north (**Image G5.12**). The chain of lakes marks the western arm of the East African Rift. Active volcanoes lie just north of the city of Goma. Zoom to 3 km (2 miles) and tilt the image to look north—note the lava flow covering a portion of the airport runway and the city (**Image G5.13**).

G5.12



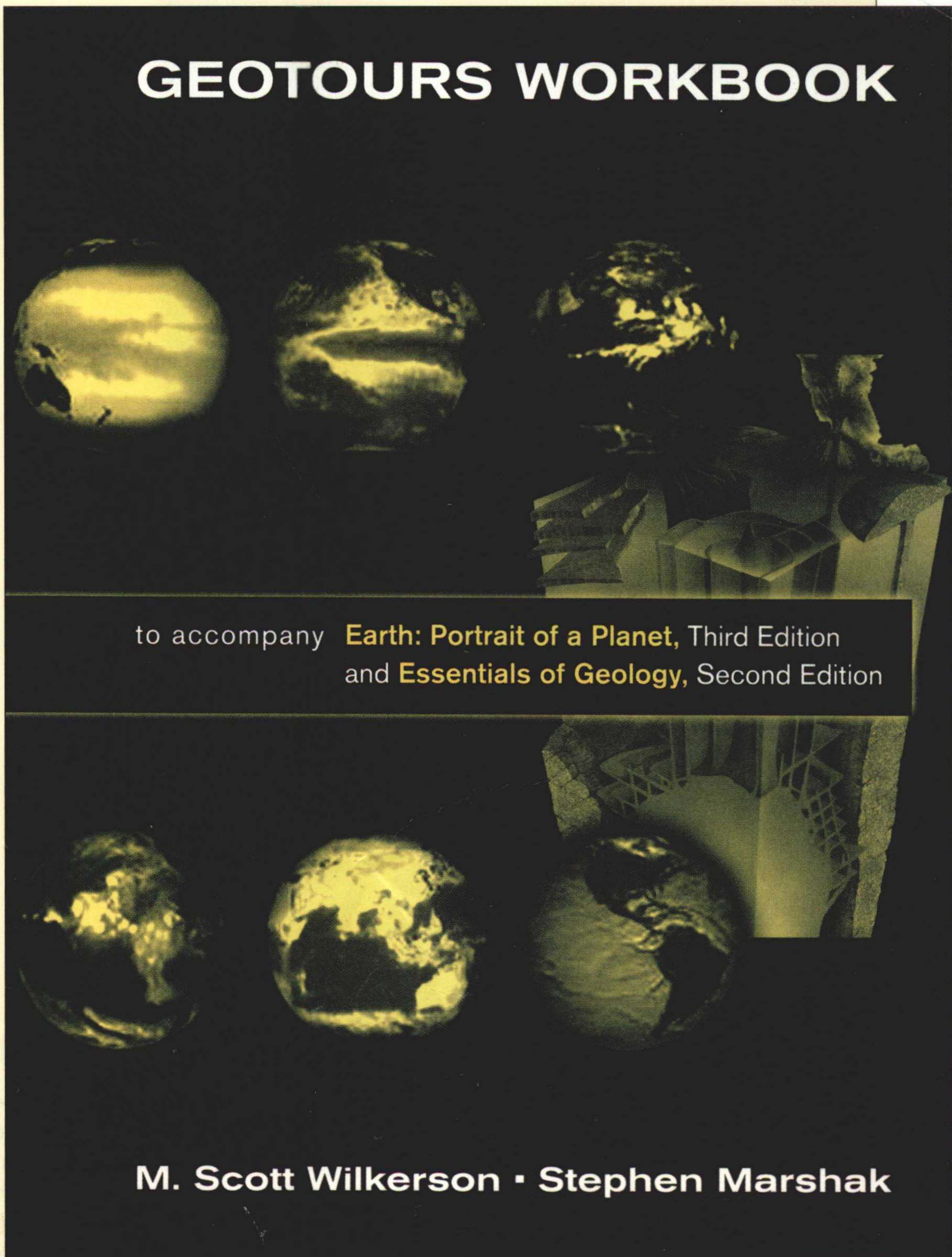
G5.13

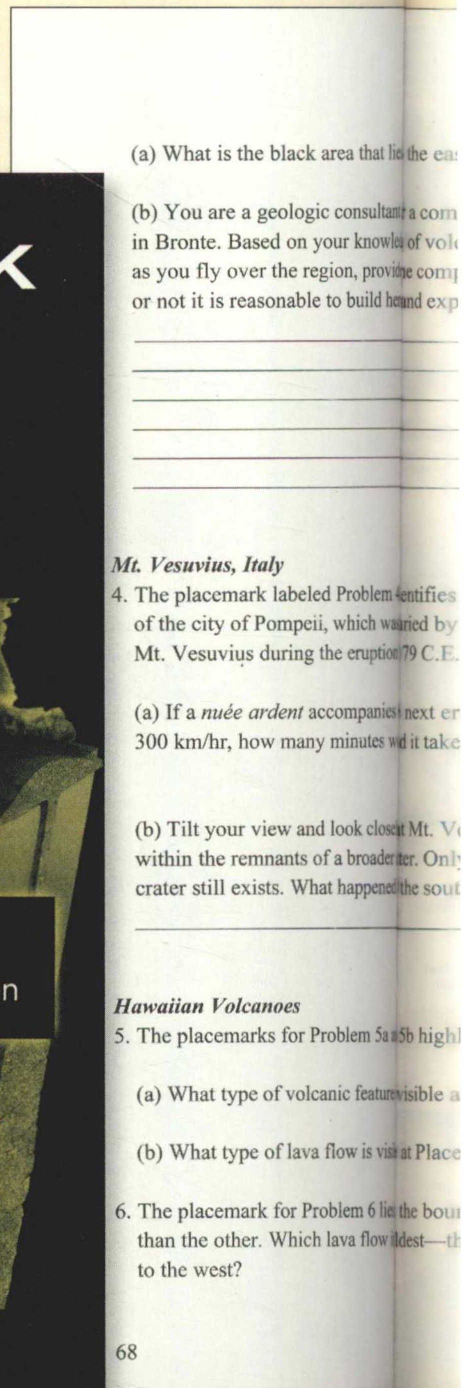
Images provided by *Google Earth*™ mapping service/DigitalGlobe, TerraMetrics, NASA, Europa Technologies—copyright 2008.

Educators have demonstrated that the most effective way for students to remember and internalize the salient features of an object is to explore the object from all angles—from above, from either side, and even from moving past it. *Google Earth*™ is an unparalleled resource that allows such exploration of geologic features—Geotours apply *Google Earth*™ to geology.

Geotours workbook contains active-learning exercises for each Geotour site

Essentials of Geology, Third Edition, helps instructors provide active-learning experiences for their students.




(a) What is the black area that li the ea

(b) You are a geologic consultant a com
in Bronte. Based on your knowle of vol
as you fly over the region, provi e com
or not it is reasonable to build h and exp

Mt. Vesuvius, Italy

4. The placemark labeled Problem entifies
of the city of Pompeii, which w ied by
Mt. Vesuvius during the eruptio 79 C.E.

(a) If a *nuée ardent* accompanies next er
300 km/hr, how many minutes w it take

(b) Tilt your view and look clos t Mt. V
within the remnants of a broader ter. Onl
crater still exists. What happened the sout

Hawaiian Volcanoes

5. The placemarks for Problem 5a 5b high

(a) What type of volcanic feature visible a

(b) What type of lava flow is vis at Place

6. The placemark for Problem 6 lie the bou
than the other. Which lava flow dest—t
to the west?

68

the east of the town? ______

a company that is considering building a factory of volcanoes and on observations that you make the company with your opinion regarding whether and explain the reasons for your recommendation.

______

entifies the location of some of the excavated ruins ried by volcanic ash and pyroclastic material from 79 C.E.

next eruption of Mt. Vesuvius and it travels at d it take to reach the site of ancient Pompeii?

______

at Mt. Vesuvius. The present conelike peak lies ter. Only a small portion of the rim of the larger the southern portion of the older, larger crater?

______

5b highlight surface textures of basaltic lava flows.

visible at Placemark 5a? ______

at Placemark 5b? ______

the boundary between two lava flows, one older ldest—the one to the east of the marker, or the one

______

Explain the basis for your answer: ______

______

7. What is the likely cause for the steep escarpment highlighted by the placemark labeled Problem 7? ______

8. Both Mauna Kea and Mauna Loa are shield volcanoes. Notably, several smaller, "parasitic" volcanoes have erupted on the flanks of Mauna Kea. Click on the placemark labeled Problem 8 to see some of these.

(a) What kind of volcanoes are these small cones? ______

(b) Why are these cones asymmetric? ______

(c) With the placemark for Problem 8 in the middle of the view, tilt the image all the way so that you are looking at Mauna Kea from the side. Now, move away from the volcano so that you can see the whole shield. What is the steepest slope on the flank of the volcano? (You will need to use a protractor to measure the angle, in degrees.)

______

Mt. Shishildan, Alaska

9. Fly to Mt. Shishildan, Alaska, by clicking on Image G9.10. This is a composite volcano. Tilt the image so that you are looking at the side of the volcano, and zoom out enough to see the whole volcano. What is the steepest slope on side of this volcano?

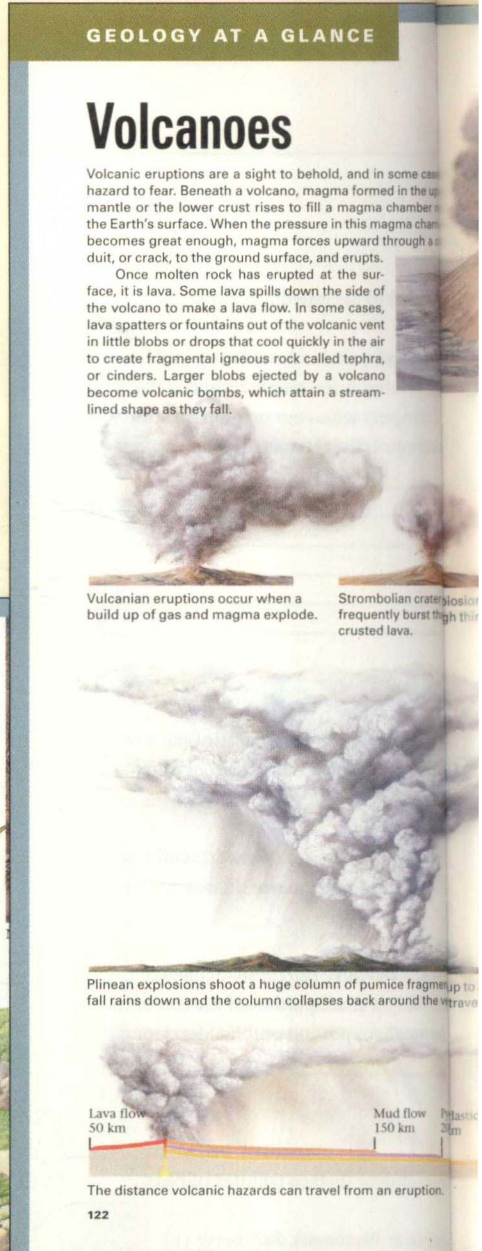
______

Which slope is steeper: Mauna Kea or Mt. Shishildan? ______

Worksheets available on StudySpace or in the free workbook accompany each Geotour. Answering the questions on the worksheets ensures that students take the time to visit the recommended sites on their own, and learn by doing. The instructor can also assign the worksheets as homework or quizzes.

Outstanding Art

Essentials of Geology, Third Edition, provides the most comprehensive set of illustrations and photographs of any introductory geology text. The figures are realistic enough to provide visual context, but are uncluttered so that the teaching point of the figure stands out. The book also contains hundreds of photos, produced at a pleasingly large scale. In addition, almost every chapter in *Essentials of Geology*, Third Edition, offers a two-page painting, entitled **Geology at a Glance**, by the most respected geology artist in the world—Gary Hincks. Each painting provides a synopsis of key points in a chapter. The paintings emphasize interconnections among the key concepts in an uncluttered and visually dramatic way—they make a lasting impression.


GEOLOGY AT A GLANCE

Volcanoes

Volcanic eruptions are a sight to behold, and in some cas… hazard to fear. Beneath a volcano, magma formed in the u… mantle or the lower crust rises to fill a magma chamber… the Earth's surface. When the pressure in this magma cha… becomes great enough, magma forces upward through a c… duit, or crack, to the ground surface, and erupts.

Once molten rock has erupted at the surface, it is lava. Some lava spills down the side of the volcano to make a lava flow. In some cases, lava spatters or fountains out of the volcanic vent in little blobs or drops that cool quickly in the air to create fragmental igneous rock called tephra, or cinders. Larger blobs ejected by a volcano become volcanic bombs, which attain a streamlined shape as they fall.

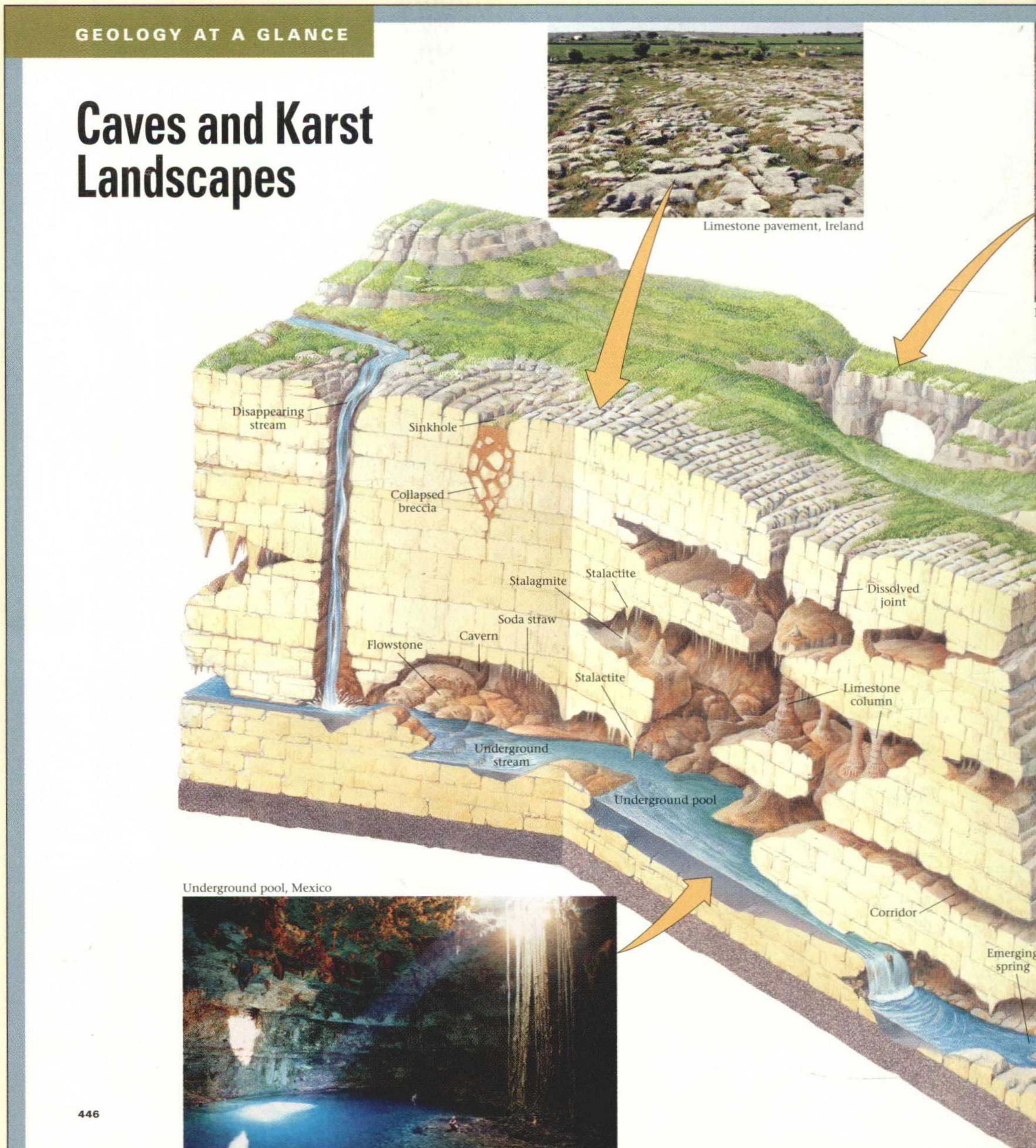
Vulcanian eruptions occur when a build up of gas and magma explode.

Strombolian crater… frequently burst th… crusted lava.

Plinean explosions shoot a huge column of pumice fragme… fall rains down and the column collapses back around the v…

The distance volcanic hazards can travel from an eruption.

122



Limestone pavement, Ireland

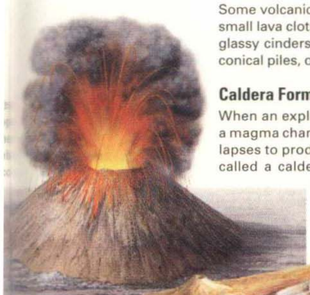
Underground pool, Mexico

Cinder Cones

Some volcanic eruptions produce fountains of small lava clots. These clots quickly freeze into glassy cinders, which accumulate rapidly into conical piles, or cinder cones, around the vent.

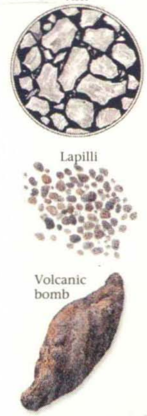
Caldera Formulation

When an explosive eruption suddenly drains a magma chamber, the overlying volcano collapses to produce a large circular depression called a caldera. Eventually, a new volcano may grow within the caldera. Some calderas fill with water and become lakes.



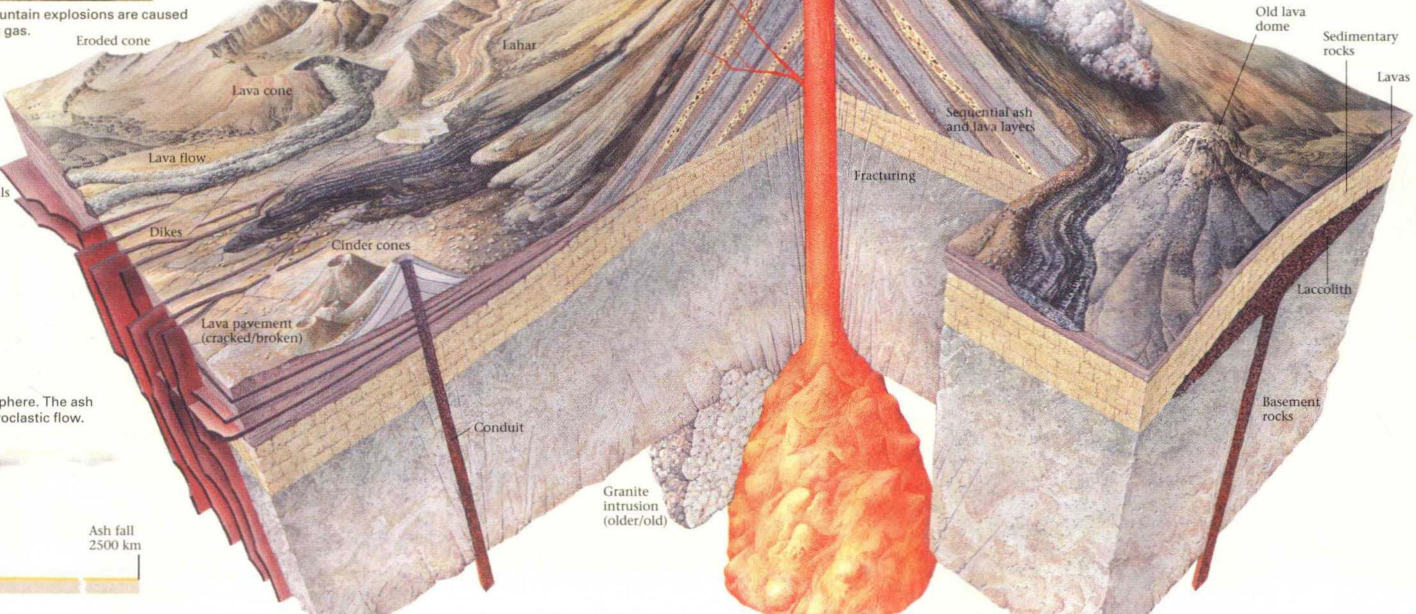
...plosions ...gh thinly

Hawaiian fountain explosions are caused by escaping gas.



Sometimes the force of the eruption sprays fine droplets of lava into the air, and these cool almost instantly to become volcanic ash. Some of the ash blasts high into the atmosphere, forming a cloud out of which ash falls like snow. Alternatively, some ash may avalanche down the side of the volcano. When it falls, ash collects to make a rock called tuff.

Not all of the magma makes it to the surface at a volcano. Some cools underground to form intrusive igneous rock (see Chapter 4). Intrusions that are blob shaped are called plutons. Plutons radiate so much heat into their surroundings that they may metamorphose adjacent rock. Some intrusions develop when magma is forced along a parallel crack, like a joint or bedding plane. These intrusions, shaped like a wall or tabletop, are called tabular intrusions. Tabular intrusions that cut across preexisisting layering are dikes; those that intrude parallel to layering are called sills. In some cases, lava pools in a subsurface, lens-shaped mass, called a laccolith, which pushes up a blister or overlying rock.



...up to 50 km into the atmosphere. The ash ...traveling overland as a pyroclastic flow.

floor. A cave's location depends on the orientation of bedding and joints, for these features localize the flow of groundwater.

Caves originally form at or near the water table (the subsurface boundary between rock or sediment in which pores contain air, and rock or sediment in which pores contain water). As the water table drops, caves empty of most water and become filled with air. In many locations, groundwater drips from the ceiling of a cave or flows along its walls. As the water evaporates and thus loses its acidity (because of the evaporation of dissolved carbon dioxide), new calcite precipitates. Over time, this calcite builds into cave formations, or speleothems, such as stalactites, stalagmites, columns, and flowstone.

Distinctive landscapes, called karst landscapes, develop at the Earth's surface over limestone bedrock. In such regions, the ground may be rough where rock has dissolved along joints; where the roofs of caves collapse, sinkholes develop. If a surface stream flows through an open joint into a cave network, we say that the stream is "disappearing." The water from such streams may flow underground for a distance and then reemerge elsewhere as a spring. In some places, the collapse of subsurface openings leaves behind natural bridges.

CHAPTER 12

Riches in Rock: Energy and Mineral Resources

Workers struggle to extinguish the inferno erupting from an oil well fire in Kuwait. Hundreds of wells were set ablaze at the end of the Gulf War in 1991. The flames are a dramatic display of the energy held in oil.

GEOPUZZLE

The average citizen of a developed nation uses about 15,000 kg of energy and mineral resources (oil, stone, salt, iron, copper, etc.) per year. Where does all this material come from and will supplies of it always exist?

Geopuzzle

Questioning is the first step in learning. Each chapter begins with a question that students can keep in mind as they read. The question prompts students to pursue answers and helps them develop a personal context for learning by thinking about what they might already know about a subject. The answer to the question, provided at the end of the chapter, serves as a brief synthesis of the chapter's theme.

many others. A large proportion of materials in your home have a geologic ancestry.

- Mineral resources are nonrenewable. Many are now or may soon be in short supply.

GEOPUZZLE REVISITED

The natural resources that sustain modern civilization come from the Earth and reflect the consequences of geologic processes. For example, hydrocarbons (oil and gas) come from the buried remains of algae and plankton, coal comes from the remnants of ancient plants, and metals come from special types of rocks called ores. Since natural resources can require long intervals of geologic time to form, many are being consumed faster than they can be replenished, and thus may eventually run out.

Key Terms

biofuel (p. 335)
biomass (p. 322)
cement (p. 346)
coal (p. 330)
coalbed methane (p. 332)
coal gasification (p. 333)
coal rank (p. 331)
energy (p. 322)
energy resource (p. 322)
fossil fuel (p. 322)
gas hydrate (p. 330)
geothermal energy (p. 336)
greenhouse effect (p. 340)
hydrocarbon reserve (p. 324)
hydrocarbon (p. 323)
kerogen (p. 324)
meltdown (of nuclear reactor) (p. 334)
metal (p. 340)
mineral resources (p. 322)
nuclear reactor (p. 334)
nuclear waste (p. 334)
Oil Age (p. 338)
oil shale (p. 324)
oil window (p. 324)
ore (p. 341)
ore deposit (p. 341)
peat (p. 330)
permeability (p. 325)
photosynthesis (p. 322)
porosity (p. 325)
reservoir rock (p. 325)
resource (p. 322)
salt dome (p. 327)
seal rock (p. 326)
source rock (p. 324)
tar sand (p. 329)
trap (p. 325)

Review Questions

1. What are the fundamental sources of energy?
2. What is the source of the organic material in oil?
3. What is the oil window, and why does oil form only there?
4. How is organic matter trapped and transformed to create an oil reserve?
5. What are tar sand and oil shale, and how can oil be extracted from them?
6. What are gas hydrates, and where do they occur?
7. Where is most of the world's oil found? At present rates of consumption, how long will it last?
8. How is coal formed?
9. Explain how coal is transformed in rank from peat to anthracite.
10. Describe the operation of a nuclear reactor.
11. Where does uranium form in the Earth's crust? Where does it usually accumulate in minable quantities?
12. What are some of the drawbacks of nuclear energy?
13. What is geothermal energy? Why is it not more widely used?
14. What is the difference between a renewable and a nonrenewable resource?
15. What is the likely future of hydrocarbon production and use in the twenty-first century?
16. Why don't we use an average granite as a source for useful metals?
17. Describe various kinds of economic mineral deposits.
18. What procedures are used to locate and mine mineral resources today?
19. How is stone cut from a quarry?
20. What are the ingredients of cement? How is Portland cement made?

Take-Home Messages

Take-Home Messages appear at the end of each section—they encourage students to pause and take stock of what they have learned, before going further. The Take-Home Messages emphasize the most important lesson of the previous section—the point that students should remember beyond the end of the course.

Review Questions

1. What role do streams have in the hydrologic cycle? Indicate various sources of water in streams.
2. Describe the different types of drainage networks.
3. What factors determine whether a stream is permanent or ephemeral?
4. How does discharge vary according to the stream's length, climate, and position along the stream course?
5. Describe how streams and running water erode the Earth's surface.
6. What are the components of sediment load in a stream?
7. Distinguish between a stream's competence and its capacity.
8. What factors determine the position of the base level? What is the difference between a local base level and the ultimate base level?
9. Why do canyons form in some places and valleys in others?
10. How does a braided stream differ from a meandering stream?
11. Describe how meanders form and are cut off and the landforms that result from the process.
12. Describe how deltas grow and develop. How do they differ from alluvial fans?
13. How does a stream-eroded landscape evolve as time passes?
14. How are superposed and antecedent drainages similar? How are they different?
15. What is the difference between a seasonal flood and a flash flood?
16. How do people try to prevent flood damage? Are the methods always successful? Why?
17. What is the recurrence interval of a flood? Why can't someone say that "the hundred-year flood happened last year, so I'm safe for another hundred years"?

On Further Thought

1. The northeastern two-thirds of Illinois, in the midwestern United States, was last covered by glaciers only 14,000 years ago. The rest of the state was last covered by glaciers over 100,000 years ago. Until the advent of modern agriculture, the recently glaciated area was a broad, grassy swamp, cut by very few stream channels. In contrast, the area that was glaciated overt 100,000 years ago is not swampy and has been cut by numerous stream valley. Why?
2. Records indicate that flood crests for a given amount of discharge along the Mississippi River have been getting higher since 1927, when a system of levees began to block off portions of the floodplain. Why?
3. The Ganges River carries an immense amount of sediment load, which has been building a huge delta in the Bay of Bengal. Look at the region using an atlas or *Google Earth*™, think about the nature of the watershed supplying water to the drainage network that feeds the Ganges, and explain why this river carries so much sediment.

THE VIEW FROM SPACE The Ganges River carries sediment to the Indian Ocean, where the river divides into ... d typhoon rains cause the low-lying area to flood.

Fortunately, such large earthquakes occur much less frequently than small earthquakes. There are about 100,000 magnitude 3 earthquakes every year, but a magnitude 8 earthquake happens only about once every three to five years (Fig. 8.12b).

TAKE-HOME MESSAGE

Seismographs measure earthquake vibrations and allow seismologists to determine the location and size of earthquakes. We specify earthquake size by an intensity value (damage caused) or a magnitude (the amplitude of ground motion). Magnitudes are logarithmic, meaning that ground shaking by a magnitude 8 event is 10 times larger than from a magnitude 7 event.

8.5 WHERE AND WHY DO EARTHQUAKES OCCUR?

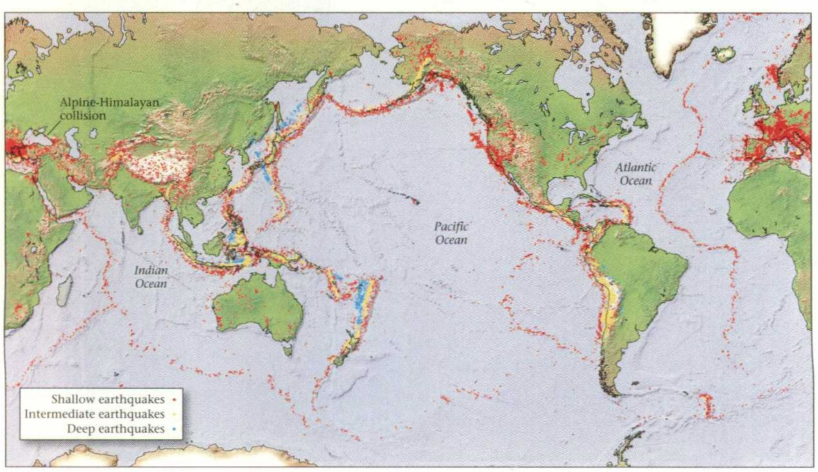
Earthquakes do not take place everywhere on the globe. By plotting the distribution of earthquake epicenters on a map, seismologists find that most, but not all, earthquakes occur in fairly narrow **seismic belts**, or seismic zones. Most seismic belts correspond with plate boundaries. Earthquakes within these belts are plate-boundary earthquakes; ones that occur away from plate boundaries are intraplate earthquakes (the prefix *intra* means within) (Fig. 8.13). Notably, 80% of the earthquake energy released on Earth comes from the plate-boundary earthquakes in the belts surrounding the Pacific Ocean.

Notably, earthquakes do not occur at random depths in the Earth. Seismologists distinguish three classes of earthquakes based on hypocenter (focus) depth: shallow earthquakes occur in the top 20 km of the Earth, intermediate earthquakes take place between 20 and 300 km, and deep earthquakes occur down to a depth of about 660 km. Earthquakes cannot happen deeper in the Earth, because rock at great depth cannot rupture or change in a manner that produces shock waves. In this section, we look at the characteristics of earthquakes in various geologic settings and learn why earthquakes take place where they do.

Earthquakes at Plate Boundaries

The majority of earthquakes happen at faults along plate boundaries, for the relative motion between plates is accommodated primarily by slip on these faults. We find different kinds of faulting at different types of plate boundaries.

FIGURE 8.13 A simplified map of epicenters emphasizes that most earthquakes occur in distinct belts along plate boundaries.

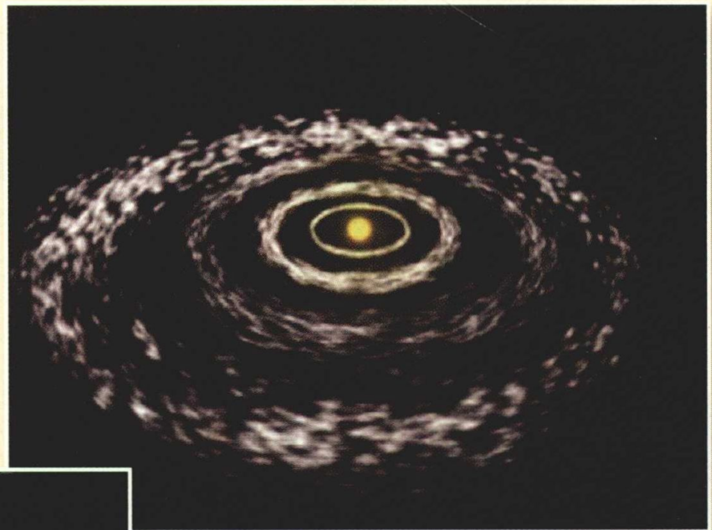


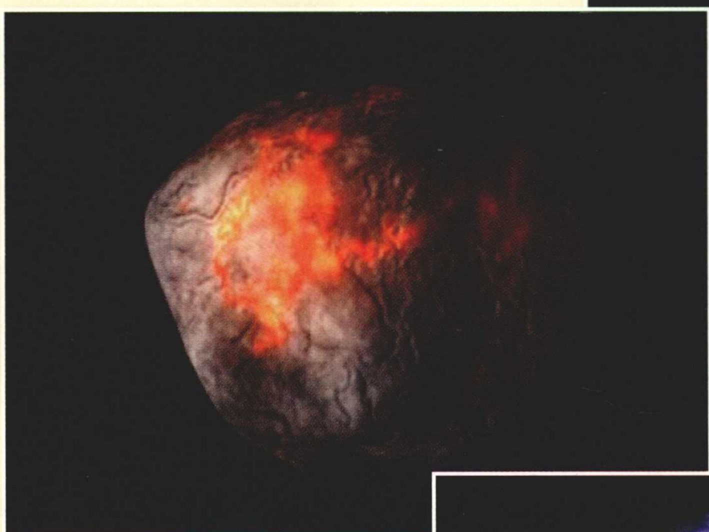
On Further Thought

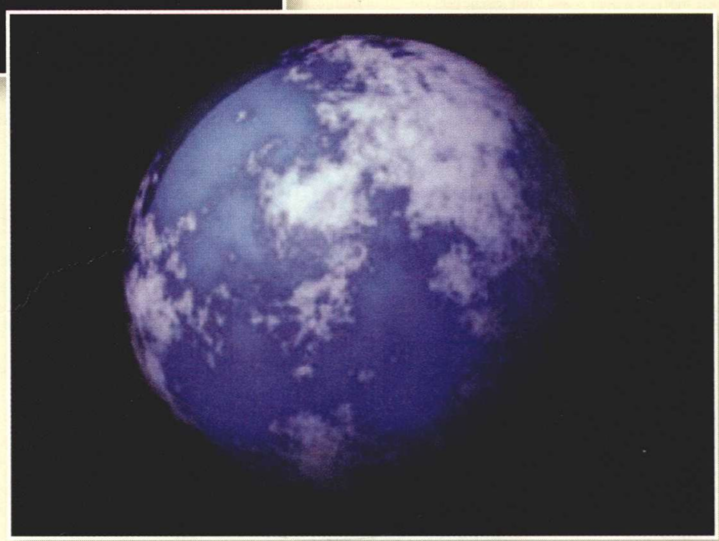
Essentials of Geology, Third Edition, helps students to go beyond the basic facts and begin to think about content and context. Each chapter provides not only a set of basic questions about content, but also a selection of critical thinking questions called On Further Thought. The questions challenge students to use the content of the chapter to address issues in the real world. They can be assigned as homework or can serve as discussion points in class.

New 3-D, Hollywood-Quality Animations

Earth: Videos of a Planet DVD Version 3.0 provides six spectacular new animations that illuminate geologic processes. These augment the existing 65 2-D animations available on StudySpace and the Instructor's CD-ROM. The new animations employ Hollywood-quality visuals that will amaze as they instruct. These state-of-the-art animations focus on the hardest-to-understand geologic processes, including *Formation of the Solar System, Plate Tectonics, Continental Collision, Meandering River, Glacier Erosion,* and more.







Outstanding Narrative

Essentials of Geology, Third Edition, contains an abundance of art, but it does not neglect the writing. Students delight in the book's comprehensive and complete narrative. Experience shows that the clear, organized explanation of a topic—in words—helps students understand the context of a concept and the relationships among concepts.

Glowing waves rise and flow, burning all life on their way, and freeze into black, crusty rock which adds to the height of the mountain and builds the land, thereby adding another day to the geologic past. . . . I became a geologist forever, by seeing with my own eyes: the Earth is alive!

—Hans Cloos (1886–1951),
on seeing the eruption of Mt. Vesuvius (Italy)

5.1 INTRODUCTION

Every few hundred years, one of the hills on Vulcano, an island in the Mediterranean Sea off the western coast of Italy, rumbles and spews out molten rock, glassy cinders, and dense "smoke" (actually a mixture of various gases, fine ash, and very tiny liquid droplets). Ancient Romans thought that such eruptions happened when Vulcan, the god of fire, fueled his forges beneath the island to manufacture weapons for the other gods. Geologic study suggests, instead, that eruptions take place when hot magma, formed by melting inside the Earth, rises through the crust and emerges at the surface. No one believes the Roman myth anymore, but the island's name evolved into the English word **volcano**, which geologists use to designate either an erupting vent through which molten rock reaches the Earth's surface or a mountain built from the products of eruption.

On the main peninsula of Italy, not far from Vulcano, another volcano, Mt. Vesuvius, towers over the Bay of Naples. Two thousand years ago, a prosperous Roman resort and trading town named Pompeii sprawled at the foot of Vesuvius. One morning in 79 C.E., earthquakes signaled the mountain's awakening. At 1:00 P.M. on August 24, a dark mottled cloud boiled up above Mt. Vesuvius's summit to a height of 27 km. As lightning sparked in its crown, the cloud drifted over Pompeii, turning day into night. Blocks and pellets of rock fell like hail, while fine ash and choking fumes enveloped the town (Fig. 5.1a). Frantic people rushed to escape, but for many it was too late. As the growing weight of volcanic debris began to crush buildings, an avalanche of hot ash swept over Pompeii, and by

FIGURE 5.1 The destruction of Pompeii.

(a) This 1817 painting by British artist J. M. W. Turner depicts the cataclysmic eruption of 79 C.E. that destroyed Pompeii.

(c) A plaster cast of a Pompeii resident who was buried in ash as he crouched in a corner of his house.

(b) The remains of Mt. Vesuvius lie in the distance, behind the excavated ruins of Pompeii. The town was buried and preserved beneath meters of ash and debris.

An Integrated and Innovative emedia program

Essentials of Geology, Third Edition, comes with an outstanding emedia package designed to create visually stunning lectures and promote learning.

Geotours

Using *Google Earth*'s 3-D satellite and aerial imagery, **Geotours** take students on virtual field trips to geologic sites around the world and can be used as lecture or homework/lab assignments. A **Geotours Workbook** is available online and in print.

Earth: Videos of a Planet DVD

For use in lecture, 3-D cinema quality animations help students visualize difficult concepts and 24 short film clips from the USGS Archive show them fascinating examples of geology in action.

Film clips include: Aspects of Eruption, Kilauea • Gas, and Lava Eruption, Kilauea • Lava Tubes, Kilauea • Lava Flow along the Coast • Sampling a Lava Flow • Basalt Lava Flows • Lava Crossing a Highway • Lava Eruption at Night • Lava Fountains • Mt. St. Helens 1980 • Hot Springs, Yellowstone • Mudpots, Yellowstone • Eruption of Old Faithful • Volcanic Hazards, Mt Rainier • Glacial Sculpting, Mt. Rainier • Exposing an Igneous Pluton • Debris Flows, Jiangjia Ravine • Grand Canyon: Bird's Eye View • Rift Basin Formation • Fault Development • Pleistocene Ice Sheet • Developing a Hurricane • Hurricane Winds in Action • Hurricane Storm Surge.

Animations

Over 60 original animations developed by Professor Marshak to illustrate dynamic Earth processes, emphasize plate tectonics, geologic hazards, and Earth Systems science concepts. These high-quality animations can be enlarged to full-screen view for lecture display and include VCR-like controls that allow instructors to control the pace of the animation. The animations can be easily accessed from the free StudySpace student website. Offline versions of the animations are available on the Instructor's DVD-ROM, linked from PowerPoint slides for easy classroom display.

Instructor's Resource DVD-ROM

Important Features on the Instructors' DVD-ROM and Instructor Website include:

- **Narrative Power Points**: This new source, developed by Stephen Marshak, presents images from the text and beyond with the appropriate sizing and spacing to show how they relate to one another. Each slide is fully customizable, with editable figures, labels, and captions.
- **Lecture PowerPoints**: These illustrated lecture outlines emphasize key points from each chapter
- **Animations**: Running locally on the instructor's computer, these classroom-ready animations require no plug-ins.
- **Zoomable Art**: Explore Gary Hincks's spectacular synoptic paintings in vivid detail using the zoomable art feature. Ideal for lecture use, these figures run locally from within PowerPoint—no plug-ins required.
- **GeoQuiz Clicker Questions**: These multiple-choice questions are perfect for use in classrooms equipped with "clicker" systems.

Instructor's Website

wwnorton.com/instructors

Online access to a rich array of resources: test bank, clicker questions, instructor's manual, art from the text, WebCT and Blackboard-ready content.

Blackboard and WebCT Coursepacks

Lecture and review resources—study plans, animations, Geotours, chapter quizzes, and more—in course-ready format.