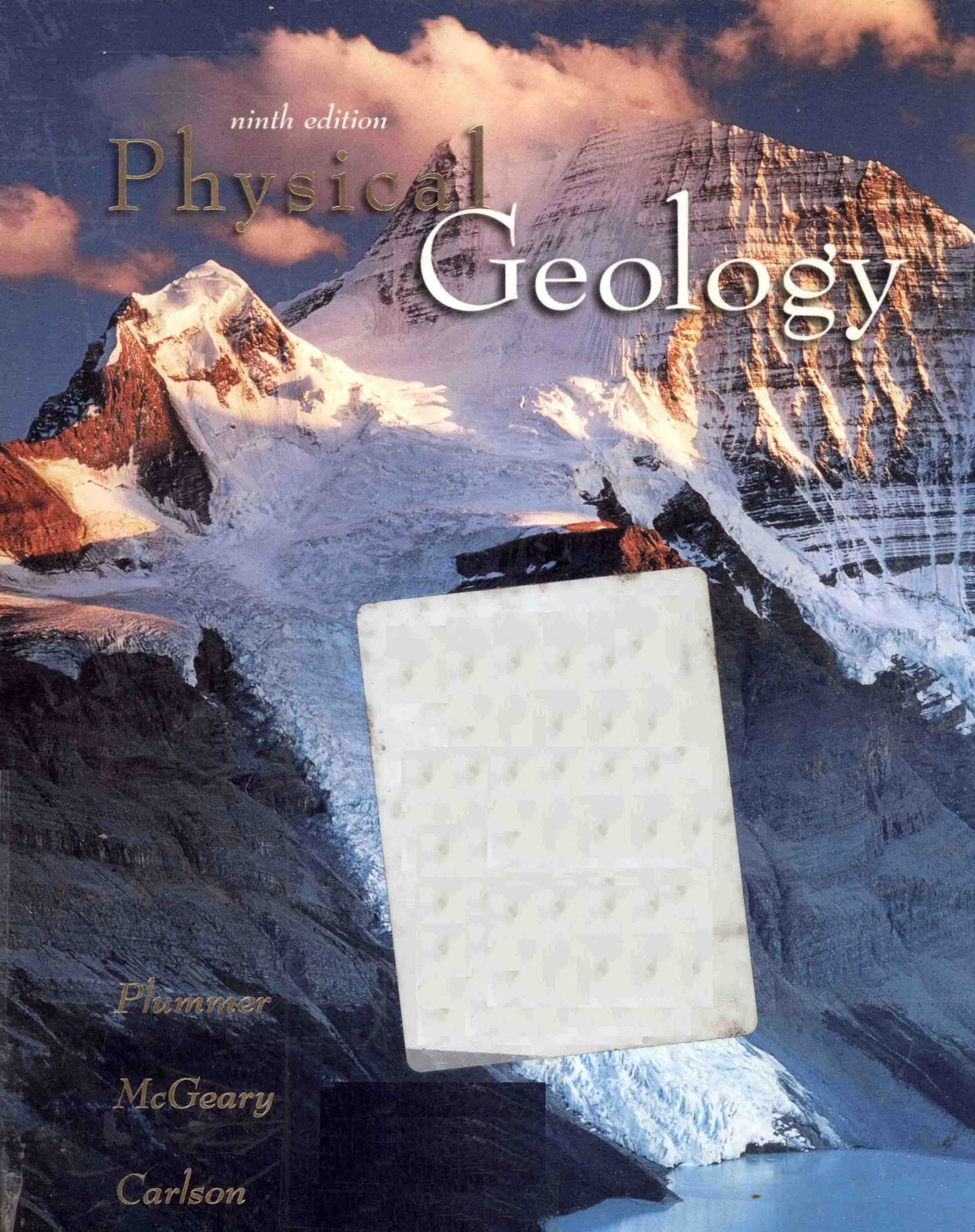
ninth edition

Physical Geology



Plummer

McGeary

Carlson

ninth edition

Physical Geology

Charles C. Plummer
California State University at Sacramento

David McGeary
Emeritus of California State University at Sacramento

Diane H. Carlson
California State University at Sacramento

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto

McGraw-Hill Higher Education

A Division of The **McGraw-Hill** Companies

PHYSICAL GEOLOGY, NINTH EDITION

This book is printed on recycled, acid-free paper containing 10% postconsumer waste.

International 1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3 2 1
Domestic 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3

ISBN 0–07–240246–6
ISBN 0–07–119951–9 (ISE)

Publisher: *Margaret J. Kemp*
Developmental editor: *Lisa Leibold*
Executive marketing manager: *Lisa Gottschalk*
Senior project manager: *Joyce M. Berendes*
Production supervisor: *Enboge Chong*
Design manager: *Stuart D. Paterson*
Cover/interior designer: *Jamie E. O'Neal*
Cover image: *Mount Robson and Berg Lake, Mount Robson Provincial Park, British Columbia, Canada.* Credit: *J.A. Kraulis /Masterfile*
Lead photo research coordinator: *Carrie K. Burger*
Photo research: *Jerry Marshall*
Supplement producer: *Brenda A. Ernzen*
Media technology producer: *Judi David*
Compositor: *Carlisle Communications, Ltd.*
Typeface: *10.5/12 Times Roman*
Printer: *Von Hoffmann Press, Inc.*

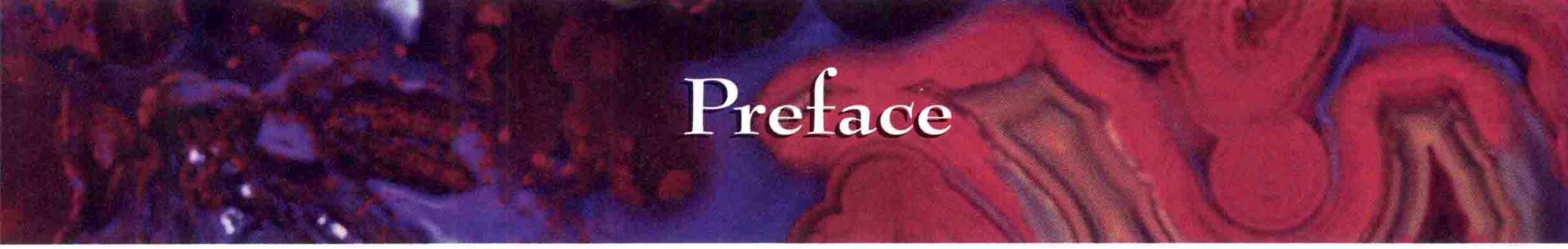
Library of Congress Cataloging-in-Publication Data

Plummer, Charles C., 1937–
Physical geology / Charles C. Plummer, David McGeary, Diane H. Carlson.—9th ed.
p. cm.
Includes index.
ISBN 0–07–240246–6 (acid-free paper)
1. Physical geology. I. McGeary, David. II. Carlson, Diane H. III. Title.

QE28.2 .P58 2003
550—dc21
2001044741
CIP

INTERNATIONAL EDITION ISBN 0–07–119951–9

www.mhhe.com



Preface

Physical Geology is a classic that has been used in classrooms for over twenty years, making it the number one physical geology text in the market today. Updated to include the latest technology and most current information, *Physical Geology* is for both non-science majors and for students contemplating majoring in geology. The new art program and interactive writing style will grab your students' attention and further their interest in the subject.

What's New in This Edition

The Internet has revolutionized the way we learn. This edition expands upon the integration of the Internet and textbook. We have added boxes that have a brief summary in the book, while the complete boxes are accessible through this book's website. We have shortened some boxes from previous editions, but placed the full box on the website. When we have found excellent and appropriate websites, we have added URLs in the text and in figure captions. Our website has enjoyable and enlightening web exercises that we have tested with our students. An exciting addition to this edition are the figures that have been animated to more clearly illustrate processes active in geology.

We have added new and revised artwork and photos. Some of the changes we have made for this edition include the following items.

In chapter 1, we have added boxes on geology as a career and the origin of the solar system. We have added isostatic adjustment to the important concepts covered in the introductory chapter and have expanded the introduction to plate tectonics. In the minerals chapter, we have added a brief section on polarizing microscopy to the discussion of double refraction and referred the interested reader to a website for more information. The introduction to the rock cycle has been moved to the beginning of the chapter on igneous rocks. In the chapter on igneous rocks and processes, we have overhauled our presentation of Bowen's reaction series to present what students need to know to understand igneous processes and use the website for a more complete presentation of the reaction series. We give a thorough, illustrated explanation of how partial melting takes place in circulating asthenosphere above subducting crust. In the volcanoes chapter we have added a section on volcanoes and myths. We have also added a section that quantifies volcanic hazards. A new box looks at Mexico's Popocatepetl's recent eruptions and the potential for a disastrous eruption.

We have added a discussion of the twelve soil orders and updated the description and diagram of a soil profile to include the E Horizon. Abrasion has been removed as an agent of erosion. Chapter 6 has been expanded to include a discussion and diagram of the relation of plate tectonic settings and types of sedimentary rock. A new astrogeology box featuring the latest Mars Global Surveyor images discusses the importance of sedimentary rock for determining whether water and life once existed on Mars; the regression and transgression box has been moved to the website and now includes animated diagrams.

In chapter 7, we have enhanced the description of the role of water in metamorphism to include why retrograde metamorphism is uncommon. We tie in the dehydration of metamorphic minerals during subduction to supplying the water necessary to partial melting of asthenosphere as described in the chapter on igneous rocks. In the chapter on geologic time, we have greatly expanded our coverage of isotopic dating to include descriptions of the mechanisms of radioactive decay. The recently dated, 4.004 billion-year-old zircon crystal and its implications regarding early Earth history are discussed in that chapter.

Chapter 10 includes new photos of Niagara Falls and braided streams. The stream piracy section has been removed. The astrogeology box has been updated to include a discussion and latest photos of stream-like features on Mars from Nanedi Vallis canyon. Web site URLs provide easy access to additional images from the Mars Orbiter Camera. Chapter 11 includes a rewrite of the Darcy's Law box to address the influence of porosity on groundwater velocity through sediment or rock as well as revision of several diagrams showing the details of groundwater flow and fluctuation. The term speleothem has been added, and a discussion of thermophyllic bacteria around hot springs and the implication for early life is presented.

In the glaciers chapter, we have added a figure showing the extent of glaciation during the ice ages for the world (rather than just North America). We have pointed out that our present sea level is not permanent, because of episodes of more extensive glaciation and global warming.

Chapter 13 has improved maps of deserts and photos of desert features and more realistic diagrams of blowouts and migration of sand dunes; an image of barchan dunes from Mars Proctor Crater has also been added. In Chapter 14, the box on rising sea level has been updated and many diagrams have been redrawn to look more realistic while retaining clarity for the beginning geology student.

In the structure chapter, text and diagrams have been rewritten and redrawn to improve clarity of difficult concepts. An exciting addition to this new edition is the animated diagrams of folding and faulting to show the mechanics of movement and accommodation of strain in the crust.

Chapter 16 has undergone a major revision to include information and spectacular photos of the recent major earthquakes that have struck around the world—Seattle, India, El Salvador, Turkey, and Taiwan. New boxes on earthquake engineering and life-saving tips on what to do before, during, and after an earthquake have been added. The discussion of tsunamis has been revised and expanded to include new diagrams, photos, and a map of travel-time and early warning systems throughout the Pacific rim.

In the chapter on Earth's interior and its geophysical properties, we have updated and expanded our coverage of the core-mantle boundary to include a discussion of the D layer and ultra low velocity zone (ULVZ) as well as incorporating exciting new discoveries about the dynamics of the deep interior of Earth. Chapter 18 includes a new astrogeology box on the origin of the ocean. Maps of features on the sea floor have been revised.

The plate tectonics chapter has been partially rewritten and expanded to include an illustrated discussion of the paleontological evidence for continental drift. It also includes new information and an accompanying figure presenting the latest ideas about the dynamics of plates and mantle plumes at depth in the mantle.

In the chapter on mountains and the continental crust, we have expanded our coverage of the Appalachians by discussing their post-orogenic erosional and uplift history. Our geologic resources chapter now includes a box on frozen methane hydrates as a potential new energy resource along with its potential to contribute to global warming.

Features

The Internet has revolutionized the way we obtain knowledge and this book makes full use of its potential to help students learn. We have made the process student-friendly by having all websites that we mention in the book, a mouse-click away from this book's website. (We also include all URLs in the textbook for those who wish to go directly to a site.)

Within our website we have Internet exercises to allow students to get the most out of appropriate sites as well as raise interest for independent, further exploration on a topic. We expect to add more sites and exercises to our web pages as we discover new ones after the book has gone to press. Our website also features on-line quizzes and a study guide to help a student succeed in a geology course.

Technology-Related Supplements

For Instructors:

- Online Learning Center at htm://www.mhhe.com/plummer9e/ containing:
    - Access to PowerWeb—Geology
    - Password Protected Instructor's Manual
    - Password Protected Test Item File
    - PowerPoint Slides containing lecture outlines, line art, and photographs from the textbook
    - Lecture Outlines
    - Web Links and more!
- Visual Resource Library CD-ROM with all line art and most photographs from the text
- Physical Geology Photo CD-ROM with 650 images (in addition to images from the textbook)
- Interactive Plate Tectonics CD-ROM
- Geoscience Videotape Library (available to qualified adopters)
- Computerized testing software
- PowerPoint CD-ROM containing lecture outlines, line art, and photographs from the textbook

For Students:

- Online Learning Center at *www.mhhe.com/plummer9e/* containing:
    - FREE Student Study Guide
    - Animations of difficult concepts
    - Interactive Quizzing
    - Key Term Flashcards
    - Access to PowerWeb—Geology
    - Web Links and more!

Printed Supplements

- 224 Transparencies
- 350 Slides
- *Laboratory Manual for Physical Geology,* 11th edition, by Zumberge, Rutford, and Carter, ISBN 0-07-239195-2
- *Laboratory Manual for Physical Geology,* 4th edition, by Jones, ISBN 0-07-243655-7
- *Student Atlas of Environmental Issues,* by Allen, ISBN 0-697-36520-4
- *You Can Make a Difference: Be Environmentally Responsible,* by Getis, ISBN 0-07-292416-0

Acknowledgements

We have tried to write a book that will be useful to both students and instructors. We would be grateful for any comments by users, especially regarding mistakes within the text or sources of good geological photographs.

Diane Carlson would like to thank her husband, Reid Buell, for his support and technical assistance with several chapters. We thank Susan Slaymaker for writing the planetary geology material originally in early editions.

We are also very grateful to the following reviewers of the ninth edition for their careful evaluation an useful suggestions for improvement.

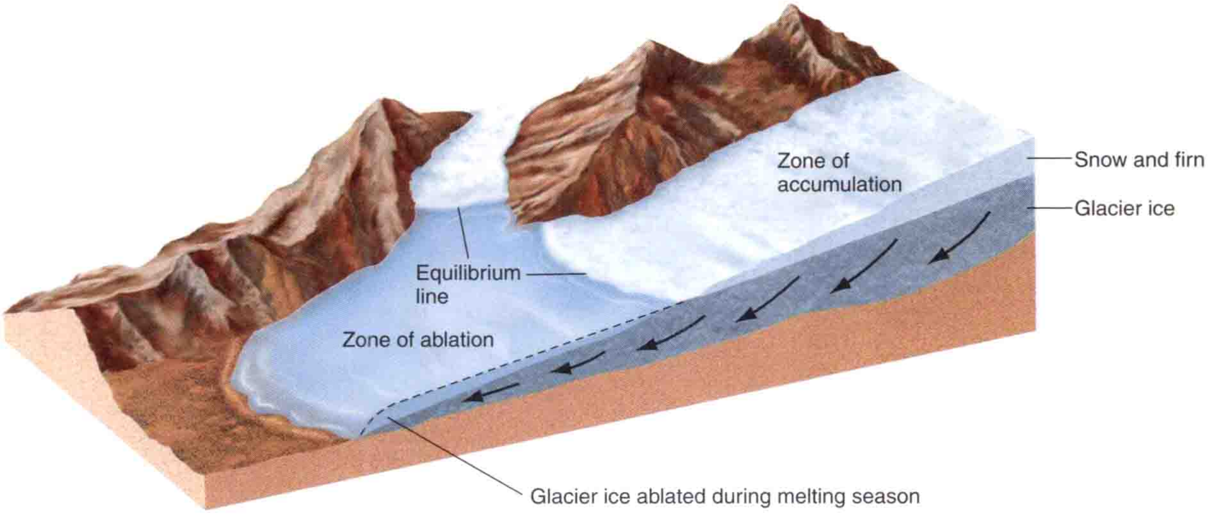
William W. Atkinson, Jr., *University of Colorado–Boulder*
J. Bret Bennington, *Hofstra University*
Stephen K. Boss, *University of Arkansas–Fayetteville*
Kevin Cornwell, *California State University, Sacramento*
P. Thompson Davis, *Bentley College*
Dave Evans, *California State University, Sacramento*
Tim Flood, *St. Norbert College*
Norm Harris, *Nassau Community College*
Tim Horner, *California State University, Sacramento*
Chris Hill, *Fullerton College*
Paul Hudak, *University of North Texas*
Leslie Kanat, *Johnson State College*
Alan Lester, *University of Colorado–Boulder*
Donald Lindsley, *SUNY at Stony Brook*
Jerry F. Magloughlin, *Colorado State University*
Penelope Morton, *University of Minnesota–Duluth*
Doug Oliver, *Tarrant County College*
Eugene Perry, *Northern Illinois University*
Dr. John D. Pigott, *University of Oklahoma*
Randye L. Rutberg, *Hunter College*
William E. Sanford, *Colorado State University*
Kevin J. Smart, *University of Oklahoma*
Mark Swanson, *University of Southern Maine*
Sarah Ulerick, *Lane Community College*
Andrew Warnock, *Colorado State University*
John Wickham, *University of Texas–Arlington*

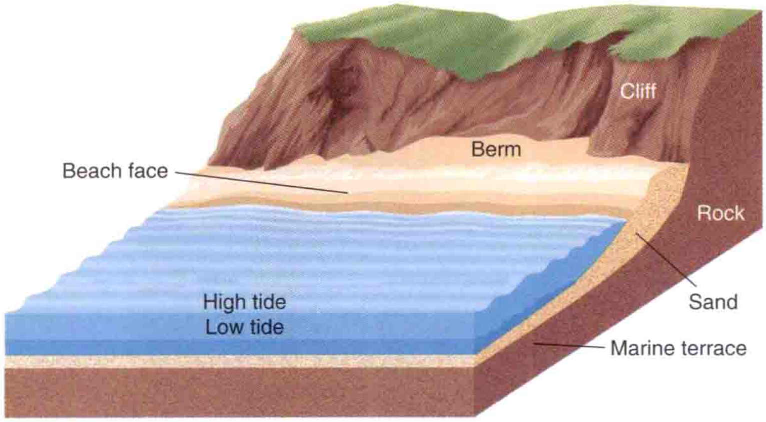
Take a Closer Look at Today's WORLD...

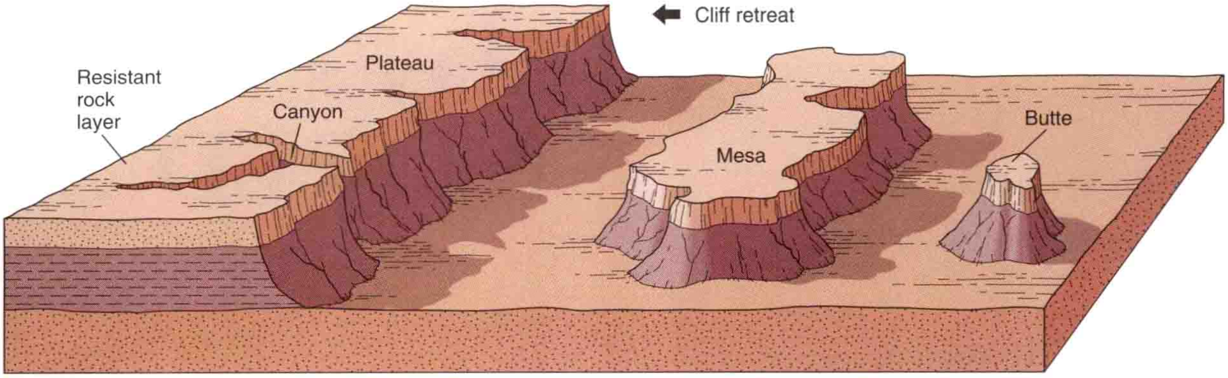
The Proven *Physical Geology* Learning System

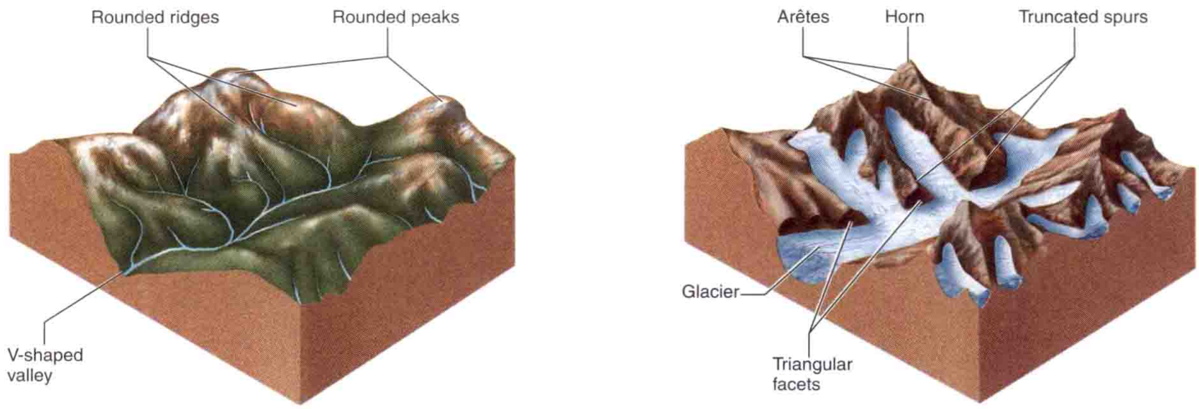
Updated Art Program

To help you visualize and comprehend difficult concepts, we have enhanced over 150 figures, many as 3-dimensional art.



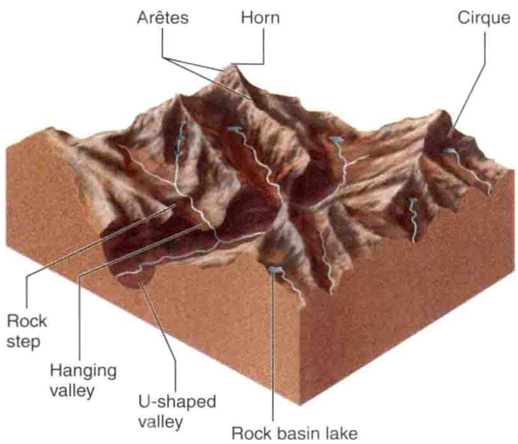






A

B

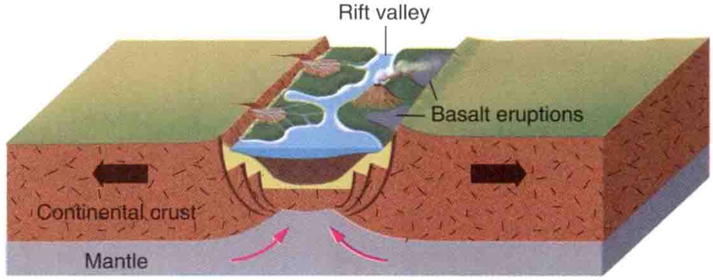


C

Learn more about this text.

Visit the Physical Geology Website:

www.mhhe.com/plummer9e



Boxed Readings

Each chapter contains at least one of 3 types of boxes—**In Greater Depth, Environmental Geology,** and **Astrogeology.** The *In Greater Depth* boxes cover interesting topics that are usually not an essential part of an introductory geology course. *Environmental geology* boxes show how material pertaining to physical geology relates environmental concerns, such as oil spills, exploiting natural resources and mitigating natural disasters. *Astrogeology* boxes relate topics discussed in the text to what has been discovered on other planets or the solar system.

9.2 ENVIRONMENTAL GEOLOGY

LOS ANGELES, A MOBILE SOCIETY

The following satirical newspaper column was written by humorist Art Buchwald in 1978, a year, like the "El Niño" year of 1998, in which southern California had many landslides because of unusually wet weather.

Los Angeles—I came to Los Angeles last week for rest and recreation, only to discover that it had become a rain forest.

I didn't realize how bad it was until I went to dinner at a friend's house. I had the right address, but when I arrived there was nothing there. I went to a neighboring house where I found a man bailing out his swimming pool.

I beg your pardon, I said. Could you tell me where the Cables live?

"They used to live above us on the hill. Then, about two years ago, their house slid down in the mud, and they lived next door to us. I think it was last Monday, during the storm, that their house slid again, and now they live two streets below us, down there. We were sorry to see them go—they were really nice neighbors."

I thanked him and slid straight down the hill to the new location of the Cables' house. Cable was clearing out the mud from his car. He apologized for not giving me the new address and explained, "Frankly, I didn't know until this morning whether the house would stay here or continue sliding down a few more blocks."

Cable, I said, you and your wife are intelligent people, why do you build your house on the top of a canyon, when you know that during a rainstorm it has a good chance of sliding away?

"We did it for the view. It really was fantastic on a clear night up there. We could sit in our Jacuzzi and see all of Los Angeles, except of course when there were brush fires.

"Even when our house slid down two years ago, we still had a great sight of the airport. Now I'm not too sure what kind of view we'll have because of the house in front of us, which slid down with ours at the same time."

But why don't you move to safe ground so that you don't have to worry about rainstorms?

"We've thought about it. But once you live high in a canyon, it's hard to move to the plains. Besides, this house is built solid and has about three more good mudslides in it."

Still, it must be kind of hairy to sit in your home during a deluge and wonder where you'll wind up next. Don't you ever have the desire to just settle down in one place?

"It's hard for people who don't live in California to understand how we people out here think. Sure we have floods, and fire and drought, but that's the price you have to pay for living the good life. When Esther and I saw this house, we knew it was a dream come true. It was located right on the tippy top of the hill, way up there. We would wake up in the morning and listen to the birds, and eat breakfast out on the patio and look down on all the smog.

"Then, after the first mudslide, we found ourselves living next to people. It was an entirely different experience. But by that time we were ready for a change. Now we've slid again and we're in a whole new neighborhood. You can't do that if you live on solid ground. Once you move into a house below Sunset Boulevard, you're stuck there for the rest of your life.

"When you live on the side of a hill in Los Angeles, you at least know it's not going to last forever."

Then, in spite of what's happened, you don't plan to move out?

"Are you crazy? You couldn't replace a house like this in L.A. for $500,000."

What happens if it keeps raining and you slide down the hill again?

"It's no problem. Esther and I figure if we slide down too far, we'll just pick up and go back to the top of the hill, and start all over again; that is, if the hill is still there after the earthquake."

Reprinted by permission of the author.

Further Reading

John McPhee's *The control of nature* contains a factual, and highly readable, account of 1978 landslides in southern California.

10.3 ASTROGEOLOGY

STREAM FEATURES ON THE PLANET MARS

There is probably no liquid water on the surface of Mars today. With the present surface temperatures, atmospheric pressures, and water content in the Martian atmosphere, any liquid water would immediately evaporate. There are some indications, however, that conditions may have been different in the past and that liquid water existed on Mars, at least temporarily. Certain features on Mars, called *channels*, closely resemble certain types of stream channels on Earth. They have tributary systems and meanders and are sometimes braided. The channels trend downslope and tend to get wider toward their mouths. These Martian channels are restricted to certain areas and appear to have been formed by intermittent episodes of erosion.

One type of stream channel on Mars appears to have formed by large flooding events and is similar in appearance to those observed in the Channeled Scablands of Washington state. The Channeled Scablands were formed by extensive flooding during the Pleistocene glacial ages when a naturally formed ice dam broke and released water from a large lake. The mouth of Ares Vallis, an ancient Martian flood channel similar to those observed in the Channeled Scablands, was selected for the July 4, 1997 landing of the Pathfinder spacecraft and Sojourner Rover. It was postulated that a variety of rock types should be present in the mouth of an ancient flood channel. The first photos from the Mars Pathfinder Lander and Sojourner Rover, a "robotic field geologist," revealed a variety of rock types (box figure 1) in what does appear to be an ancient outflow channel.

Box 10.3 — FIGURE 2
Meandering channel and flat terraces within the Nanedi Vallis canyon, which resemble stream features cut by running water on Earth.
Photo courtesy NASA

A second kind of Martian channel (box figure 2), a meandering streamlike feature, occurs on the older surfaces of Mars (more than 3.5 billion years old) and may indicate that early in the history of Mars temperature and atmospheric conditions were such that rainfall could have occurred and long-lived river systems

Box 10.3 — FIGURE 1
View from the Mars Pathfinder Lander showing the Sojourner Rover and a variety of rocks from Ares Vallis.
Photo courtesy of Jet Propulsion Laboratory/NASA

8.1 IN GREATER DEPTH

HIGHLIGHTS OF THE EVOLUTION OF LIFE THROUGH TIME

The oldest 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, similar to viruses, 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 650 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 8.21) evolved into many species and were particularly abundant during the Cambrian. 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 of fish (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 animals. Land plants, however, date back to the Ordovician. Reptiles 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 reptiles 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, such as ichthysaurs, lived in the Mesozoic seas while flying reptiles, pterosaurs, 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 the 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), however, mammals pale in comparison to insects. Insects have been around far longer than mammals and now account for an estimated 1 million species.

Related Web Resource
University of California Museum of Paleontology
www.ucmp.berkeley.edu/

End of Chapter Learning Aids

Additional support helps you make the grade.

Use these helpful end-of-chapter learning aids to prepare for test and quizzes:

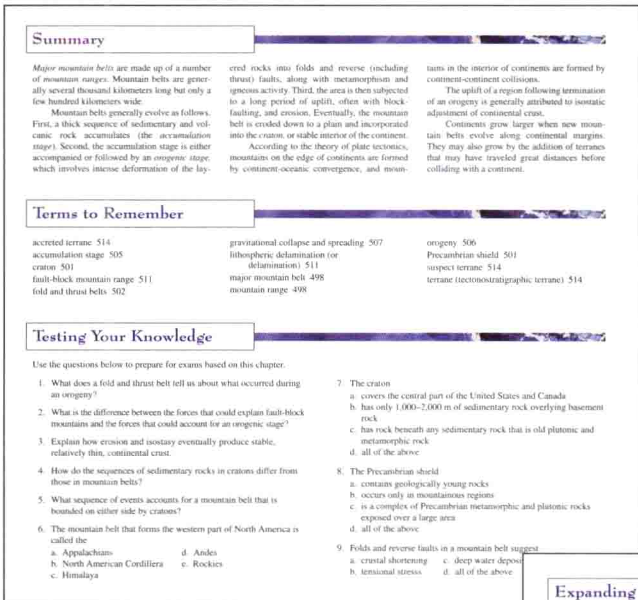
Summary—overviews of chapter content.

Terms to Remember—important terms to review and remember.

Testing Your Knowledge—realistic sample tests you can use to prepare for exams and improve your grades.

Expanding Your Knowledge—questions that help you develop critical thinking skills.

Exploring Resources—supplemental references in a number of different media.



Summary

Major mountain belts are made up of a number of *mountain ranges*. Mountain belts are generally several thousand kilometers long but only a few hundred kilometers wide.

Mountain belts generally evolve as follows. First, a thick sequence of sedimentary and volcanic rock accumulates (the *accumulation stage*). Second, the accumulation stage is either accompanied or followed by an *orogenic stage*, which involves intense deformation of the layered rocks into folds and reverse (including thrust) faults, along with metamorphism and igneous activity. Third, the area is then subjected to a long period of uplift, often with block-faulting, and erosion. Eventually, the mountain belt is eroded down to a plain and incorporated into the *craton*, or stable interior of the continent.

According to the theory of plate tectonics, mountains on the edge of continents are formed by continent-oceanic convergence, and mountains in the interior of continents are formed by continent-continent collisions.

The uplift of a region following termination of an orogeny is generally attributed to isostatic adjustment of continental crust.

Continents grow larger when new mountain belts evolve along continental margins. They may also grow by the addition of terranes that may have traveled great distances before colliding with a continent.

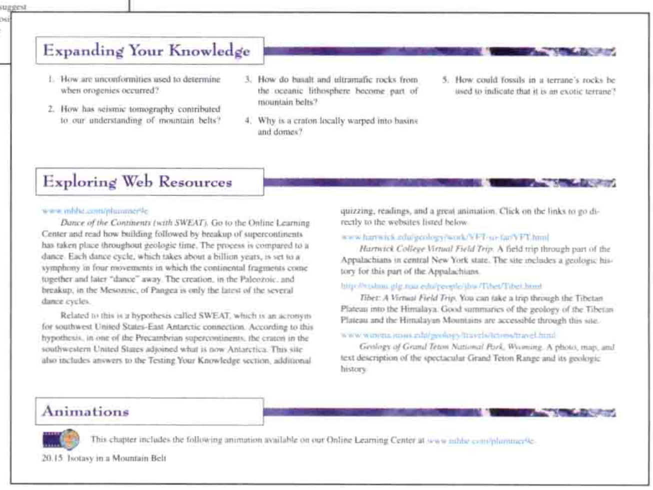
Terms to Remember

accreted terrane 514
accumulation stage 505
craton 501
fault-block mountain range 511
fold and thrust belts 502
gravitational collapse and spreading 507
lithospheric delamination (or delamination) 511
major mountain belt 498
mountain range 498
orogeny 506
Precambrian shield 501
suspect terrane 514
terrane (tectonostratigraphic terrane) 514

Testing Your Knowledge

Use the questions below to prepare for exams based on this chapter.

1. What does a fold and thrust belt tell us about what occurred during an orogeny?
2. What is the difference between the forces that could explain fault-block mountains and the forces that could account for an orogenic stage?
3. Explain how erosion and isostasy eventually produce stable, relatively thin, continental crust.
4. How do the sequences of sedimentary rocks in cratons differ from those in mountain belts?
5. What sequence of events accounts for a mountain belt that is bounded on either side by cratons?
6. The mountain belt that forms the western part of North America is called the
   a. Appalachians
   b. North American Cordillera
   c. Himalaya
   d. Andes
   e. Rockies
7. The craton
   a. covers the central part of the United States and Canada
   b. has only 1,000–2,000 m of sedimentary rock overlying basement rock
   c. has rock beneath any sedimentary rock that is old plutonic and metamorphic rock
   d. all of the above
8. The Precambrian shield
   a. contains geologically young rocks
   b. occurs only in mountainous regions
   c. is a complex of Precambrian metamorphic and plutonic rocks exposed over a large area
   d. all of the above
9. Folds and reverse faults in a mountain belt suggest
   a. crustal shortening
   b. tensional stresss
   c. deep water deposi
   d. all of the above



Expanding Your Knowledge

1. How are unconformities used to determine when orogenies occurred?
2. How has seismic tomography contributed to our understanding of mountain belts?
3. How do basalt and ultramafic rocks from the oceanic lithosphere become part of mountain belts?
4. Why is a craton locally warped into basins and domes?
5. How could fossils in a terrane's rocks be used to indicate that it is an exotic terrane?

Exploring Web Resources

www.mhhe.com/plummer9e

Dance of the Continents (with SWEAT). Go to the Online Learning Center and read how building followed by breakup of supercontinents has taken place throughout geologic time. The process is compared to a dance. Each dance cycle, which takes about a billion years, is set to a symphony in four movements in which the continental fragments come together and later "dance" away. The creation, in the Paleozoic, and breakup, in the Mesozoic, of Pangea is only the latest of the several dance cycles.

Related to this is a hypothesis called SWEAT, which is an acronym for southwest United States-East Antarctic connection. According to this hypothesis, in one of the Precambrian supercontinents, the craton in the southwestern United States adjoined what is now Antarctica. This site also includes answers to the Testing Your Knowledge section, additional quizzing, readings, and a great animation. Click on the links to go directly to the websites listed below.

www.hartwick.edu/geology/work/VFT-so-far/VFT.html

Hartwick College Virtual Field Trip. A field trip through part of the Appalachians in central New York state. The site includes a geologic history for this part of the Appalachians.

Tibet: A Virtual Field Trip. You can take a trip through the Tibetan Plateau into the Himalaya. Good summaries of the geology of the Tibetan Plateau and the Himalayan Mountains are accessible through this site.

www.winona.msus.edu/geology/travels/tetons/travel.html

Geology of Grand Teton National Park, Wyoming. A photo, map, and text description of the spectacular Grand Teton Range and its geologic history.

Animations

This chapter includes the following animation available on our Online Learning Center at www.mhhe.com/plummer9e.

20.15 Isotasy in a Mountain Belt

PageOut

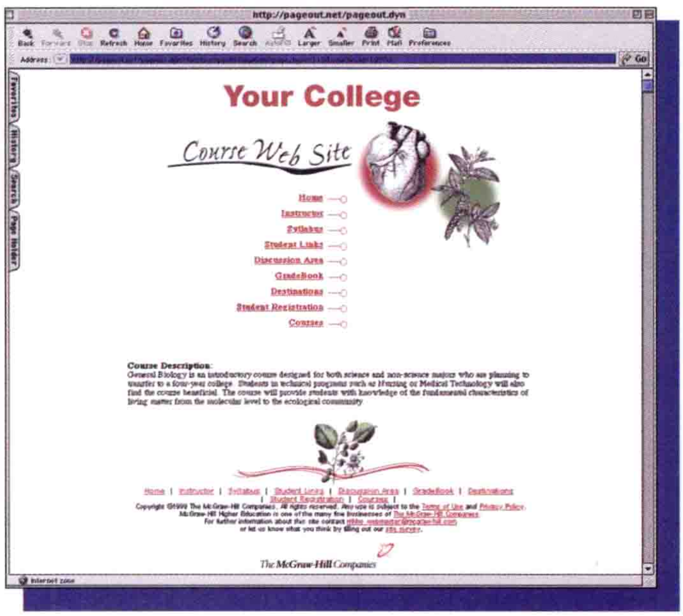
Proven. Reliable. Class-tested.

More than 16,000 professors have chosen **PageOut** to create course websites. And for good reason: **PageOut** offers powerful features, yet is incredibly easy to use.

Now you can be the first to use an even better version of **PageOut.** Through class-testing and customer feedback, we have made key improvements to the grade book, as well as the quizzing and discussion areas. Best of all, **PageOut** is still free with every McGraw-Hill textbook. And students needn't bother with any special tokens or fees to access your **PageOut** website.

Customize the site to coincide with your lectures.

Complete the **PageOut** templates with your course information and you will have an interactive syllabus online. This feature lets you post content to coincide with your lectures. When students visit your **PageOut** website, your syllabus will direct them to components of McGraw-Hill web content germane to your text, or specific material of your own.



New Features based on customer feedback:

- Specific question selection for quizzes
- Ability to copy your course and share it with colleagues or use as a foundation for a new semester
- Enhanced gradebook with reporting features
- Ability to use the **PageOut** discussion area, or add your own third party discussion tool
- Password protected courses

Short on time? Let us do the work.

Send your course materials to our McGraw-Hill service team. They will call you for a 30-minute consultation. A team member will then create your **PageOut** website and provide training to get you up and running. Contact your McGraw-Hill Representative for details.

Contact your McGraw-Hill sales representative for more information or visit *www.mhhe.com*.

The Online Learning Center

Your Password to Success

http://www.mhhe.com/plummer9e/

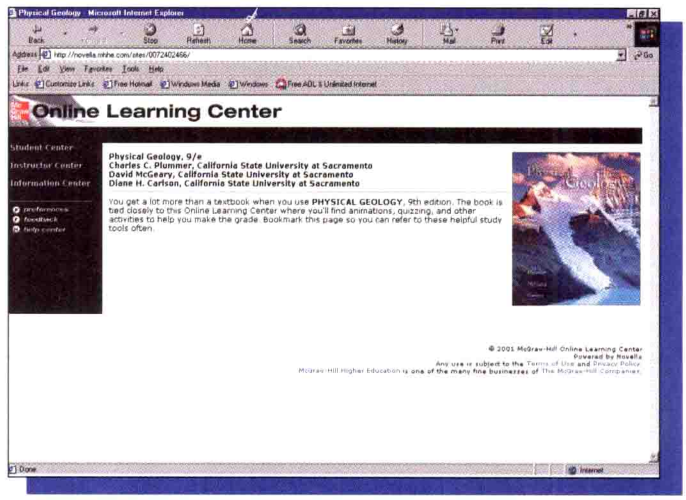
This text-specific website allows students and instructors from all over the world to communicate. Instructors can create a more interactive course with the integration of this site, and students will find tools such as practice quizzes, key term flashcards, and a FREE student study guide that will help them improve their grades and learn that physical geology can be fun.

Student Resources

- Free Student Study Guide
- Animations of difficult concepts
- Interactive Quizzing
- Key Term Flashcards
- Access to PowerWeb—Geology
- Web Links and more!

Instructor Resources

- Access to PowerWeb—Geology
- Password Protected Instructor's Manual
- Password Protected Test Item File
- PowerPoint Slides containing lecture outlines, line art, and photographs from the textbook
- Web links and more!



Imagine the advantages of having so many learning and teaching tools all in one place—all at your fingertips—FREE.

Contact your McGraw-Hill sales representative for more information or visit *www.mhhe.com*.

PowerWeb—Geology

www.dushkin.com/powerweb

Free Power Web—your professor's turnkey solution for keeping your course current with the Internet!

PowerWeb is a password protected Web site developed by McGraw-Hill/Dushkin giving instructors and students:

- Course-specific materials
- Refereed course-specific web links and articles
- Student study tools—quizzing, review forms, time management tools, web research
- Interactive exercises.
- Weekly updates with assessment
- Informative and timely world news
- Access to Northern Light Research Engine (received multiple Editor's Choice awards for superior capabilities from "PC Magazine")
- Material on how to conduct Web research
- Daily news feed of topic specific news

Meet the Authors

David McGeary, Diane Carlson, and Charles Plummer at an outcrop of a Sierra Nevadan intrusive body.

Charles Plummer

Professor Charles "Carlos" Plummer grew up in the shadows of volcanoes in Mexico City. There, he developed a love for mountains and mountaineering that eventually led him into geology. He received his B.A. degree from Dartmouth College. After graduation, he served in the U.S. Army as an artillery officer. He resumed his geological education at the University of Washington where he received his M.S. and PhD degrees. His geologic work has been in mountainous and polar regions, notably Antarctica (where a glacier is named in his honor). He taught at Olympic Community College in Washington before joining the faculty at California State University, Sacramento.

At CSUS he taught optical mineralogy, metamorphic petrology, and field courses before his semi-retirement. He continues to teach introductory courses. He flies airplanes, skis, and recently became a certified open water SCUBA diver. (plummercc@csus.edu)

David McGeary

David McGeary retired from teaching in 1992 and from textbook writing in 1995. His activities today are non-geological—tending his house and land, traveling, carpentry, blacksmithing, and acting in community theatre.

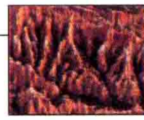
Diane Carlson

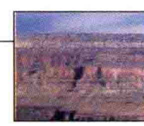
Professor Diane Carlson grew up on the glaciated Precambrian shield of northern Wisconsin and received an A.A. degree at Nicolet College in Rhinelander and her B.S. in geology at the University of Wisconsin at Eau Claire. She continued her studies at the University of Minnesota–Duluth where she studied the structural complexities of high-grade metamorphic rocks along the margin of the Idaho batholith for her master's thesis. The lure of the West and an opportunity to work with the U.S. Geological Survey to map the Colville batholith in northeastern Washington, led her to Washington State University for her PhD. Dr. Carlson accepted a position at California State University, Sacramento after her PhD and teaches physical geology, structural geology, environmental geology, and field geology. Professor Carlson is a recipient of the Outstanding Teacher Award from the CSUS School of Arts and Sciences. She is also actively engaged in researching the structural and tectonic evolution of part of the Foothill Fault System in the northern Sierra Nevada of California. (*carlsondh@csus.edu*)

Contents in Brief

Contents

*These end-of-chapter sections appear in every chapter.





Chapter 9

Chapter 10

Chapter 11

Chapter 12

Chapter 13