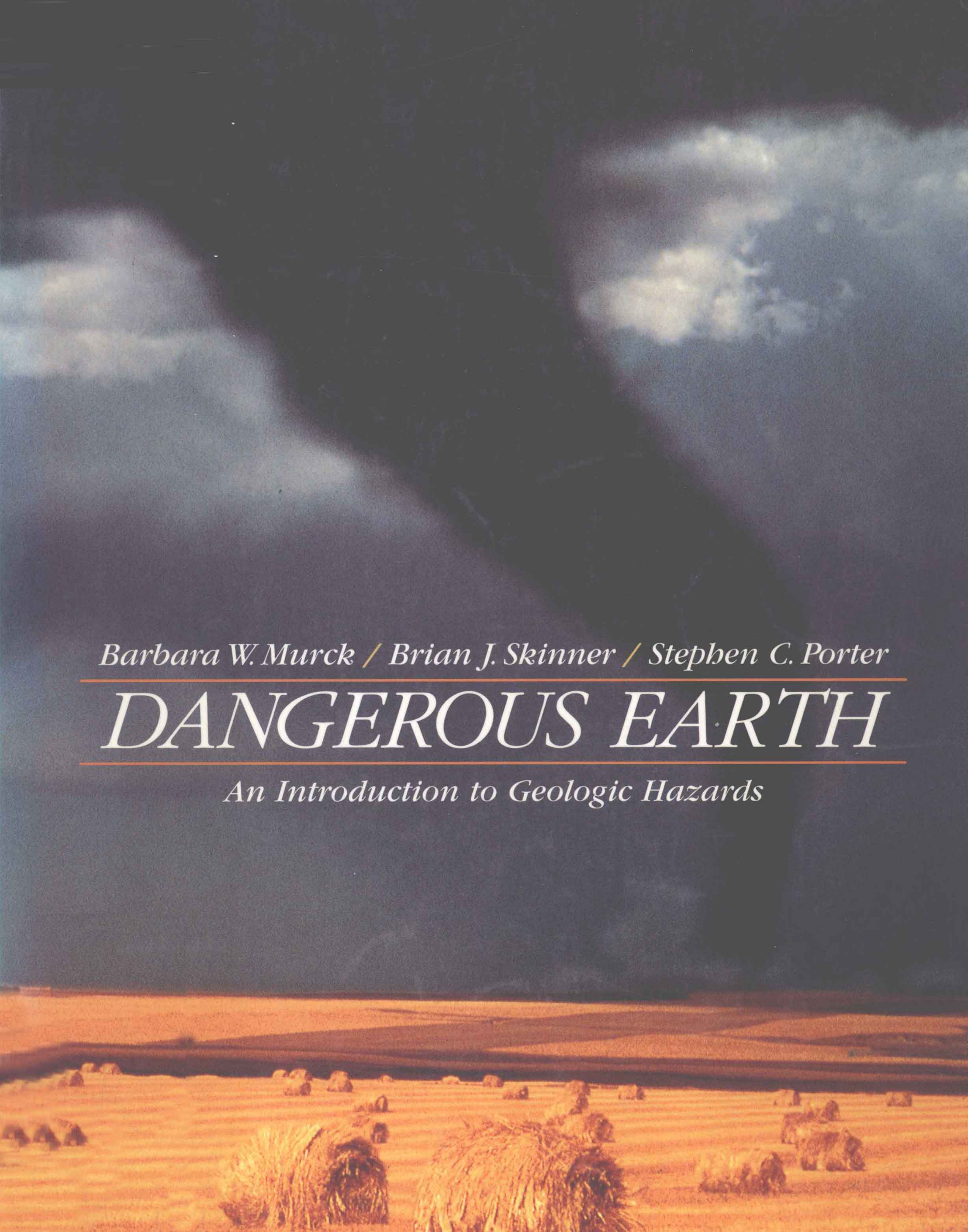

Barbara W. Murck / Brian J. Skinner / Stephen C. Porter

DANGEROUS EARTH

An Introduction to Geologic Hazards

DANGEROUS EARTH

An Introduction to Geologic Hazards

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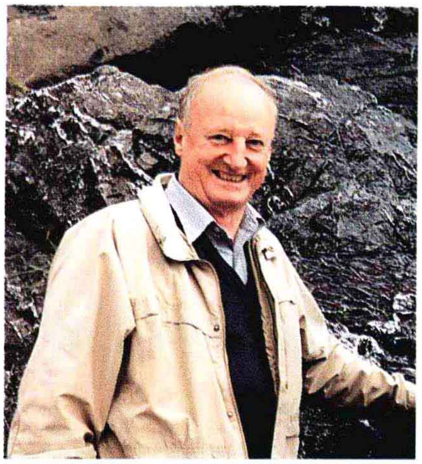
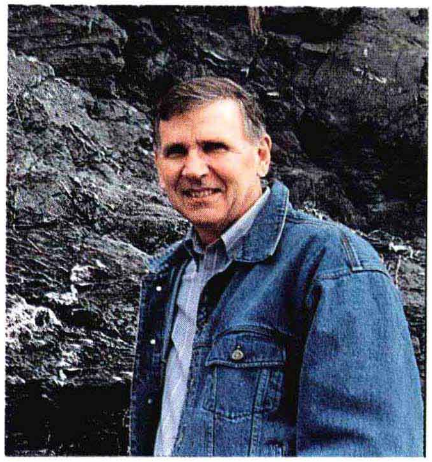
ABOUT THE AUTHORS

*T*he authors of this book bring a wealth of professional and personal knowledge, training, and experience to the project. Among them, they have carried out geologic fieldwork on all of the Earth's continents. The diversity demonstrated in their own careers reflects the broad range of challenges that characterize geology today.

As an undergraduate ***Barbara Murck*** was a confirmed nonscientist, until an introductory geology course changed her plans. Since then her professional focus has ranged from igneous geochemistry and ore-deposit petrography to alternative energy sources and state-of-the-environment reporting. Her current work focuses primarily on environmental management training for decision makers in developing countries.



Throughout his career as a geologist, ***Brian Skinner's*** research has focused on the physical properties of minerals and on the genesis of base-metal deposits. He has worked extensively in Australia, Africa, and North America and with students in Asia and Europe. With Yale University colleagues, he has had the opportunity to explore a diversity of Earth science topics, including oceanography and climatic change, volcanic gases, economic models of resource depletion, and the geologic aspects of the space program.



Stephen Porter's professional career has largely been concerned with studies of glaciation in many of the world's major mountain systems and with the history of the climatic changes their deposits record. He has also studied the evolution of midocean and continental volcanoes and the products of their prehistoric eruptions and how volcanic eruptions may have influenced the Earth's climate. With colleagues from around the world, he has studied the hazards of large rockfalls in the Alps and the thick, extensive deposits of windblown dust in China that provide one of the longest continuous records of climatic change during the past several million years.

The authors' global perspective is reflected in this book by examples and illustrations from numerous foreign areas, for it is important to emphasize that geology is a global science—a science that recognizes no political boundaries. Only by studying the Earth in its entirety can we hope to understand how our amazing planet works, how geologic hazards affect our lives, and how, in turn, human activities affect the functioning of the Earth system.

PREFACE

HOW *DANGEROUS EARTH* CAME TO BE

Geologic hazards are always with us. Even when we are not personally threatened by events such as floods, earthquakes, tornadoes, and volcanic eruptions, we are exposed to a constant stream of news reports of the impacts of hazardous events elsewhere. Recognizing the magnitude of these impacts on modern society, the National Academy of Sciences, supported by the United Nations and other institutions around the world, declared the 1990s to be the International Decade of Natural Hazard Reduction. In light of so much attention, departments of geology and environmental science have found it increasingly helpful to develop undergraduate courses devoted to the study of hazards. The concept for *Dangerous Earth* grew out of the need for a comprehensive, full-color hazards text to serve such courses. As explained on page xi, *Dangerous Earth* comprises those parts of a more comprehensive text, *Environmental Geology,* that are specifically devoted to hazards and the basic geologic concepts needed to understand them.

Students respond best when they understand the reasons for learning; hence, frequent explanations are offered. They ask, for example, why it is important to learn about the interior of the Earth? The answer: because internal Earth processes are fundamental in forming the landscape and in causing hazardous Earth processes like earthquakes and volcanoes. They wonder, why is it necessary to study the properties of rocks, minerals, and soils? The response: because these properties can affect human interests in a wide variety of ways—in their ability to resist mass wasting, or in the way they transmit earthquake waves, for example. The basic geology topics covered in this book were selected to provide the foundation of concepts and terminology needed to understand the impacts of geologic hazards on human interests. We hope that *Dangerous Earth* will help readers become more aware of the geologic nature of our environment and the role of geoscientists in events of public concern. And we hope our readers will emerge better prepared to make informed decisions about the natural processes that affect our lives on a daily basis.

Organization and Special Features

In *Part I: Geologic Framework* we provide a brief background of Earth system science and physical geology. In this part of the book you will find basic concepts and terminology concerning the structure and materials of the Earth and the functioning of Earth systems and cycles. *Part II: Hazardous Geologic Processes* covers the broad range of geologic events that are damaging to human interests, such as earthquakes, volcanic eruptions, landslides, floods, meteorite impacts, and others. We look at both the human impacts of such events and the geologic processes that underlie them. Each of the two main parts opens with an essay designed to set the context and provide an overview of fundamental concepts in the ensuing chapters. The essay for Part I, entitled *The Home Planet,* puts the Earth in perspective by placing it in the context of the solar system as a whole and examining some of the Earth-forming processes that have made this planet hospitable to life. *Assessing Geologic Hazards and Risks,* the essay for Part II, introduces natural, geologic, technologic, and anthropogenic hazards as well as some of the approaches used to assess human vulnerability to these hazards.

Each chapter opens with a short vignette or anecdote. The purpose of these vignettes is to provide a glimpse into some aspect of the geologic environment and to show how that environment affects humans (and vice versa). Each chapter also includes a *Summary* of key points and a list of *Important Terms to Remember.* A page reference is given for each of the important terms, and a complete *Glossary* is provided at the end of the book. The *Questions and Activities* that end each chapter are meant to stimulate independent thought and study and critical thinking. Throughout each chapter you will also find material set aside in shaded boxes. The boxes perform two distinct functions: (1) Boxes entitled *The Human Perspective* are intended to highlight particular aspects of the human–planet relationship, such as human impacts on the environment, the impacts of geologic processes on human interests, or human institutions (projects, programs, etc.) devoted to some aspect of geology. (2) Boxes entitled *Focus On . . .* are intended to provide an in-depth look at some of the more technical aspects of geology and related sciences. The *Appendices* at the end of the book contain useful reference information for students (and instructors) on units and conversions, the chemical elements, and the geologic time scale.

Supplements

A full range of supplementary material is available to assist both instructors and students using either *Environmental Geology* or *Dangerous Earth.* The ***Environmental Geology Study Guide*** provides an inexpensive way for students to get the most out of these textbooks. It includes chapter summaries, brief discussions of the most important terms and key points in each chapter, study pointers and guidelines, and practice questions to help students review and apply concepts and prepare for tests. The ***Environmental Geology Instructor's Manual and Test Bank*** includes chapter synopses and lecture lead-ins, sample syllabi and options for course organization, suggestions for further reading, a full description of supplementary materials, and additional written, audiovisual, and computer resources. The *Test Bank* is also available in computerized format.

The ***Wiley Geology Transparency Set*** includes 150 full-color textbook illustrations, resized and edited for maximum effectiveness in large lecture halls. The ***Wiley Geology Slide Set*** comprises the 150 images provided as transparency acetates in 35-mm slide form. The ***Environmental Geology Overhead Transparency Set*** consists of full-color line drawings, also available as 35-mm slides in the ***Environmental Geology Slide Set.*** The ***Wiley Geosciences CD-ROM*** provides animations of key concepts and many images from *Environmental Geology* and *Dangerous Earth,* as well as from *Dynamic Earth* and *The Blue Planet,* by Brian J. Skinner and Stephen C. Porter.

ACKNOWLEDGMENTS

As always, it has been a pleasure to work with the talented, efficient, and ever-patient professionals at John Wiley & Sons and the freelance experts associated with them. The concept of producing the *Environmental Geology* text originated with Barry Harmon, then Earth Sciences editor, and publisher Kaye Pace, and continued under the editorial guidance of Chris Rogers. Developmental editor Rachel Nelson guided *Environmental Geology* to a successful finish. Others who contributed their considerable talents to the success of *Environmental Geology* include (in no particular order): Bonnie Cabot, Stella Kupferberg, Alexandra Truitt, Kim Khatchatourian, Michelle Orlans, Anna Melhorn, Karin Kincheloe, John Woolsey and his staff, Eric Stano, Carolyn Smith, Cathy Faduska, Diane Kraut, Beth Balch, and Pui Szeto. Special mention is due to Judith Peatross, who contributed editorial advice and authored a number of the boxes that appear throughout the book.

The idea of building on the foundation of *Environmental Geology* to produce a full-color geologic hazards text was proposed by editor Cliff Mills, assisted by Cathy Donovan. The project was approved by publisher Kaye Pace and executive editor Nedah Rose. The production coordinators for *Dangerous Earth* were Elizabeth Swain and Jeanie Berke, who deftly handled many last-minute changes. Many of those mentioned above also contributed further efforts to *Dangerous Earth.*

Careful reading and extensive commentary by many colleagues improved both *Environmental Geology* and *Dangerous Earth* immeasurably. The thoughtful suggestions of these reviewers touched on every aspect, from overall organization to the tiniest details. They helped keep us up-to-date in a science that is constantly changing. Through their comments the reviewers made available to us their many years of collective experience in conveying this material to students. Thank you to those who assisted us by reviewing all or part of these manuscripts. They include:

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P U B L I S H E R ' S N O T E

Dangerous Earth is the first ten chapters of a more comprehensive 18 chapter text entitled Environmental Geology by Barbara W. Murck, Brian J. Skinner and Stephen C. Porter. These ten chapters are devoted to basic geologic concepts (Part I) and geologic hazards (Part II). The Preface and Introduction have been rewritten to reflect the content of the new book. In the text of Dangerous Earth, you will occasionally run across references to the material contained in the omitted chapters, so please overlook these references. The glossary also contains material from the chapters of Environmental Geology, and some of this material is not relevant to Dangerous Earth. It is our hope that this concise and focused text will meet the needs of courses devoted to the study of geologic and natural hazards.

The chapters contained in the text Environmental Geology that are not contained in Dangerous Earth are as follows: Part III, Using and Caring for Earth Resources; Chapter 11, Energy from Fossil Fuels; Chapter 12, Energy Alternatives; Chapter 13, Mineral Resources; Chapter 14, Soil Resources; Chapter 15, Water Resources. Part IV, Human Impacts on the Environment; Chapter 16, Waste Disposal; Chapter 17, Contaminants in the Geologic Environment; Chapter 18, Atmospheric Change.

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CHAPTER 1
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EARTH SYSTEMS AND CYCLES

Earth Viewer URL:
http://www.fourmilab.ch/earthview/vplanet.html

View either a map of the Earth showing the day and night regions at this moment, or view the Earth from the Sun, the Moon, the night side of the Earth, above any location on the planet specified by latitude, longitude, and altitude, or from a satellite in Earth orbit. Images can be generated based on a topographical map of the Earth, up-to-date weather satellite imagery, or a composite image of cloud cover superimposed on a map of the Earth.

Earth and Environmental Science URL.:
http://info.er.usgs.gov/network/science/earth/earth.html

CHAPTER 2
WEB LINKS
EARTH STRUCTURE AND MATERIALS

Petrographic Workshop URL:
http://pong.igpp.ucla.edu/pet/pet_intro.html

An interactive database on petrography. The program is designed as a source of mineralogical information used in the identification process of rocks and minerals.

Rock "U" URL:
http://www.ucs.usl.edu/~amg6262/rocku.html

Explains various rock groups with images and text.

The Active Tectonics Web Site URL:
http://www.muohio.edu/tectonics/activetectonics.html

Plate Tectonics and the Dynamic Earth URL:
http://zebu.uoregon.edu/geol.html

Structural Geology Home Page URL:
http://www-geol.unine.ch/STRUCTURAL/Structural_HomePage.html

CHAPTER 3
WEB LINKS
EARTHQUAKES

Earthquakes and Plate Tectonics URL:
http://gldfs.cr.usgs.gov/neis/general/handouts/rift_man.html

An introduction via text and a few diagrams by the USGS.

Access to the Current Seismicity URL:
http://quake.wr.usgs.gov/QUAKES/CURRENT/current.html

The April 22, 1991 Valle de la Estrella Costa Rica Earthquake URL:
http://www.eqe.com/publications/costaric/costaric.htm

Oklahoma Earthquake Catalog URL:
gopher://wealake.oksurvey1.gov:70/11/okeqcat

The Southern Arizona Seismological Observatory URL:
http://www.geo.arizona.edu/saso/

An online seismograph.

CHAPTER 4
WEB LINKS
VOLCANIC ERUPTIONS

The Electronic Volcano URL:
http://mmm.dartmouth.edu/pages/stoiber/elecvolc.html

Eruptions of Mount Spurr Volcano. Alaska URL:
ftp://mojave.wr.usgs.gov/pub/spurr/Spurr.htm

Photographs of the 1992 eruptions.

Volcano Watch URL:
http://www.soest.hawaii.edu/hvo/

Volcano World URL:
http://volcano.und.nodak.edu/

World-Wide Volcanism URL:
http://skye.gsfc.nasa.gov/wwvolcano.html

Natural Disaster Info URL:
http://web66.coled.umn.edu/hillside/franklin/disaster/Project.html

This site, created by students, is an excellect introduction to all kinds of natural disasters such as earthquakes and volcanoes.

CHAPTER 5
WEB LINKS
TSUNAMIS

Tsunami URL:
http://tsunami.ce.washington.edu/tsumani/intro.html

Hawaii Tsunami Page URL:
http://lumahai.soest.hawaii.edu/tsunami.html

CHAPTER 7
WEB LINKS
SUBSIDENCE

The Edwards Aquifier Home Page URL:
http://www.txdirect.net/users/eckhardt/

CHAPTER 8
WEB LINKS
FLOODS

Mississippi River URL:
http://www.jpl.nasa.gov/sircxsar/mississippi.html

This image shows regions of the southern United States that are prone to flooding.

CHAPTER 9
WEB LINKS
HAZARDS OF OCEAN AND WEATHER

Sea-Level Increase URL:
ftp://ftp.hmc.edu/pub/science/sci.answers/.mirror.OLD/sea-level

Weather Maps & Movies URL:
http://rs560.cl.msu.edu/weather/

Hurricanes

Hurricane Dynamics URL:
http://www.gfdl.gov/hurricane.html

Hurricane Tracking Map URL:
http://lumahai.soest.hawaii.edu/Tropical_Weather/atlantic_track.gif

Scanned image of a blank tracking map.

Hurricane Watch URL:
http://www.netcreations.com/hurricane/

Hurricane tracking resources.

Hurricane.com URL:
http://www.huricane.com/

Will accept information, pictures, or data about any present or future hurricane or tropical storm.

Hurricane Tropical Data URL:
http://thunder.atms.purdue.edu/hurricane.html

Hurricane—Living With Tropical Weather Systems URL:
http://www.flinet.com/~reiter/

Information and graphics packed resource on hurricane and tropical weather. Practical information on preparing for, surviving, and recovering from a hurricane.

Tracking the Eye URL:
http://www.cyberspy.com/~gencode/trackeye.html

Hurricane tracking software for Windows or Windows 95. This page also provides links to current hurricane coordinate information.

USA Today-Guide to Hurricanes URL:
http://www.yahoo.com/?http://www.usatoday.com/weather-whur0.htm

VNO: All About Hurricanes URL:
http://www.yatcom.com/neworl/weather/hurricane.html

Worldwide Hurricane/Typhoon Tracks and Forecasts URL:
http://www.solar.ifa.hawaii.edu/Tropical/tropical.html

Tornadoes

Bloom, Steve - Stock Photography URL:
http://ourworld.compuserve.com/homepages/S_Bloom/

Digital photographic artist specialising in wildlife and "impossible" photography. See his tornado, running cheetah, charging rhino, leaping dolphins, and exploding prism.

Bears Cage URL:
http://www.ionet.net/~tornado1/index.shtml

Storm chaser information with links to other chasers and pictures of tornadoes and other weather images.

The Tornado Page URL:
http://cc.usu.edu/~kforsyth/Tornado.html

An introduction to tornadoes.

CHAPTER 10
WEB LINKS
METEORITE IMPACTS

Near Earth Asteroid Rendezvous URL:
http://utopia.eps.jhu.edu/near.html

Planet Earth Home Page URL:
http://www.nosc.mil/planet_earth/info_modern.html

Virtual library text version.

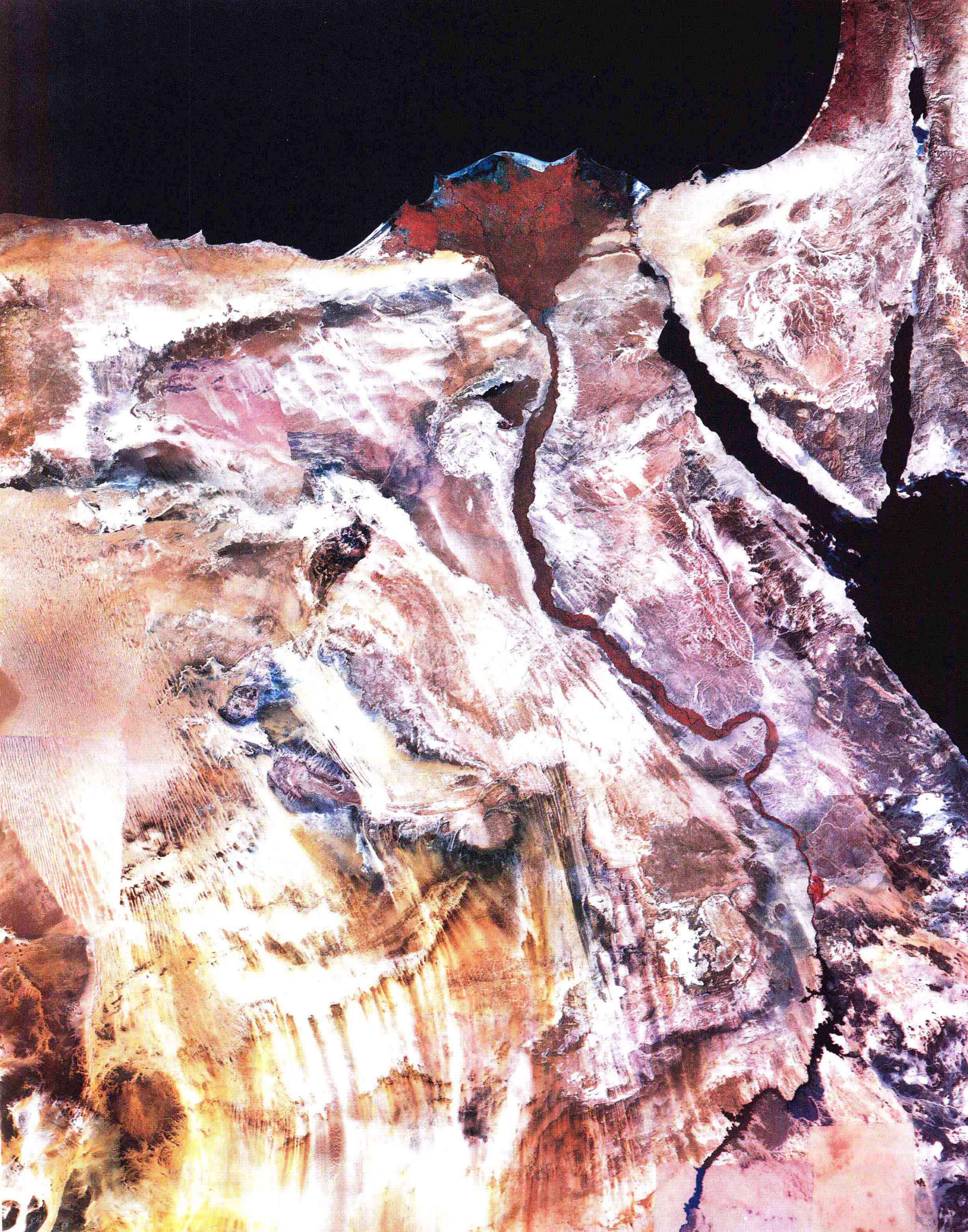
Planetary Geophysics Home Page URL:
http://www.wdcb.rssi.ru/

Asteroid and Comet Impact Hazard URL:
http://ccf.arc.nasa.gov/sst/

Fireball Reporting Form URL:
http://www_dsa.uqac.uquebec.ca/Divers/Higgins/fireball.htm

Earth Science and Solar System Exploration Division URL:
http://www-sn.jsc.nasa.gov/

DANGEROUS EARTH



INTRODUCTION
LIVING WITH DANGER

Geology controls our lives.
• Jack Oliver

*E*gypt has always been dominated by its geology. Upper Egypt consists of a long valley carved by the Nile River into the rocky desert plateau of the eastern Sahara. Lower Egypt is a vast delta built outward into the Mediterranean Sea by the deposition of sediment from the Nile. Ancient Egyptians called the Nile Valley *Kemit,* "the Black Land," referring to the dark, fertile soil along the banks of the river. The deserts bordering the valley were known as "the Red Land," also named for their distinctive soil. This region was harsh and forbidding, yet it was the source of the great mineral wealth that made Egypt a powerful center of civilization.

The role of geology in Egyptian civilization is reflected in mythology, especially in the figure of Osiris. Osiris was killed by his jealous brother Set, who cut his body into fourteen pieces and threw the pieces into the Nile. Isis, the wife of Osiris, found the pieces and, with the help of the gods, restored Osiris to life. The power of resurrection vested in Osiris was associated with the fertilizing effects of the annual flooding of the Nile, which watered and enriched the valley. Each year for a period of about 100 days the river swelled as if by magic, since Egypt experienced no great rains. The flooding left behind deposits rich in potash and soft silts that were easily tilled. These rich muds formed a natural fertilizer that, when warmed by the spring sun, allowed crops to flourish. Yet as soon as one crop was harvested, the nutrients in the sediment were essentially exhausted. Only the next flooding by the Nile would render the field suitable for cultivation again.

The Nile was also a destructive force for the ancient Egyptians. Only through the coordination of human efforts could its power be brought under control. The success of Egyptian agriculture required not only local control of the river but a united effort throughout the two lands. Regions were divided into political districts and taxes were based on the height of flood waters. The river thus became the impetus for agricultural innovation, technological advancement, and the development of governmental and legal systems.

For modern Egyptians the Nile remains both a provider and a destroyer. The heritage of technological control over geologic processes survives in the form of the Aswân High Dam, which generates more than half the electricity produced in Egypt. The construction of the dam and the creation of Lake Nasser added significantly to the amount of arable land in Egypt. At the same time, however, the dam has interfered with the distribution of sediment to agricultural areas downstream, forcing them to become dependent on chemical fertilizers. The lack of nutrient-laden sediments reaching the Mediterranean has affected the offshore fishing industry. Other unexpected effects include salinization of irrigated areas, erosion of sediment-starved coastlines, saltwater intrusion of coastal freshwater supplies, and the spread of water-borne diseases such as schistosomiasis. The Egyptian people have exerted a massive amount of effort to control the force of the Nile and to draw resources from it, but these activities have had some unanticipated consequences.

◄ ***Egypt and the River Nile viewed from space. This LANDSAT image was made in the infrared so vegetation shows up red. The red ribbon is the floodplain of the Nile and it has the color it does because it is farmed intensively. The river is the thin, wavy blue line inside the red ribbon. The direction of river flow is northward, from the bottom of the page to the top; the triangular region at the top is the delta, where the river empties into the Mediterranean Sea. Cairo is the blue-grey area at the apex of the delta. The Aswân Dam and Lake Nasser are visible at the bottom of the image.***

HAZARDOUS PROCESSES

Geologic processes affect every inhabitant of the Earth every day. The impacts of some of these processes, such as earthquakes, landslides, and floods, are obvious. Others are more subtle. They include the role of mountains in controlling the weather and shaping climatic zones; the influence of volcanism on the chemical evolution of the atmosphere; and the contribution of floodwaters to the creation of fertile agricultural soils, as in the example of the Nile Valley. Because the Earth is a dynamic planet, many of these geologic processes have risks associated with them; that is, they may negatively affect human interests, activities, or health. In order to understand these processes and assess the risks and impacts associated with them, we turn to **geology,** the scientific study of the Earth.

The Role of Geology

Traditionally, geology has been divided into two broad areas with related but differing aims. **Physical geology** is concerned with understanding the *processes* that operate at or beneath the surface of the Earth and the *materials* on which those processes operate. The causes of volcanic eruptions, earthquakes, landslides, and floods are processes. Materials include soils, sediments, rocks, air, and seawater. **Historical geology** is concerned with the chronology of *events,* both physical and biological, that have occurred in the past. It seeks to resolve questions such as when the oceans formed, when dinosaurs first appeared, when the Rocky Mountains rose, and when and where the first trees appeared.

To these two traditional branches of geology we may now add a third, **environmental geology,** which focuses on the ways in which Earth systems and geologic processes affect and are affected by human activities. One component of environmental geology is the study of **geologic hazards,** that is, the wide range of geologic circumstances, materials, processes, and occurrences that are harmful, hazardous, or costly to humans, such as earthquakes, volcanic eruptions, floods, and landslides. In addition to geologic hazards, environmental geology is concerned with Earth resources—such as minerals, soil, water, and fossil fuels—and the behavior of wastes and contaminants in the natural environment.

Environmental geology in general, and the study of geologic hazards in particular, necessarily encompass some aspects of both historical *and* physical geology. The physical characteristics and chemical composition of the Earth, inside and out, affect our lives in many different ways. For example, the internal structure of the Earth plays a significant role in shaping our landscape and causing geologic events that may be hazardous for humans. Physical geology emphasizes the study of processes such as the release of heat from the interior of the Earth (Fig. In.1), the movement of

▲ FIGURE In.1
Lava dome at Soufrière Hills on the island of Montserrat, West Indies. At the beginning of 1996, nearby residents were evacuated because of increasing eruptive activity from this volcano. The release of heat from the Earth's interior is directly or indirectly responsible for many natural hazards, including volcanic eruptions.