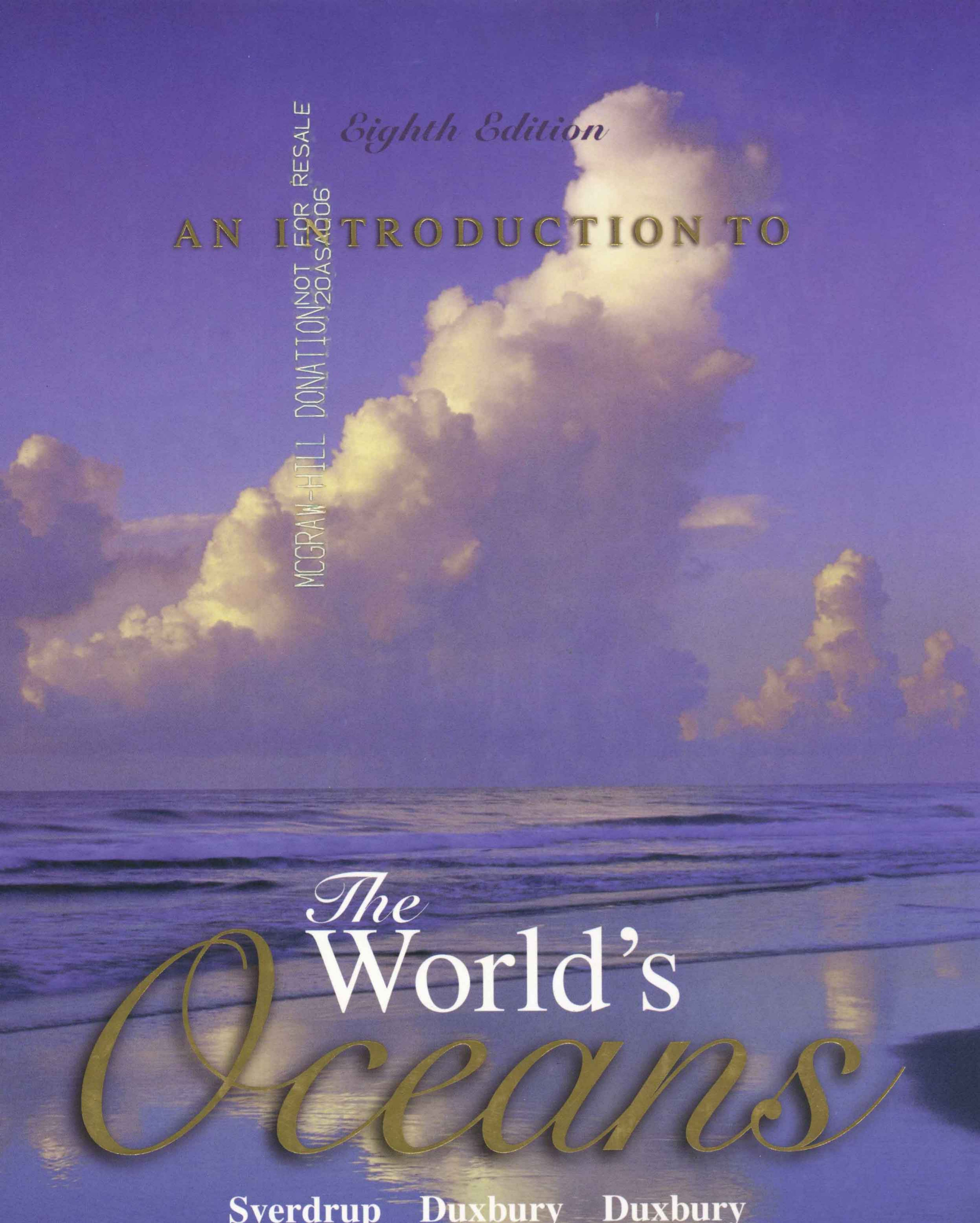

Eighth Edition

AN INTRODUCTION TO *The* World's *Oceans*

Sverdrup Duxbury Duxbury

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University of Wisconsin–Milwaukee

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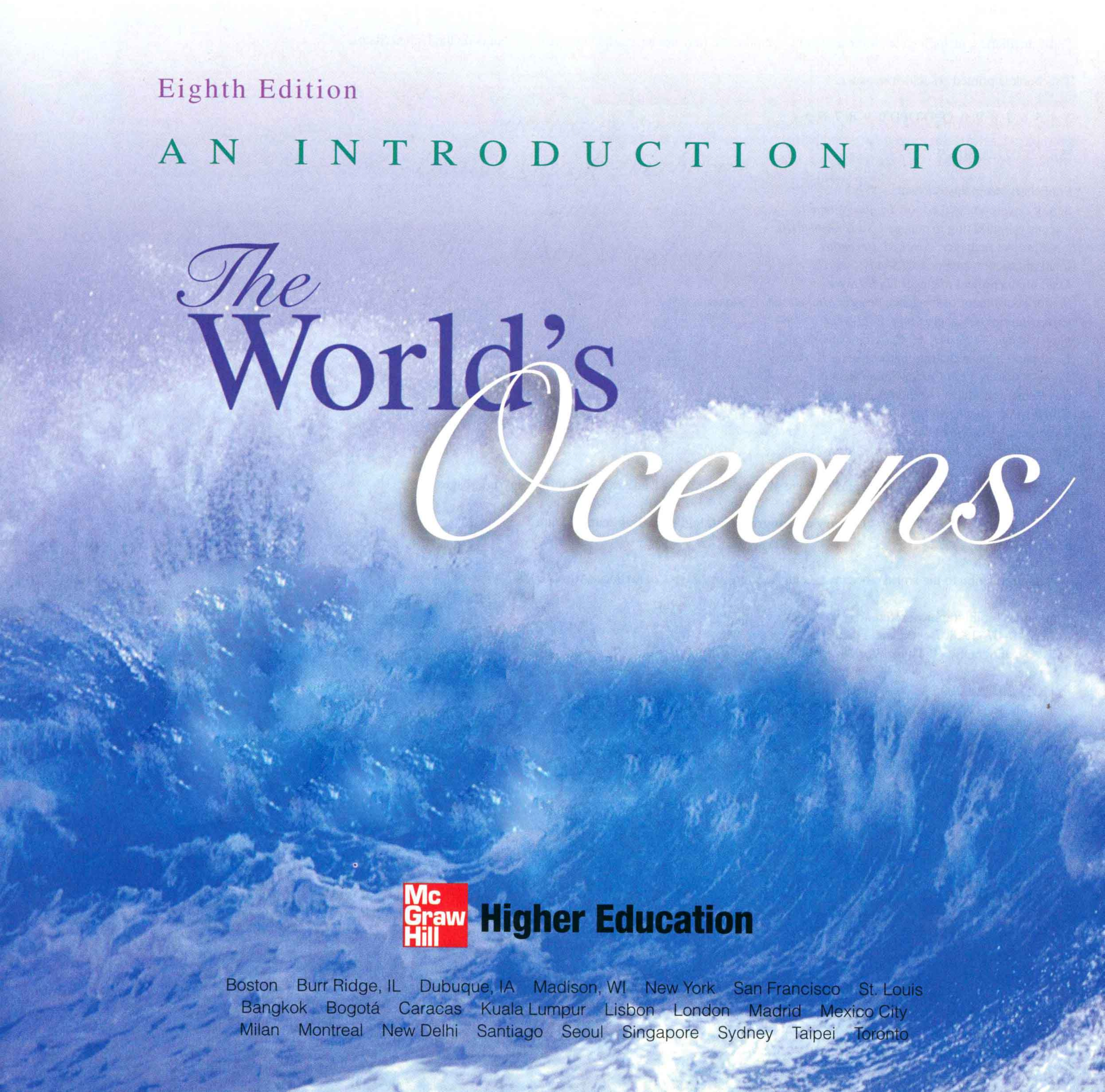

Eighth Edition

AN INTRODUCTION TO The World's Oceans

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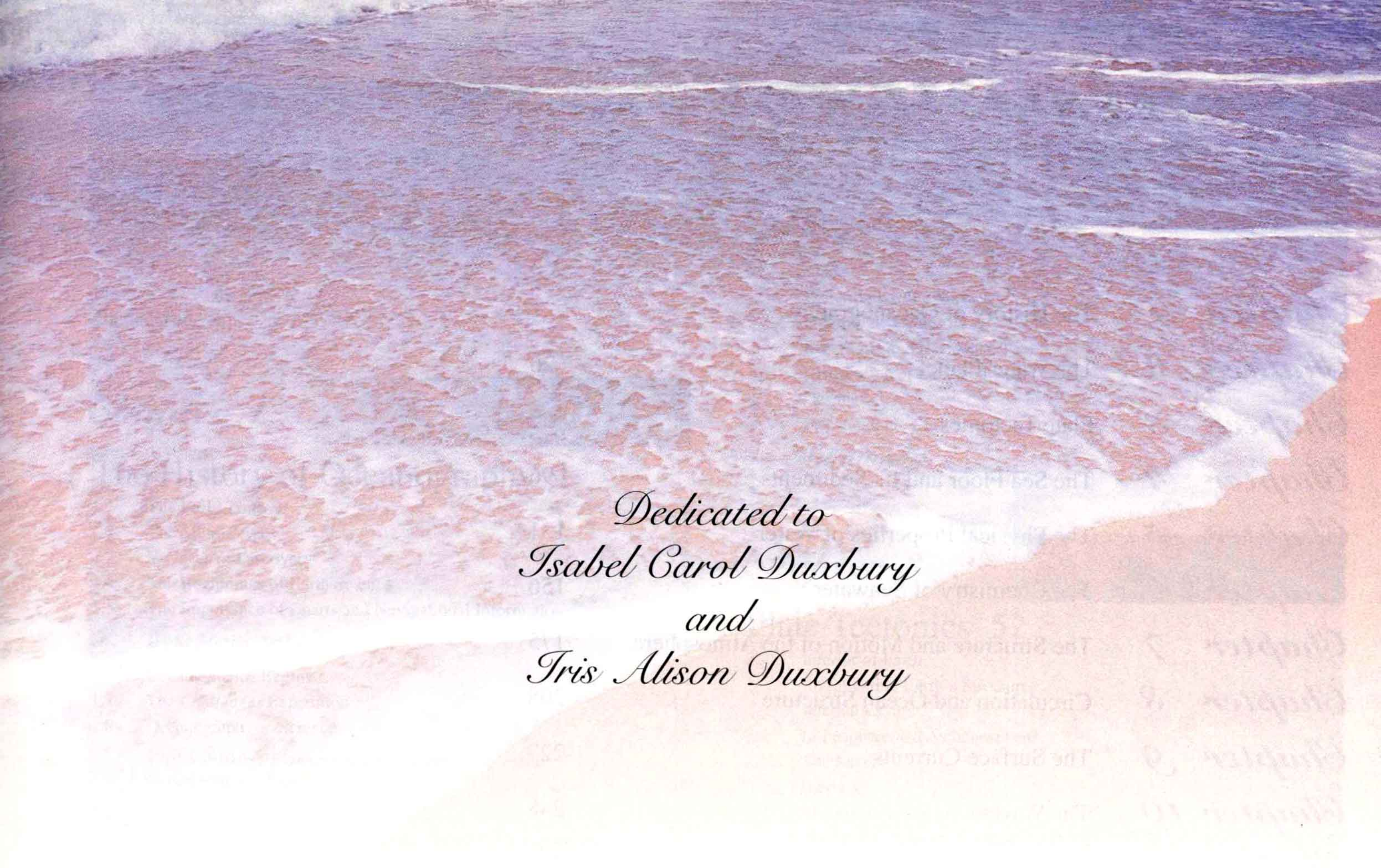

Dedicated to
Isabel Carol Duxbury
and
Iris Alison Duxbury

Preface

A Note to Students

Human beings have been curious about the oceans since they first walked along their shores. As people have learned more about the oceans, they have come to understand more fully and appreciate the tremendous influence these bodies of salt water have on our lives. The oceans cover over 70% of Earth's surface, creating a habitat for thousands of known species and countless others still to be discovered. The sea contains vast quantities of diverse natural resources in the water and on the sea floor; some are actively exploited today, and many more may be recovered in the future with improved technology and greater demand. Global climate and weather are strongly influenced by the oceans as they interact with the atmosphere through the transfer of moisture and heat energy. The ocean basins also serve as the location of great geological processes and features such as earthquakes, volcanoes, massive mountain ranges, and deep trenches, all of which are related to the creation and destruction of sea floor in the process of plate tectonics.

Much of what happens in the oceans and on the sea floor is hidden from direct observation. Although the *Hubble Space Telescope* can form images from light that has traveled over 10 billion trillion kilometers, we can not see more than a few tens of meters below the ocean's surface even under the most favorable conditions because of the efficient scattering and absorption of light by seawater. Consequently, most of what we know about the oceans comes from indirect, or remote, methods of observation. With constantly improving technology and innovative applications of that technology, we continue to learn more about the geological, physical, chemical, and biological characteristics of the oceans.

Although careful scientific study of the oceans is often difficult and challenging, it is both necessary and rewarding. Our lives are so intimately tied to the oceans that we benefit from each new fact that we discover. Continued research and a better understanding of the oceans become increasingly important, as the population of this planet grows ever larger. Early in the new millennium, there is both good news and bad news concerning global population growth. The rate of population increase has slowed with falling birth rates, and there is some indication that the human population will level off by the end of this century. But even if the human population does stabilize, it will not do so before there is an increase of several billion people over today's population. We clearly will continue to face difficult environmental decisions affecting the oceans as well as the land in the foreseeable future. Our best chance of dealing wisely and effectively with these challenges is to promote more widespread understanding of the oceans.

Although it is critical that we continue to train marine scientists to study the oceans, it is no less important for people in all walks of life to develop a basic understanding of how the oceans influence our lives and how our actions influence the oceans. In studying oceanography, you are preparing yourself to be an informed global citizen. It is likely that at some point in the future you will have the opportunity to voice your concern about the health of the oceans, either directly or through the governmental process. Your interest in and study of oceanography will help you participate in future discussions and decision-making processes in an informed manner.

The Online Learning Center at www.mhhe.com/sverdrup8 provides you with links to Internet addresses relevant to this text. To expand your knowledge of oceanography, Internet exercises for many of these sites are found within the Online Learning Center. Also included is a comprehensive student study guide that includes detailed outlines of the chapters and questions to test your understanding.

A Note to Instructors

A major objective of this text is to stimulate student interest and curiosity by blending contemporary information and research with basic principles in order to present an integrated introduction to the many and varied sciences used in the study of the oceans. To do so, we have extensively reviewed and rewritten material from the seventh edition to produce this new eighth edition. In the face of constant and rapid change, we have added new material for both content and interest. We have also invited five scientists to write guest essays in their fields of specialization. There is also a sixth essay written by a chief scientist and a ship's captain on planning and executing an oceanographic expedition.

We realize that the students who use this book come from diverse backgrounds and that for many of them this is an elective course. The content continues to be reasonably rigorous, but we have chosen to use simple algebra rather than advanced mathematics. For instance, we use centrifugal force to explain tidal principles because most students do not have much background in vectors.

An ecological approach and descriptive material are used to integrate the biological chapters with the other subject fields. We strive to emphasize oceanography as a cohesive and united whole rather than a collection of subjects gathered under a marine umbrella.

In order to understand the constant barrage of information concerning our planet and marine issues, students must have a basic command of the language of marine science in addition to mastering processes and principles. For this reason we maintain an emphasis on critical vocabulary. All terms are defined in the text; terms that are particularly important are printed in boldface. A list of important terms appears at the end of each chapter, with a glossary included at the end of the book. The Online Learning Center for this text also hosts interactive flashcards of key terms for student study.

End-of-chapter Summaries provide quick reviews of key concepts. Study Problems are included in many chapters, and Study Questions are at the end of each chapter. The Study Questions are not intended merely for review, but also to challenge students to think further about the lessons of the chapter.

This book may be used in a one-quarter or one-semester course. Because the experience and emphasis of faculty using this book will differ, it is expected that each instructor will emphasize and elaborate on some topic at the expense of other topics. We continue to make each chapter stand as independently as possible and encourage instructors to use the chapters in the order that best suits their purposes. Cross-references from one chapter to another indicate discussion of topics elsewhere in the text. Faculty wishing to use a more quantitative approach in some areas are encouraged to make use of Appendix C, Equations and Quantitative Relationships. The answers to the Study Questions and Study Problems from the text appear in the Instructor's Manual, within the password-protected instructor's area of the Online Learning Center.

Changes to the Eighth Edition

In addition to revisions and updates based on current research, this edition contains several new guest essays entitled "Field Notes." Chapter 1 contains a Field Notes box written by Dr. Marcia McNutt and Captain Ian Young on the roles of the chief scientist and ship's captain in planning and executing a successful oceanographic expedition. In Chapter 2 we have included a discussion on the possible existence of extraterrestrial oceans in our solar system. Chapter 3 includes a Field Notes box on Project Neptune on the Juan de Fuca plate. Chapter 3's discussion of plate tectonics, especially convergent plate boundaries, has been completely revised and updated, with new figures added. Giant Hawaiian landslides are now discussed in Chapter 4's Field Notes box. In Chapter 5 the description of the interaction of light and seawater has been extensively revised, and the attenuation of light with depth is discussed in greater detail. Chapter 6 includes a new description of the different units, including moles/liter, used in expressing the concentration of dissolved constituents in seawater. Chapter 7 contains an updated and significantly revised discussion of ENSO. Chapter 8 includes an updated discussion of oceanic internal structure and circulation. It also covers topics in upwelling and downwelling, the layering of the oceans, and updated material on sampling methods and measurement techniques. The Arctic Ocean Studies box includes new information on circulation and changing ice cover. Chapter 9 has been re-titled The Surface Currents; new information has been added to the sections on geostrophic flow and modeling of ocean currents. Chapter 10's discussion of wave energy has been rewritten to increase clarity. Chapter 11's discussion of Energy from Tides has been updated and rewritten to include new British and Norwegian sea-floor power plants. Also, all tide and current tables have been updated. An updated and expanded discussion of oil spills is found in Chapter 13, including the wreck of the *Prestige* and the disposal of municipal solid waste. Chapter 14 contains new information on marine biodiversity projects. Chapter 15 includes new tables on World Ocean Production and Ocean Food Production. Chapter 16's Field Notes box describes Pico-Plankton, and the chapter hosts a new section on vents and their microbial communities along the Juan de Fuca Ridge. The krill section has been rewritten and information on a jellyfish fishery off the Atlantic coast has been added. Difficulties in research on Pfiesteria are also discussed. Chapter 17 has a Field Notes box on biofouling, updated material on whaling, manatee and dugong populations, and new information on ground fisheries and fish farming. Chapter 18 presents new data on fisheries and mariculture, a new section on deepwater corals, and coral reef updates.

Instructor Supplements

McGraw-Hill offers a variety of supplements to assist instructors with both preparation and classroom presentation.

The Digital Content Manager CD-ROM is a multimedia collection that offers a wide selection of photos, figures, and tables from the text, as well as additional photos, animations and also 34 videos from Scripps Institution of Oceanography. PowerPoint Lecture Outlines are available for each chapter on this CD. The Digital Content Manager allows instructors to utilize these assets in multiple formats to create customized classroom presentations, dynamic course website content, or attractive printed support materials. The digital resources on this cross-platform 2 CD-ROM set are grouped within easy-to-use folders and organized by chapter to go with the eighth edition of this text. The Scripps video segments are also available on videotape.

A text-specific Online Learning Center (OLC), which can be found at www.mhhe.com/sverdrup8 provides resources for both students and instructors. The password-protected Online Learning Center contains the Instructor's Manual, which includes answers to the Study Questions and Study Problems from the text. PowerWeb: Oceanography can be accessed through the Online Learning Center, and contains articles from current magazines, newspapers, and journals; weekly updates of current issues; web research tips; an online library of updated research links to help you find the right information; up-to-the-minute headlines from around the world including course-specific and general news; and online quizzing and assessments for your students. This text's Online Learning Center is available at www.mhhe.com/sverdrup8.

The Instructor's Testing and Resource CD is a cross-platform tool that contains questions specific to each chapter to help instructors generate tests, and this CD also contains an Instructor's Manual which includes the Answers to Study Questions and Study Problems from the text. A set of 100 overhead transparencies provides figures from the text in full color. These ancillaries are available to instructors through their McGraw-Hill sales representative.

For instructors wishing to incorporate hands-on oceanography exercises into their course, McGraw-Hill offers an exceptional workbook entitled "Investigating the Ocean" by R. Leckie and R. Yuretich of University of Massachusetts-Amherst. Additional earth science supplements offered by McGraw-Hill appropriate for this course include the "Journey Through Geology" CD-ROM by the Smithsonian Institution and a geoscience videotape library. Contact your McGraw-Hill sales representative for details on these products.

Student Supplements

The Internet makes oceanographic information and data available to researchers and it also provides images and information in many forms to instructors and students. Public agencies and museums, universities and research laboratories, satellites and oceanographic projects, interest groups and individuals all over the planet provide information that can be publicly accessed. The text-specific Online Learning Center (OLC) website, which can be found at www.mhhe.com/sverdrup8, provides chapter-sorted links to many websites that contain information pertinent to each chapter's content. In addition, web links are provided within the OLC for further information on many figures and boxed readings within each chapter. Wherever you see this icon web link in your textbook, you will find associated web links for the indicated figure or boxed reading on the OLC. The OLC also hosts a complete Student Study Guide, chapter quizzing, interactive key term flashcards, animations, and Internet exercises to help with chapter study. In addition, PowerWeb is a great way to get information you need quickly and easily! Through the OLC, students can access PowerWeb: Oceanography, which contains articles from current magazines, newspapers, and journals; weekly updates of current issues; web research tips; an online library of updated research links to help you find the right information; up-to-the-minute headlines from around the world including course-specific and general news; online quizzing and assessments to measure your understanding of course material, and more!

Acknowledgments

As a book is the product of many experiences, it is also the product of people other than the authors. We extend many thanks to our friends and colleagues who have graciously answered our questions and provided us with information and access to their photo files. We owe very special thanks to faculty and staff of the School of Oceanography, College of Ocean and Fishery Sciences, University of Washington, and to the scientists and staff of the National Oceanic and Atmospheric Administration's Northwest Regional Office, who have answered questions, supplied data and provided many of the illustrations in this edition. We are also grateful to Scripps Institution of Oceanography, which has allowed us the privilege of providing their videotape series as an instructor ancillary to this eighth edition of the text.

We would particularly like to thank the following people who authored the Field Notes boxes that are new to this edition:

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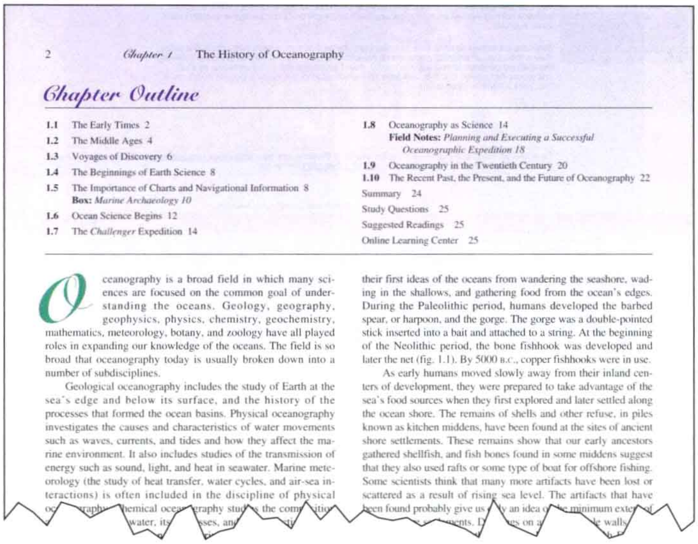
We thank all members of the team at McGraw-Hill, without whose help, enthusiasm, and coordinated efforts this eighth edition could not have been completed.

Guided Tour

A variety of tools within this textbook have been designed to assist with chapter review and critical analysis of chapter topics.

Chapter Outline

Each chapter begins with an outline of the subsections and boxed readings within each chapter.



2 *Chapter 1* The History of Oceanography

Chapter Outline

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Oceanography is a broad field in which many sciences are focused on the common goal of understanding the oceans. Geology, geography, geophysics, physics, chemistry, geochemistry, mathematics, meteorology, botany, and zoology have all played roles in expanding our knowledge of the oceans. The field is so broad that oceanography today is usually broken down into a number of subdisciplines.

Geological oceanography includes the study of Earth at the sea's edge and below its surface, and the history of the processes that formed the ocean basins. Physical oceanography investigates the causes and characteristics of water movements such as waves, currents, and tides and how they affect the marine environment. It also includes studies of the transmission of energy such as sound, light, and heat in seawater. Marine meteorology (the study of heat transfer, water cycles, and air-sea interactions) is often included in the discipline of physical

their first ideas of the oceans from wandering the seashore, wading in the shallows, and gathering food from the ocean's edges. During the Paleolithic period, humans developed the barbed spear, or harpoon, and the gorge. The gorge was a double-pointed stick inserted into a bait and attached to a string. At the beginning of the Neolithic period, the bone fishhook was developed and later the net (fig. 1.1). By 5000 B.C., copper fishhooks were in use.

As early humans moved slowly away from their inland centers of development, they were prepared to take advantage of the sea's food sources when they first explored and later settled along the ocean shore. The remains of shells and other refuse, in piles known as kitchen middens, have been found at the sites of ancient shore settlements. These remains show that our early ancestors gathered shellfish, and fish bones found in some middens suggest that they also used rafts or some type of boat for offshore fishing. Some scientists think that many more artifacts have been lost or scattered as a result of rising sea level. The artifacts that have

Field Notes Boxes

The essays represented within these boxes are new to this edition and written by oceanographers in the field. These readings highlight relevant oceanographic topics and provide insights into engaging oceanographic careers.

Field Notes

Exploring the Oceans on Earth and Elsewhere

by Dr. John Delaney

Dr. John Delaney is a Professor of Oceanography at the University of Washington, specializing in marine geology. His research focuses on the deep-sea volcanic activity of the Juan de Fuca Ridge in the northeast Pacific Ocean.

Microbes thrive in the toxic, superheated brew of water and dissolved gases that circulates through the volcanic rocks beneath the sea floor. These microbes are called *Archaea*. When the sea floor rocks crack or shift due to an earthquake or a submarine volcanic eruption, the subsurface water and its *Archaea* are released into the marine environment as a potentially significant source of organic material.

This deep biosphere below the sea floor was largely unknown and unexplored until recently. For the past decade, marine scientists have been visiting erupting volcanoes on the sea floor of the Pacific Ocean, and in each case, they found billowing clouds of heated water and microbial material venting from sea floor cracks. After viewing and sampling these venting waters, scientists concluded there is a deep, hot microbial habitat in the volcanically active portion of the oceanic crust. Some of the microbes do not begin to reproduce until the temperatures are higher than 60°C. These life forms do not require sunlight as a source of energy; instead, they use chemicals dissolved out of the rocks and carried in the hot venting water, a process known as chemosynthesis. Speculation is growing that life on Earth may have originated billions of years ago under similar submarine volcanic conditions.

One of today's most compelling questions in the planetary sciences focuses on identifying and quantifying the linkages among a host of plate-tectonic processes and microbial productivity near the sea floor and just below it within Earth's crust. Deformation and volcanism, which occur most frequently near plate margins and less frequently within plate interiors, result in forced fluid flow within the crust. This flow may be uniform with time, may change periodically, or both. The percolating fluid flow operating at spreading centers, subduction zones, along transform faults, or at volcanically active midplate regions transfers heat and chemically active organic and inorganic compounds that provide nutritional support for a widespread but poorly understood microbial biosphere.

Oceanographers have considerable experience studying organic production by photosynthesis at the sea surface and its dependence on sunlight, nutrients, and gas exchange between the ocean and atmosphere. Scientists, however, are currently ill-prepared to assess the importance of fluid-driven, plate-controlled chemosynthetic productivity linked to fluid flow across the water-rock boundary at the bottom of the ocean. The input of active compounds derived from the oceanic crust tends to be localized along faults, fissures, and other venting structures near plate boundaries. The scale and pattern of the venting are variable and cannot be predicted. Studies are required to assess the relative proportions of worldwide organic production from photosynthesis at the sea surface and from chemosynthesis at the sea floor.

The venting of crustal water with its microbial population is a tectonically forced process that operates at rates governed by plate dynamics. The forecasting of where, how, and when nutrient-laden crustal fluids are discharged from the crust into the overlying ocean requires new approaches and may represent the initial steps to understanding a process that also operates on other bodies in our solar system and beyond. The study of these processes at the scale of a single tectonic plate could lead to a new type of deep-sea research, research that is designed to become the basis for a long-term quantitative study of heat, chemistry, and biomass transfers in the deep sea. The local, regional, and global importance of these processes on Earth and on other active, water-bearing planets will be a major focus of research for decades.

To fully explore and understand such a system, scientists must enter and interact will all aspects of the marine environment at the scale of a single tectonic plate, including the water column, sea floor and sub-sea floor. Such studies require long periods of time to allow the collection of data that will reveal patterns and trends on scales of decades rather than a few weeks or a month, as in the traditional ship and underwater vehicle surveys. Advancements in fields including robotics, communications, distributed power, computing, sensor development, and information management are allowing a new phase of oceanographic research and education to emerge.

Integrating these technologies will allow the placement of thousands of sensors in three-dimensional arrays on, above, and within the sea floor. Computers will control monitoring programs and compare measurements against models of plate and oceanic processes. Fiber-optic and power cables will supply power and allow researchers two-way, real-time communication with a network of experiment sites on the sea floor. This observatory system will enable rapid and adaptive responses to changing conditions. Via the Internet, shore-based users will have command and control of ocean-based sensors, instruments, and underwater vehicles. Within the next decade, users on land may have electronic "ringside seats" during submarine volcanic eruptions, thanks to cameras on the sea floor and real-time Internet connections to shore. Indeed, oceanographers today stand on the edge of a revolution.

Efforts to develop coastal and regional cabled ocean observatories are under way in many countries, including the United States, Canada, and Japan, as well as the European Union. A joint

80

Chapter Summary

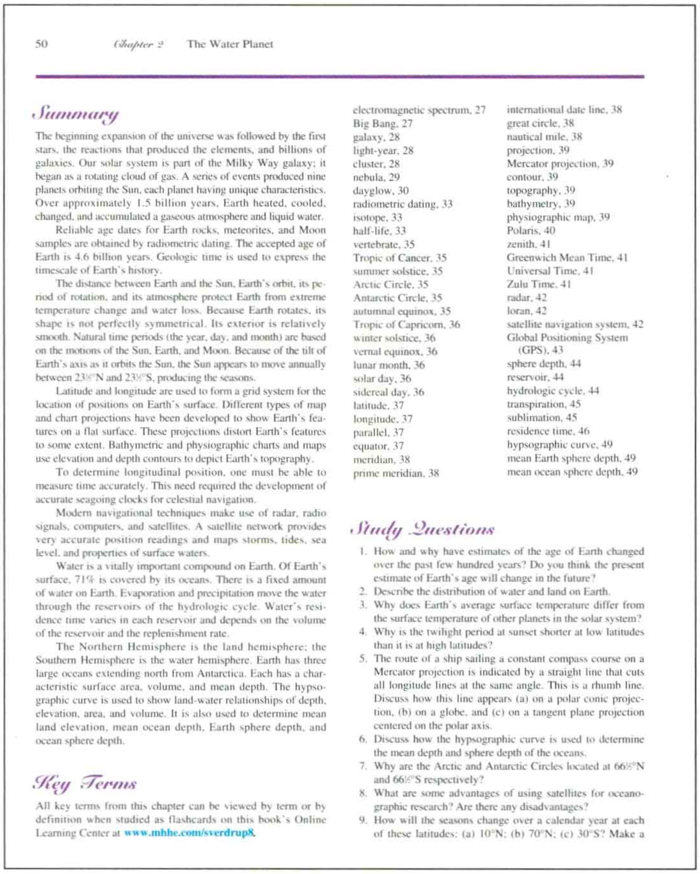
Each chapter's summary provides a quick review of key concepts.

Key Terms

Key Terms are boldfaced and defined within the text, and end-of-chapter key terms listings indicate the most important terms and their locations within each chapter.

Study Questions and Problems

Study Questions and Study Problems serve not only as a concept review, but challenge students to think further about the lessons within each chapter.



50 *Chapter 2* The Water Planet

Summary

The beginning expansion of the universe was followed by the first stars, the reactions that produced the elements, and billions of galaxies. Our solar system is part of the Milky Way galaxy; it began as a rotating cloud of gas. A series of events produced nine planets orbiting the Sun, each planet having unique characteristics. Over approximately 1.5 billion years, Earth heated, cooled, changed, and accumulated a gaseous atmosphere and liquid water.

Reliable age dates for Earth rocks, meteorites, and Moon samples are obtained by radiometric dating. The accepted age of Earth is 4.6 billion years. Geologic time is used to express the timescale of Earth's history.

The distance between Earth and the Sun, Earth's orbit, its period of rotation, and its atmosphere protect Earth from extreme temperature change and water loss. Because Earth rotates, its shape is not perfectly symmetrical. Its exterior is relatively smooth. Natural time periods (the year, day, and month) are based on the motions of the Sun, Earth, and Moon. Because of the tilt of Earth's axis as it orbits the Sun, the Sun appears to move annually between 23½°N and 23½°S, producing the seasons.

Latitude and longitude are used to form a grid system for the location of positions on Earth's surface. Different types of map and chart projections have been developed to show Earth's features on a flat surface. These projections distort Earth's features to some extent. Bathymetric and physiographic charts and maps use elevation and depth contours to depict Earth's topography.

To determine longitudinal position, one must be able to measure time accurately. This need required the development of accurate seagoing clocks for celestial navigation.

Modern navigational techniques make use of radar, radio signals, computers, and satellites. A satellite network provides very accurate position readings and maps storms, tides, sea level, and properties of surface waters.

Water is a vitally important compound on Earth. Of Earth's surface, 71% is covered by its oceans. There is a fixed amount of water on Earth. Evaporation and precipitation move the water through the reservoirs of the hydrologic cycle. Water's residence time varies in each reservoir and depends on the volume of the reservoir and the replenishment rate.

The Northern Hemisphere is the land hemisphere; the Southern Hemisphere is the water hemisphere. Earth has three large oceans extending north from Antarctica. Each has a characteristic surface area, volume, and mean depth. The hypsographic curve is used to show land-water relationships of depth, elevation, area, and volume. It is also used to determine mean land elevation, mean ocean depth, Earth sphere depth, and ocean sphere depth.

Key Terms

All key terms from this chapter can be viewed by term or by definition when studied as flashcards on this book's Online Learning Center at **www.mhhe.com/sverdrup8**.

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light-year, 28
cluster, 28
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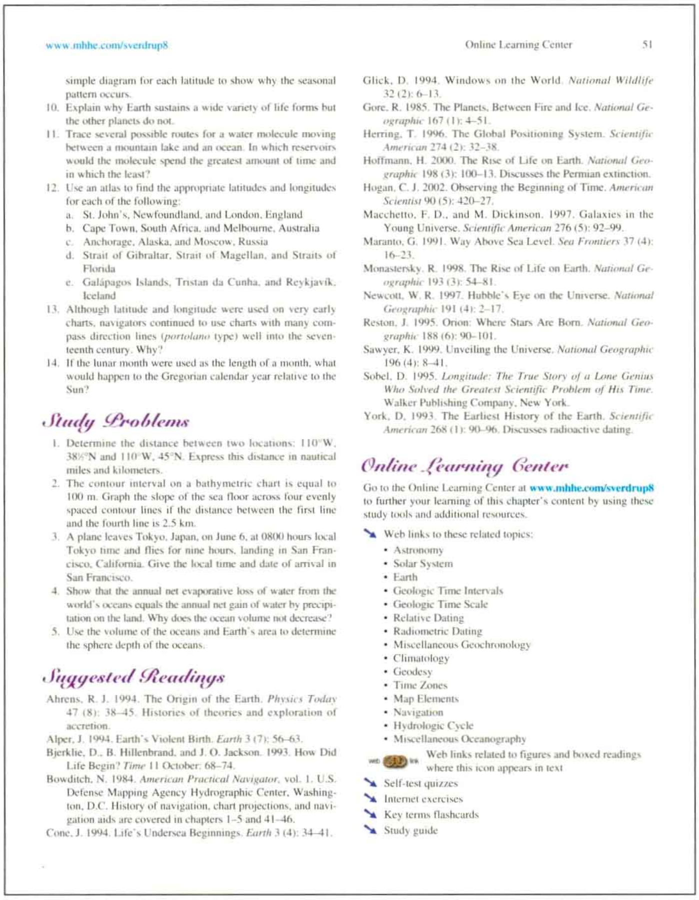
Study Questions

1. How and why have estimates of the age of Earth changed over the past few hundred years? Do you think the present estimate of Earth's age will change in the future?
2. Describe the distribution of water and land on Earth.
3. Why does Earth's average surface temperature differ from the surface temperature of other planets in the solar system?
4. Why is the twilight period at sunset shorter at low latitudes than it is at high latitudes?
5. The route of a ship sailing a constant compass course on a Mercator projection is indicated by a straight line that cuts all longitude lines at the same angle. This is a rhumb line. Discuss how this line appears (a) on a polar conic projection, (b) on a globe, and (c) on a tangent plane projection centered on the polar axis.
6. Discuss how the hypsographic curve is used to determine the mean depth and sphere depth of the oceans.
7. Why are the Arctic and Antarctic Circles located at 66½°N and 66½°S respectively?
8. What are some advantages of using satellites for oceanographic research? Are there any disadvantages?
9. How will the seasons change over a calendar year at each of these latitudes: (a) 10°N; (b) 70°N; (c) 30°S? Make a



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simple diagram for each latitude to show why the seasonal pattern occurs.

10. Explain why Earth sustains a wide variety of life forms but the other planets do not.
11. Trace several possible routes for a water molecule moving between a mountain lake and an ocean. In which reservoirs would the molecule spend the greatest amount of time and in which the least?
12. Use an atlas to find the appropriate latitudes and longitudes for each of the following:
    a. St. John's, Newfoundland, and London, England
    b. Cape Town, South Africa, and Melbourne, Australia
    c. Anchorage, Alaska, and Moscow, Russia
    d. Strait of Gibraltar, Strait of Magellan, and Straits of Florida
    e. Galápagos Islands, Tristan da Cunha, and Reykjavík, Iceland
13. Although latitude and longitude were used on very early charts, navigators continued to use charts with many compass direction lines (*portolano* type) well into the seventeenth century. Why?
14. If the lunar month were used as the length of a month, what would happen to the Gregorian calendar year relative to the Sun?

Study Problems

1. Determine the distance between two locations: 110°W, 38½°N and 110°W, 45°N. Express this distance in nautical miles and kilometers.
2. The contour interval on a bathymetric chart is equal to 100 m. Graph the slope of the sea floor across four evenly spaced contour lines if the distance between the first line and the fourth line is 2.5 km.
3. A plane leaves Tokyo, Japan, on June 6, at 0800 hours local Tokyo time and flies for nine hours, landing in San Francisco, California. Give the local time and date of arrival in San Francisco.
4. Show that the annual net evaporative loss of water from the world's oceans equals the annual net gain of water by precipitation on the land. Why does the ocean volume not decrease?
5. Use the volume of the oceans and Earth's area to determine the sphere depth of the oceans.

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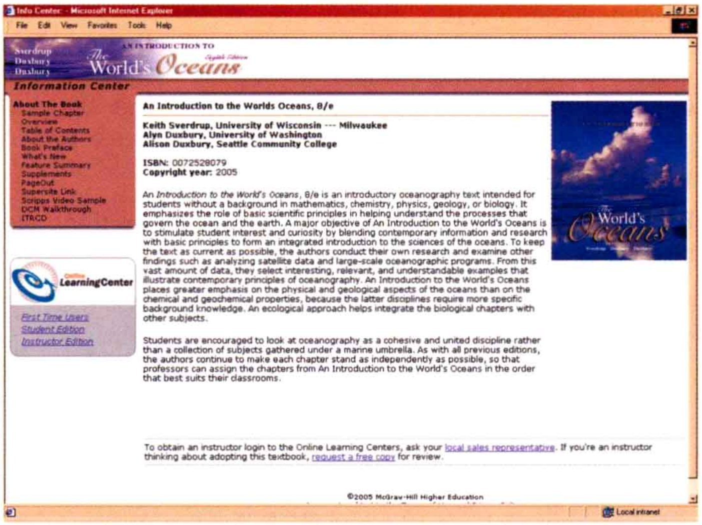
This text-specific website hosts many useful tools for the instructor, as well as features to help students sharpen their study skills and make the grade in their oceanography course. The **Instructor's Manual** can be found within the password-protected Instructor Resources section of the Online Learning Center. Students will find a complete **Study Guide** for each chapter, which includes Chapter Objectives, Key Concepts in lecture outline format, and a variety of self-test tools to help understand and retain the content found within each chapter of the textbook. Also available are interactive Key Term Flashcards, related web links



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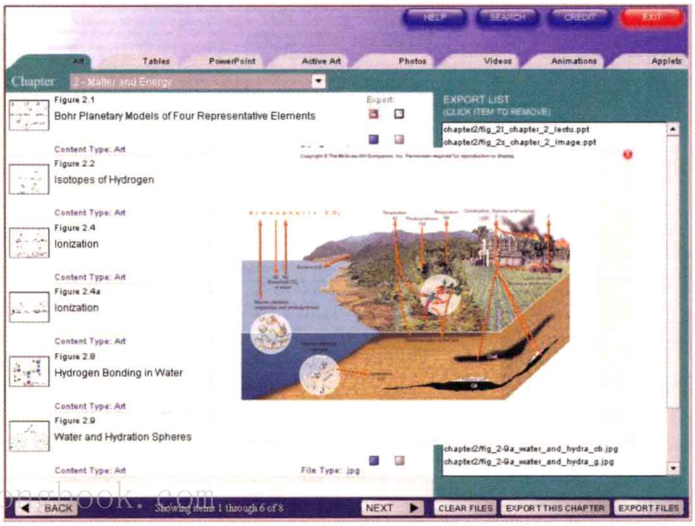

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