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 cannot 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/sverdrup9e 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 eighth edition to produce this new ninth edition. In the face of constant and rapid change, we have added new material for both content and interest. We have also invited six scientists to write guest essays in their fields of specialization. There is also a seventh 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 Ninth Edition

In **Chapter 1** we have added a discussion of the scientific method, including an explanation of the difference between a hypothesis and a theory. We have also undated information on the Integrated Ocean Drilling Program. In **Chapter 4** we have updated the discussion of gas hydrates. A new table on the properties of water has been added to **Chapter 5,** and we have extended the discussion of specific heat and heat capacity to make the difference between the two clear to readers. We have reorganized **Chapter 6** to put the discussion of pH after the discussion of dissolved gases in seawater. We have also rewritten large sections of the discussion on gases in seawater. In **Chapter 7** we have updated the material on greenhouse gases and the ozone holes over the Arctic and Antarctic. We have also included a discussion of the effects of Hurricanes Katrina and Rita on the Gulf Coast. In **Chapter 10** we have written about the devastating tsunami in the Indian Ocean. In addition, we have a new guest essay entitled "Field Notes: Modeling the December 26,2004 Sumatra Tsunami" written by Dr. Eddie Bernard. In **Chapter 11** we have updated the tide and current tables and added a number of new study questions at the end of the chapter to help students understand the tides. **Chapter 13** has an updated discussion of the Gulf of Mexico dead zone as well as the tanker Prestige oil spill. **Chapter 14** has been revised and updated and includes a new discussion of biomechanics. In addition, more examples are presented for the roles microorganisms play in the marine environment. New images of microorganisms have been included. **Chapter 15** has been revised and updated. More detailed discussions of satellite images, food web dynamics, and the biological pump have been added. A more detailed section has also been included to describe a decade's worth of large-scale iron fertilization experiments. New satellite images have been included. **Chapter 16's** description of phytoplankton and bacterioplankton has been updated. The section on toxic phytoplankton has been expanded. Some of the latest techniques for analyzing the very smallest plankton, including DNA analyses and flow cytometry, are described. New images of phytoplankton have been included.

Instructor Supplements

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

The **Online Learning Center** (www.mhhe.com/sverdrup9e) offers a wealth of teaching and learning tools for instructors and students. Instructors will appreciate:

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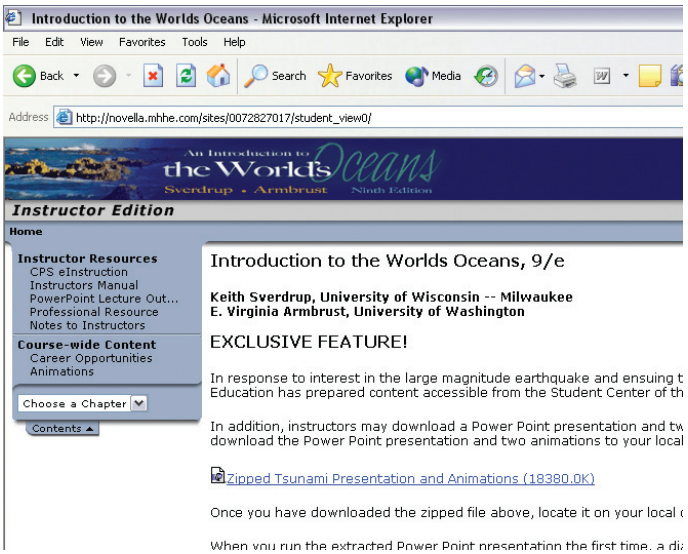
- PowerPoint lecture outlines
- Scripps videos
- Animations
- Access to the new online **Presentation Center** including all of the illustrations, photographs, and tables from the text in convenient jpeg format
- A student center with multiple-choice quizzes, a student study guide, key term flashcards, Internet exercises, and web links to chapter related material



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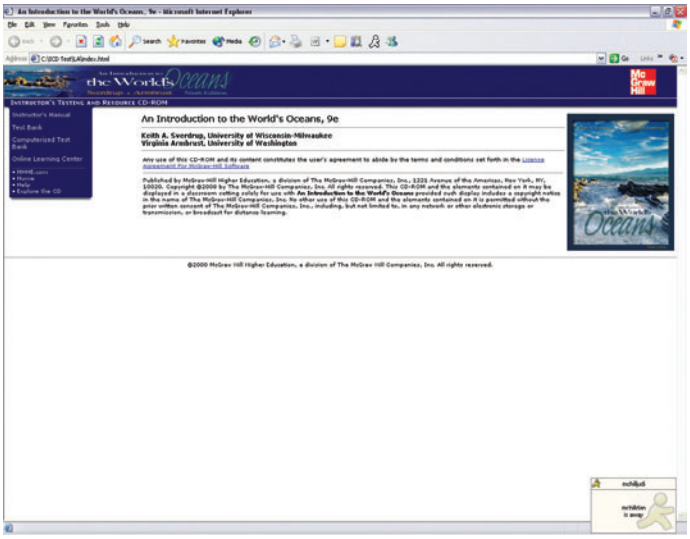
This cross platform CD includes an Instructor's Manual and test bank utilizing McGraw-Hill's EZ Test software. EZ Test is a flexible and easy-to-use electronic testing program that allows instructors to create tests in a wide variety of question types. Instructors may use the test questions provided by McGraw-Hill, add their own questions, create multiple versions of a test, and export tests for use with course management systems such as WebCT, and BlackBoard.



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The transparency set includes 100 illustrations from the text, all enlarged for excellent visibility in the classroom.

Earth and Environmental Science Digitized Videos

This exciting cross-platform DVD produced by Discovery Education offers short, three-to-five minute videos on ecology, evolution, conservation, energy, and physical sciences. Instructors can search from 50 different topics and download videos into their PowerPoint presentations to provide stunning examples of plate tectonics, solar energy, currents, waves, tides, rocks and minerals, and more!

(Available to colleges and universities.) Contact your sales representative for a detailed listing of topics. ISBN 978-0-07-352541-9 (MHID 0-07-352541-3)

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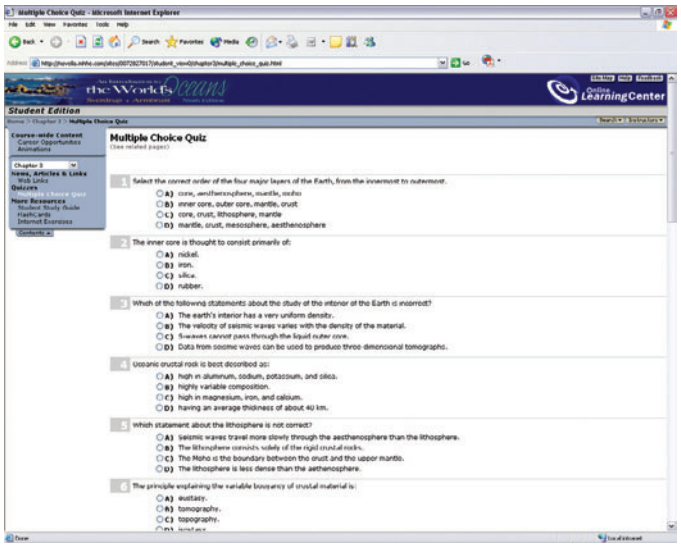
Student Supplements

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. Wherever you see this icon web link in your textbook, you will find associated text-specific Online Learning Center web links for the indicated figure or boxed reading.

The **Online Learning Center** for An Introduction to the World's Oceans is a great place to review chapter material and enhance your study routine. Visit www.mhhe.com/sverdrup9e for access to the following online study tools:

- Multiple choice quizzes
- Student study guide
- Key term flashcards
- Internet exercises
- Web links to chapter-related material



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, staff, and students of the School of Oceanography and to students from the School of Aquatic and Fisheries Science, both within the College of Ocean and Fishery Sciences, University of Washington. They have answered numerous questions, shared data, and provided insights into how to convey concepts presented 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 ninth edition of the text.

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

Field Notes for the Ninth Edition

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Greg Smith, *Edison College*

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

Alyn C. Duxbury and Alison B. Duxbury

Finally, we would like to acknowledge the tremendous debt we owe to Alyn and Alison Duxbury who are responsible for having created the first edition of this text as well as its companion book *Fundamentals of Oceanography*, also published by McGraw-Hill.

Alyn Duxbury received a Bachelor of Science in Oceanography at the University of Washington in 1955. The University of Washington's undergraduate program in Oceanography was the first one in the United States, Alyn received the first Bachelor of Science in Oceanography degree awarded in the country. He also received a Master of Science degree in Physical Oceanography from the University of Washington.

Alyn and Alison met while Alison was a graduate student at the University of California—Berkeley where she received her Master of Science in Botany, specializing in marine algae. They were married in 1956.

In 1967, while Alyn was a research faculty member in the Department of Oceanography, Alyn and Alison worked together to conduct the first oceanography correspondence course in the country. In 1971, Alyn authored his first oceanography textbook, *The Earth and Its Oceans,* Addison-Wesley publishers. Alison then began teaching oceanography and biology at Seattle Community College. In 1984 Alyn and Alison teamed up to write the first edition of this book, *An Introduction to the World's Oceans* for Addison-Wesley. Addison-Wesley later dropped its line of "geology" textbooks, and the second edition of the book was published by William C. Brown publishers in 1989. New editions appeared roughly every three years. Alyn and Alison often had new material in the books before it had come out in scientific journals. The book first appeared in full color with the fourth edition in 1994.

The first change in authorship came with the sixth edition in 2000, when Alyn and Alison invited Keith Sverdrup to join them. Keith's primary responsibility was marine geology. Alyn, Alison, and Keith co-authored the sixth through eighth editions of the book. Following publication of the eighth edition of *An Introduction to the World's Oceans* Alyn and Alison retired from the textbook authorship business. With this, the ninth edition of the book, Keith has taken over Alyn's duties, and Ginger Armbrust has joined Keith to take over the marine biology chapters.

Over the years, tens of thousands of undergraduate students have been introduced to the science and wonder of the oceans by Alyn and Alison's teaching and their authorship of many editions of this book. Many of these students have gone on to major in oceanography and eventually enter rewarding and important careers in marine science and affiliated areas. We are very grateful to the Duxburys for giving us the opportunity to follow in their footsteps by continuing new editions of *An Introduction to the World's Oceans.*

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

Guided Tour

Chapter Outline

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

2

Chapter Outline

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. Oceanography today is usually broken down into a number of subdisciplines because the field is extremely interdisciplinary.

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 oceanography. Chemical oceanography studies the composition and history of the water, its processes, and its interactions. Biological oceanography concerns marine organisms and the relationship between these organisms and the environment in the oceans. Ocean engineering is the discipline that designs and plans equipment and installations for use at sea.

Scientists make discoveries about the natural world, both

considered to be a valid hypothesis, recognizing that it may be replaced by a more complete hypothesis in the future.

If a hypothesis is consistently supported by repeated, different experiments, then it may be advanced to the level of a **theory**. The great value of a theory is its ability to predict the existence of phenomena or relationships that had not previously been recognized. Scientists use the word "theory" in a much more restrictive sense than the general public, who use the word in the same way the word "speculation" is used. A scientific theory is not an idle speculation, however. It is a tested, reliable, and precise statement of the relationships among reproducible observations.

A collection of hourly measurements of sea surface elevation at a specific point would comprise a set of scientific data or facts. An initial explanation of these data might be the hypothesis that sea surface elevation varies in response to tidal forces. This hypothesis could be expressed as a mathematical equation. If repeated measurements elsewhere in the oceans yielded reproducible data that continued to be accurately explained by the hypothesis, it would rise to the level of tidal theory (discussed in chapter 11).

Even when a hypothesis is elevated to the status of a theory, the scientific investigation will not necessarily stop. Scientists do not discard accepted theories

Field Notes

Modeling the December 26, 2004, Sumatra Tsunami

By Dr. Eddie Bernard

Dr. Eddie Bernard is the Director of the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle, Washington. He directs a broad range of oceanographic research programs including ocean climate dynamics, fisheries oceanography, El Niño forecasts, tsunamis, and seafloor spreading. Dr. Bernard is an expert in the study of tsunamis.

At 07:59 Local Time (00.59 UTC) on December 26, 2004, a magnitude 9.3 megathrust earthquake occurred along 1300 km (800 mi) of the oceanic subduction zone located 100 km (62 mi) west of Sumatra and the Nicobar and Andaman Islands in the eastern Indian Ocean. Highly destructive tsunamis were generated by up to 10 m (33 ft) vertical displacements of the sea floor associated with massive (more than 20 m [65 ft] horizontally) sudden movements of adjacent plates during this event. Although the exact numbers will never be accurately known, it is estimated that 237,000 people died and over $13 billion in damage occurred. Some economists estimate that the tsunami devastation will place about 1 million people in poverty for the rest of their lives. The tsunami was in excess of 20 m (65 ft) as it assaulted the Sumatra coastline (box fig. 1) and was recorded around the world. This tsunami is the first for which there are high-quality worldwide tide gauge measurements and for which there are multiple-satellite altimetry passes that were able to measure the tsunami wave height in the open-ocean. These widespread coastal and open-ocean measurements of the tsunami height have been used to further refine a global tsunami numerical model, known as MOST (Method of Splitting Tsunami), used to predict the propagation and wave heights of tsunamis all over the world. The objective of tsunami modeling is to develop faster and more reliable forecasts of tsunamis striking coastal regions. A comparison of the actual measured tsunami heights with the predicted heights from the MOST model have revealed some factors that contributed to the propagation of the tsunami's energy thousands of kilometers throughout the world oceans.

The first instrumental tsunami measurements were available about three hours after the earthquake from the real-time reporting tide gauge at the Cocos Islands (box fig. 2) located approximately 1700 km (1056 mi) south of the earthquake source area. Data from this gauge revealed a 30 cm (11.8 in)-high first wave followed by a long train of water level oscillations with maximum peak-to-trough ranges of 53 cm (21 in). Gauge data and inundation measurements from sites in India and Sri Lanka at similar distances from the epicenter yielded amplitudes almost ten times greater than the Cocos Islands values. These significant wave height differences were consistent with numerical modeling results that clearly demonstrate the highly directional nature of the Sumatra tsunami (box fig. 2).

Satellite altimetry measurements of tsunami amplitude were obtained from the Jason-1 and Topex/Poseidon satellites (see chapter 1, section 1.10) as they transited the Indian Ocean about

Box Figure 1 Tsunami inundation along the northern Sumatra coastline where flooding exceeded 30m (98 ft) and caused the most deaths and damage. The white staff in the center of the photograph is 5m (16.5 ft). Photo courtesy of Jose Borrero, University of Southern California.

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Field Notes Boxes

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

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.

Online Links to Related Topics

Find Internet links to each chapter's content, boxed readings, and figures inside the Online Learning Center for this text at www.mhhe.com/sverdrup9e. This icon web link within text indicates that a web link is provided for further reading within the Online Learning Center.

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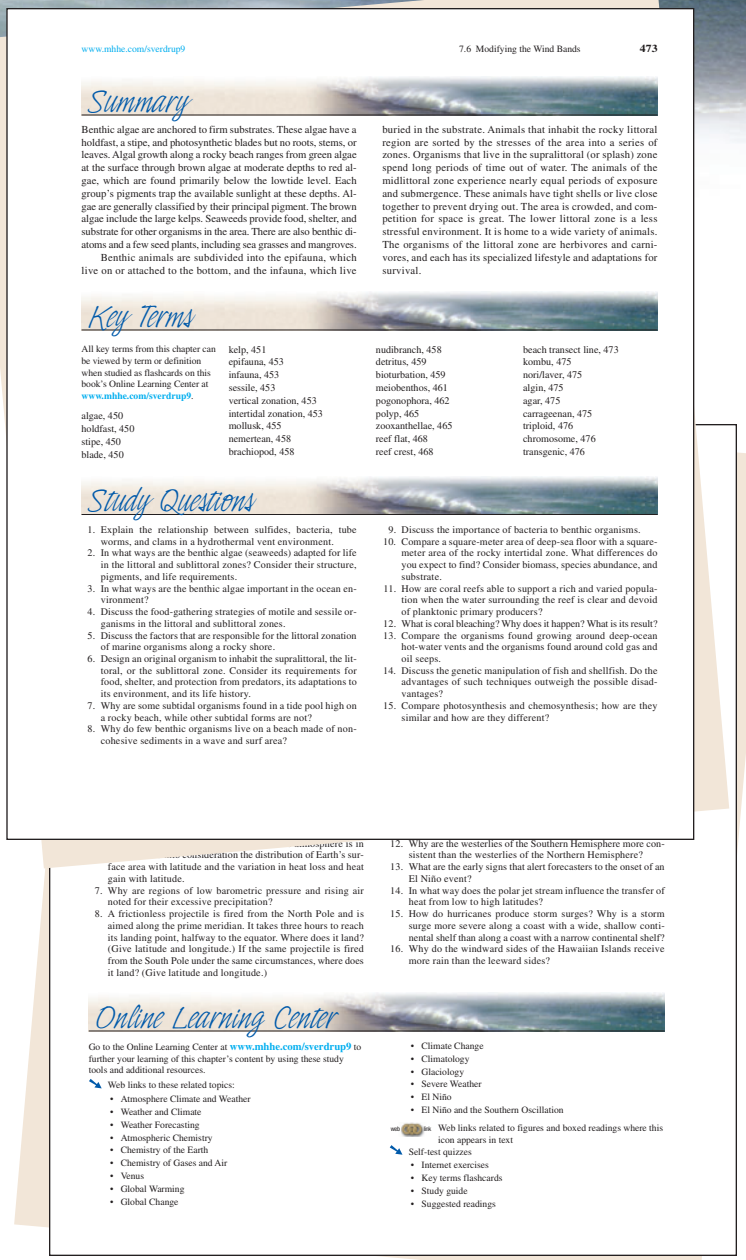

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Summary

Benthic algae are anchored to firm substrates. These algae have a holdfast, a stipe, and photosynthetic blades but no roots, stems, or leaves. Algal growth along a rocky beach ranges from green algae at the surface through brown algae at moderate depths to red algae, which are found primarily below the lowtide level. Each group's pigments trap the available sunlight at these depths. Algae are generally classified by their principal pigment. The brown algae include the large kelps. Seaweeds provide food, shelter, and substrate for other organisms in the area. There are also benthic diatoms and a few seed plants, including sea grasses and mangroves.

Benthic animals are subdivided into the epifauna, which live on or attached to the bottom, and the infauna, which live buried in the substrate. Animals that inhabit the rocky littoral region are sorted by the stresses of the area into a series of zones. Organisms that live in the supralittoral (or splash) zone spend long periods of time out of water. The animals of the midlittoral zone experience nearly equal periods of exposure and submergence. These animals have tight shells or live close together to prevent drying out. The area is crowded, and competition for space is great. The lower littoral zone is a less stressful environment. It is home to a wide variety of animals. The organisms of the littoral zone are herbivores and carnivores, and each has its specialized lifestyle and adaptations for survival.

Key Terms

All key terms from this chapter can be viewed by term or definition when studied as flashcards on this book's Online Learning Center at www.mhhe.com/sverdrup9.

algae, 450
holdfast, 450
stipe, 450
blade, 450
kelp, 451
epifauna, 453
infauna, 453
sessile, 453
vertical zonation, 453
intertidal zonation, 453
mollusk, 455
nemertean, 458
brachiopod, 458
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detritus, 459
bioturbation, 459
meiobenthos, 461
pogonophora, 462
polyp, 465
zooxanthellae, 465
reef flat, 468
reef crest, 468
beach transect line, 473
kombu, 475
nori/laver, 475
algin, 475
agar, 475
carrageenan, 475
triploid, 476
chromosome, 476
transgenic, 476

Study Questions

1. Explain the relationship between sulfides, bacteria, tube worms, and clams in a hydrothermal vent environment.
2. In what ways are the benthic algae (seaweeds) adapted for life in the littoral and sublittoral zones? Consider their structure, pigments, and life requirements.
3. In what ways are the benthic algae important in the ocean environment?
4. Discuss the food-gathering strategies of motile and sessile organisms in the littoral and sublittoral zones.
5. Discuss the factors that are responsible for the littoral zonation of marine organisms along a rocky shore.
6. Design an original organism to inhabit the supralittoral, the littoral, or the sublittoral zone. Consider its requirements for food, shelter, and protection from predators, its adaptations to its environment, and its life history.
7. Why are some subtidal organisms found in a tide pool high on a rocky beach, while other subtidal forms are not?
8. Why do few benthic organisms live on a beach made of noncohesive sediments in a wave and surf area?
9. Discuss the importance of bacteria to benthic organisms.
10. Compare a square-meter area of deep-sea floor with a square-meter area of the rocky intertidal zone. What differences do you expect to find? Consider biomass, species abundance, and substrate.
11. How are coral reefs able to support a rich and varied population when the water surrounding the reef is clear and devoid of planktonic primary producers?
12. What is coral bleaching? Why does it happen? What is its result?
13. Compare the organisms found growing around deep-ocean hot-water vents and the organisms found around cold gas and oil seeps.
14. Discuss the genetic manipulation of fish and shellfish. Do the advantages of such techniques outweigh the possible disadvantages?
15. Compare photosynthesis and chemosynthesis; how are they similar and how are they different?

...sphere is in ... consideration the distribution of Earth's surface area with latitude and the variation in heat loss and heat gain with latitude.

7. Why are regions of low barometric pressure and rising air noted for their excessive precipitation?
8. A frictionless projectile is fired from the North Pole and is aimed along the prime meridian. It takes three hours to reach its landing point, halfway to the equator. Where does it land? (Give latitude and longitude.) If the same projectile is fired from the South Pole under the same circumstances, where does it land? (Give latitude and longitude.)
12. Why are the westerlies of the Southern Hemisphere more consistent than the westerlies of the Northern Hemisphere?
13. What are the early signs that alert forecasters to the onset of an El Niño event?
14. In what way does the polar jet stream influence the transfer of heat from low to high latitudes?
15. How do hurricanes produce storm surges? Why is a storm surge more severe along a coast with a wide, shallow continental shelf than along a coast with a narrow continental shelf?
16. Why do the windward sides of the Hawaiian Islands receive more rain than the leeward sides?

Online Learning Center

Go to the Online Learning Center at www.mhhe.com/sverdrup9 to further your learning of this chapter's content by using these study tools and additional resources.

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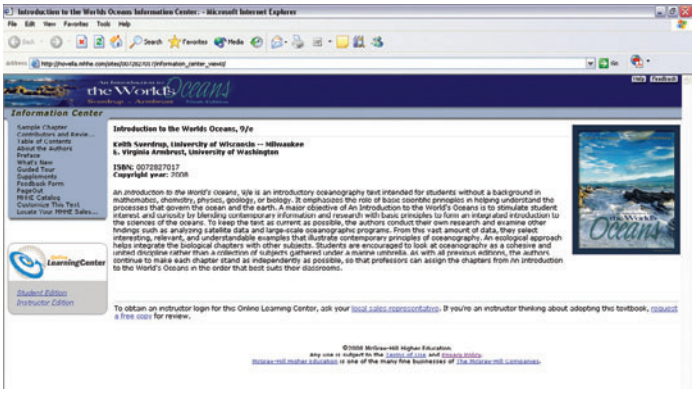
- Weather and Climate
- Weather Forecasting
- Atmospheric Chemistry
- Chemistry of the Earth
- Chemistry of Gases and Air
- Venus
- Global Warming
- Global Change
- Climate Change
- Climatology
- Glaciology
- Severe Weather
- El Niño
- El Niño and the Southern Oscillation

web link Web links related to figures and boxed readings where this icon appears in text

Self-test quizzes

- Internet exercises
- Key terms flashcards
- Study guide
- Suggested readings



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- Internet exercises
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