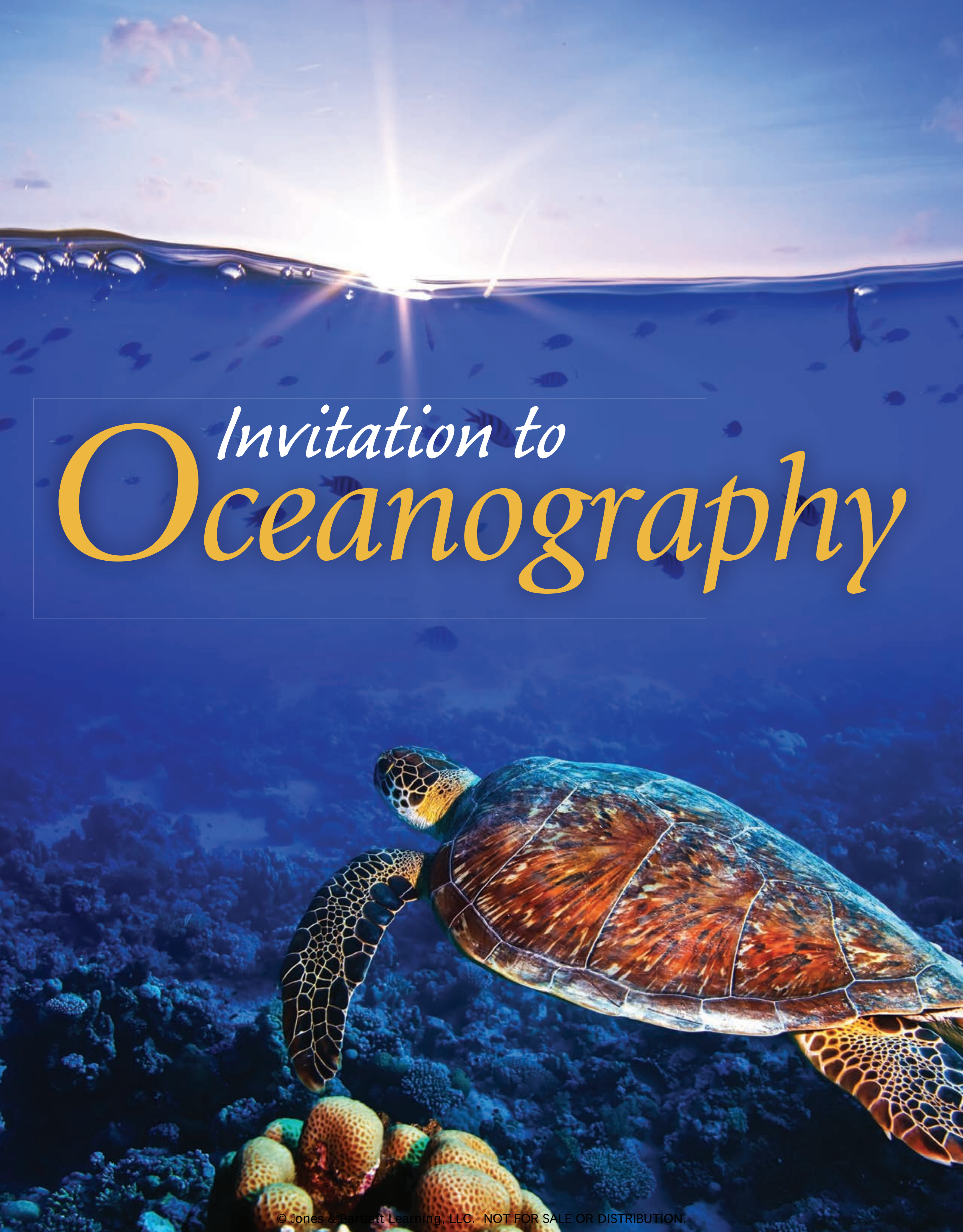
Invitation to Oceanography



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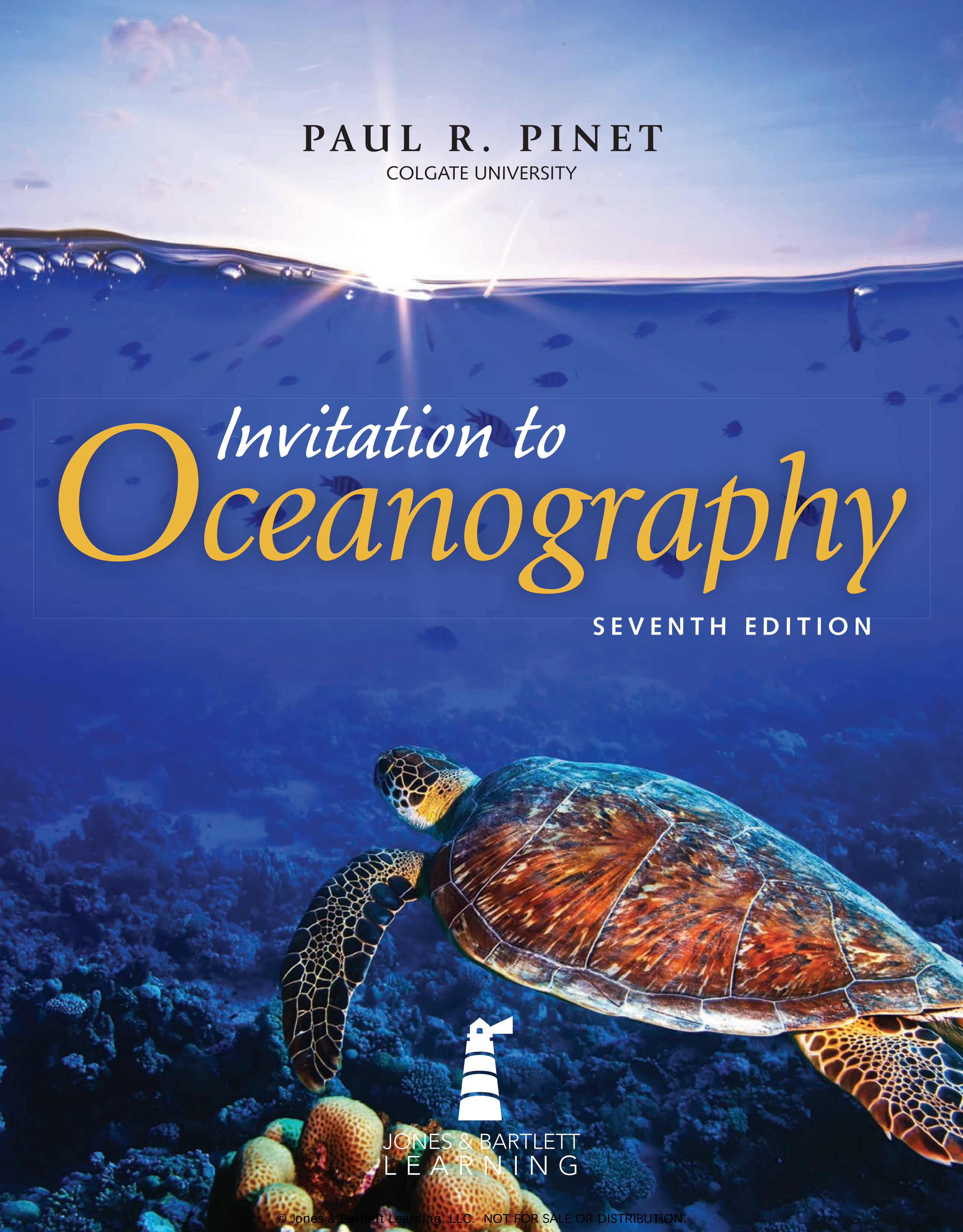

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To Marita E. Hyman, a wise, passionate, caring partner who shares her life with me living on a special parcel of land on a large Earth in a vast universe.

Ocean: © Willyam Bradberry/Shutterstock, Inc.

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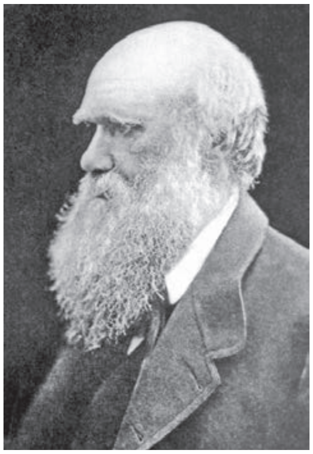

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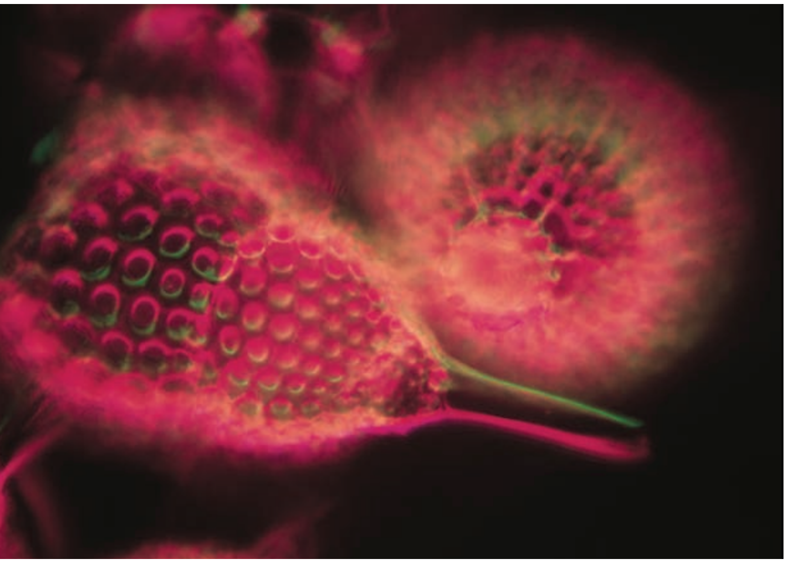

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Preface

This book deals with the workings of the ocean, the dynamic processes that affect its water, seafloor, and abundant life forms. The approach used is a broad one, relying on basic concepts to explain the ocean's many mysteries. Anybody—whether sailor, surfer, beachcomber, or student—can learn about the processes and creatures of the oceans. No background in science is required to grasp the many important ideas that are relevant to the working of the oceans. Wherever appropriate, the underlying science is first explained clearly, and only then is it used to account for ocean processes. These overarching scientific concepts are summarized conveniently as "Key Concepts" at the end of every chapter. In order to help those unfamiliar with the practice of science, a series of "process of science" boxes provides an explanation of how scientists reason and draw conclusions about the natural world. In the glossary, important words are clearly defined and many are accompanied by figure numbers that refer you to the figure that illustrates the term.

The figures and their accompanying captions do not merely illustrate but also supplement the written text. All the drawings have been beautifully and accurately rendered by a team of talented artists and illustrators in order to present in visual form ideas that are at times necessarily abstract. They should be studied carefully before advancing to the next section of the chapter, because they help provide concreteness to the ideas discussed. It has been the author's experience that those students who truly understand the "ins and outs" of the illustrations tend to have a solid grasp of the chapters' main concepts. This will take a bit of time, but it is time well invested.

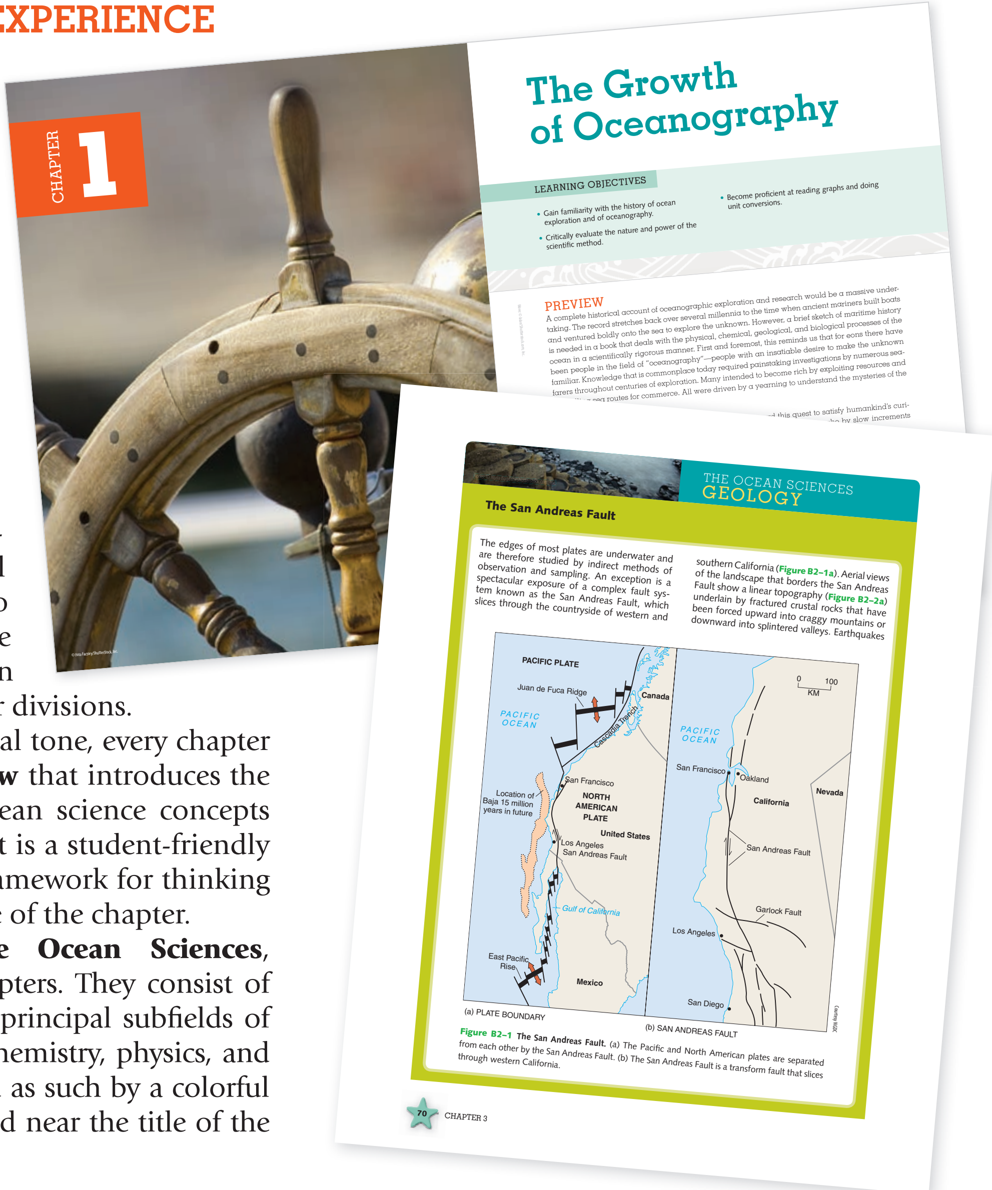
ORGANIZATION

The seventh edition of *Invitation to Oceanography* incorporates new and updated material, based on the many valuable suggestions made by faculty and students who have worked with the previous editions of the book. This means that the organization of the material, the development of the ideas, and the quality of the prose and illustrations are better than ever. We are always working to improve each succeeding version of the book, and so we welcome all comments and criticisms from our readers. Both faculty and students agree that the development of key oceanographic concepts flows logically and systematically from chapter to chapter, as well as from section to section.

The first two chapters review the long history of ocean exploration and research as well as the fundamental structure of the Earth's interior and its exterior ocean basins. Chapters 3 through 10 examine the geology, chemistry, physics, and biology of the sea, highlighting the key scientific concepts and latest discoveries in these subdisciplines of oceanography. In some sense, the material and concepts in these seven chapters represent the core ideas of the ocean sciences, and when comprehended and synthesized, they provide the framework for understanding ocean habitats as whole, functional ecosystems—the chapter topics of the remainder of the book. For example, Chapters 11 and 12 examine the intriguing intricacies of dynamic coastal environments, including beaches, dunes, barrier islands, estuaries, deltas, salt marshes, mangrove swamps, lagoons, and coral reefs. Two chapters are devoted to coastal ecosystems, because we are most familiar and come in regular contact with the shoreline rather than the open ocean. It is likely that many of us as voting citizens will be in a position to influence regulatory legislation and management practices of these fragile habitats. Chapter 13 provides an overview of the many fascinating and exotic ecosystems that are found far offshore, either in open water or on the deep-sea floor. Chapter 14 surveys the ocean's abundant resources, both living (fish) and nonliving (petroleum, metals, phosphate), that are vital for the modern human world. Chapter 15 presents a balanced appraisal of the environmental stresses brought about by human activity, showing the nature and alarming extent of this impact and providing examples of groups of concerned citizens who are striving hard and successfully to reverse environmental despoilment. Throughout the book, local and regional examples are drawn from all parts of the U.S. coastline, including the Pacific coast as far north as Alaska, the Atlantic seaboard as well as maritime Canada, and the Gulf of Mexico. Examples from foreign seas are used where appropriate.

Chapter 16 examines a most timely global issue—climate change. How will warming of the atmosphere and oceans affect the processes and biodiversity of marine ecosystems? What can we do individually and collectively to mitigate the impacts of global warming so that our children can enjoy the ocean's beauty?

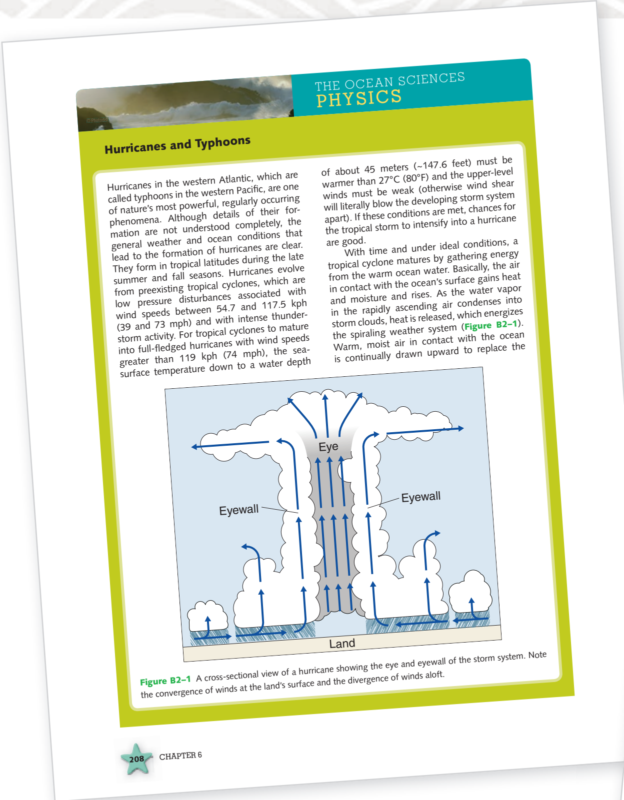
THE STUDENT EXPERIENCE



Every chapter opens with a succinct list of **Learning Objectives**. Students should review this list prior to diving into the chapter to help guide their focus. As they progress through the chapter, they should periodically flip back to the Learning Objectives to ensure they are fully grasping that chapter's key oceanographic concepts. This practice will encourage students to think critically about the fascinating field of ocean science and its four major divisions. Written in a conversational tone, every chapter also opens with a **Preview** that introduces the reader to the specific ocean science concepts they are about to study. It is a student-friendly primer that provides a framework for thinking critically about the theme of the chapter.

Featured boxes, **The Ocean Sciences**, abound in all of the chapters. They consist of four types, based on the principal subfields of oceanography: geology, chemistry, physics, and biology. Each is identified as such by a colorful and distinctive logo placed near the title of the box.

- **Geology** boxes dig deep into key geologic oceanographic concepts by exploring specific places, such as the Red Sea, the San Andreas Fault, the Mediterranean Sea, and other global examples, including a new discussion on the impact of Hurricane Sandy on the New York and New Jersey shorelines.


THE OCEAN SCIENCES
PHYSICS

Hurricanes and Typhoons

Hurricanes in the western Atlantic, which are called typhoons in the western Pacific, are one of nature's most powerful, regularly occurring phenomena. Although details of their formation are not understood completely, the general weather and ocean conditions that lead to the formation of hurricanes are clear. They form in tropical latitudes during the late summer and fall seasons. Hurricanes evolve from preexisting tropical cyclones, which are low pressure disturbances associated with wind speeds between 54.7 and 117.5 kph (39 and 73 mph) and with intense thunderstorm activity. For tropical cyclones to mature into full-fledged hurricanes with wind speeds greater than 119 kph (74 mph), the sea-surface temperature down to a water depth of about 45 meters (~147.6 feet) must be warmer than 27°C (80°F) and the upper-level winds must be weak (otherwise wind shear will literally blow the developing storm system apart). If these conditions are met, chances for the tropical storm to intensify into a hurricane are good.

With time and under ideal conditions, a tropical cyclone matures by gathering energy from the warm ocean water. Basically, the air in contact with the ocean's surface gains heat and moisture and rises. As the water vapor in the rapidly ascending air condenses into storm clouds, heat is released, which energizes the spiraling weather system (Figure B2–1). Warm, moist air in contact with the ocean is continually drawn upward to replace the

Figure B2–1 A cross-sectional view of a hurricane showing the eye and eyewall of the storm system. Note the convergence of winds at the land's surface and the divergence of winds aloft.

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- **Physics** boxes expand the chapter material and illuminate key concepts by diving deep into specific examples. For instance, hurricanes and typhoons are highlighted in the chapter covering wind and ocean circulation and the megatsunamis of 2006 and 2011 are featured in the chapter discussing waves. These boxes provide students with practical applications of key oceanographic principles.


THE OCEAN SCIENCES
CHEMISTRY

Chemical Techniques

In trying to characterize and explain the chemical properties of seawater, marine chemists find it critically important to collect sufficient and appropriate seawater samples, prevent their chemical contamination, determine sampling depths, and use accurate and precise analytical procedures.

› SAMPLE COLLECTION

Seawater samples for chemical analysis are collected in metallic or plastic cylindrical bottles. The metallic bottles have interior liners composed of inert plastic to prevent contamination of the sample by metal ions. One such sampling device, the Niskin bottle, has valves on both ends that are opened and attached to a cable (Figure B2–1). Typically, several open bottles are attached at predetermined positions on the cable. After the bottles are lowered, a weight, known as a *messenger*, is fastened to the cable and released. When the messenger strikes the first water bottle, it causes it to close tightly, trapping a sample of seawater. A messenger attached to a clamp beneath the first bottle is then released, dropping and triggering the next bottle below. The procedure is repeated until all the bottles on the cable have been closed. Depending on the nature of the study, chemists usually collect seawater volumes of between 1 and 3 liters (~1.06 and 3.17 quarts) with these bottle samplers.

A more elaborate sample-bottle configuration is known as the *rosette cluster*. It consists of a rigid frame that holds a number of collection bottles upright, arranged in a circular pattern (Figure B2–2). The bottles can be set to open and close automatically, or a

Courtesy of Michael Van Woert, NESDIS, ORA/NOAA

Figure B2–1 **Niskin bottles.** Open Niskin bottles are attached to a cable and lowered to water depths where seawater samples are to be obtained for chemical analysis. A metal messenger "trips" each bottle on the cable individually, causing it to fill with water and close securely.

Courtesy of Captain Robert A. Pawlowski, NOAA Corps/NOAA

Figure B2–2 **A rosette cluster.** Water collecting bottles are arranged around a rigid, circular frame in a rosette pattern. Technicians are able to close the bottles individually as the array is lowered or raised through the water column.

(*Continued*)

The Properties of Seawater 143

- **Chemistry** boxes review scientific experiments conducted by oceanographers to investigate the chemical processes of the seas, offering students a chance to explore the techniques oceanographers use in the field.


THE OCEAN SCIENCES
BIOLOGY

Penguins

Most seabirds, including puffins, albatrosses, petrels, shearwaters, and penguins (Figure B1–1), eat fish as part of their diet. Some of them, such as albatrosses and penguins, prey on squid at night. Among the seabirds, penguins have lost their ability to fly and have become specialized in swimming and diving. They have evolved large, heavy bodies, big bones, thick fatty deposits for insulation, greasy feathers that repel water, and streamlined bodies and stubby wings for "flying" underwater (Figure B1–2). Emperor penguins, for example, have been clocked at speeds of over 15 kilometers per hour (~9.5 mph), and have remained submerged for up to 15 and 20 minutes at a time, diving as deeply as 250 meters (~825 feet) below the water surface while hunting squid.

Penguins, which range from the size of a large seagull to a height of 1.3 meters (~4.3 feet), are native to the Southern Hemisphere only. Of the eighteen species of penguins, the Adélie and Emperor penguins are the only two that have rookeries along the shoreline of Antarctica. The Adélie (Figure B1–3a), which is as tall as 60 centimeters (~24 inches), displays the classic tuxedo color pattern seen so often in cartoon characters. They gather in large rookeries to breed during the spring and summer on land and spend the winter at sea. The Emperor, the largest penguin (Figure B1–3b), incubates its eggs on land during the Antarctic winter! It survives the incredibly cold temperatures and high winds by huddling in tight groups in order to conserve body heat. Periodically, the "toasty" members in the middle of a group work their way to the outside. This allows the colder members at the fringe to move toward the center of the group and warm up. Most penguins hunt in water not far from shore. Fishery biologists estimate that penguins take almost 35 million tons of food from the ocean each year.

Currently, global climate change is affecting the population of Adélie penguins that occupies territory on the western Antarctic Peninsula. Their numbers are diminishing alarmingly (Figure B1–4) for two reasons. The sea ice cover is less extensive, which prevents Adélie penguins from reaching their

(a) PUFFIN
(b) PETREL
(c) ALBATROSS

Figure B1–1 **Seabirds.** Seabirds are important members of marine food webs. Many of them prey heavily on fish, squid, and shrimp. Examples of some important seabirds include (a) puffins, (b) petrels, and (c) albatrosses.

(*Continued*)

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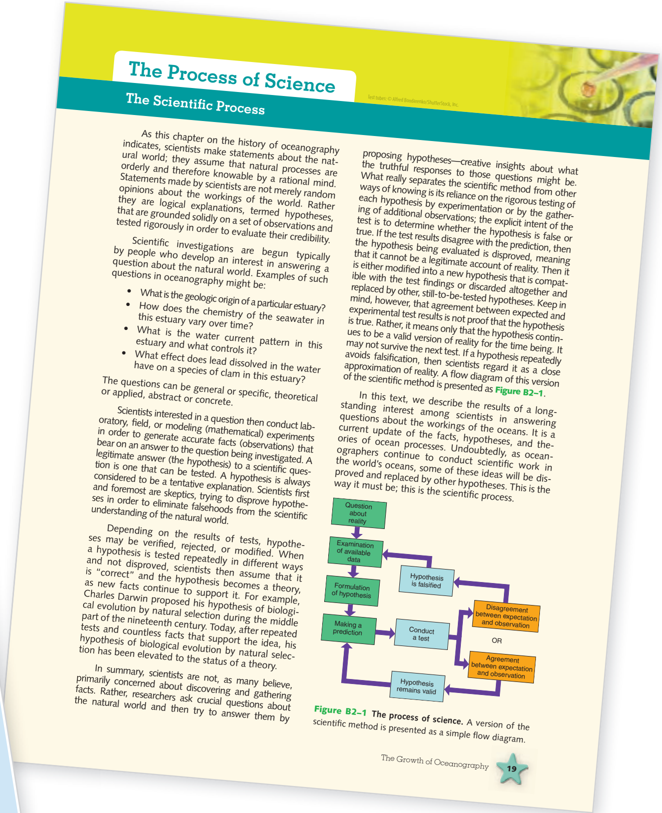
- **Biology** boxes spotlight specific species that depend on the oceans for survival, such as penguins and killer whales, as well as the unique marine ecology of particular regions, including an exploration of Chesapeake Bay and the Gulf of Mexico. These boxes also discuss recent events that have impacted the seas, including a look into the *Exxon Valdez* and the *Deepwater Horizon* oil spills.

- **The Process of Science** presents a hypothesis regarding a global issue, such as climate variability and rising sea levels, and explores the scientific processes employed in gathering and analyzing information to develop a scientific theory. By exploring historical research from leading scientists and current scientific data, students are challenged to think critically about the future landscape of Earth and its seas.



The Process of Science

The Scientific Process

Test tubes: © Alfred Bondarenko/ShutterStock, Inc.

As this chapter on the history of oceanography indicates, scientists make statements about the natural world; they assume that natural processes are orderly and therefore knowable by a rational mind. Statements made by scientists are not merely random opinions about the workings of the world. Rather they are logical explanations, termed hypotheses, that are grounded solidly on a set of observations and tested rigorously in order to evaluate their credibility.

Scientific investigations are begun typically by people who develop an interest in answering a question about the natural world. Examples of such questions in oceanography might be:

- What is the geologic origin of a particular estuary?
- How does the chemistry of the seawater in this estuary vary over time?
- What is the water current pattern in this estuary and what controls it?
- What effect does lead dissolved in the water have on a species of clam in this estuary?

The questions can be general or specific, theoretical or applied, abstract or concrete.

Scientists interested in a question then conduct laboratory, field, or modeling (mathematical) experiments in order to generate accurate facts (observations) that bear on an answer to the question being investigated. A legitimate answer (the hypothesis) to a scientific question is one that can be tested. A hypothesis is always considered to be a tentative explanation. Scientists first and foremost are skeptics, trying to disprove hypotheses in order to eliminate falsehoods from the scientific understanding of the natural world.

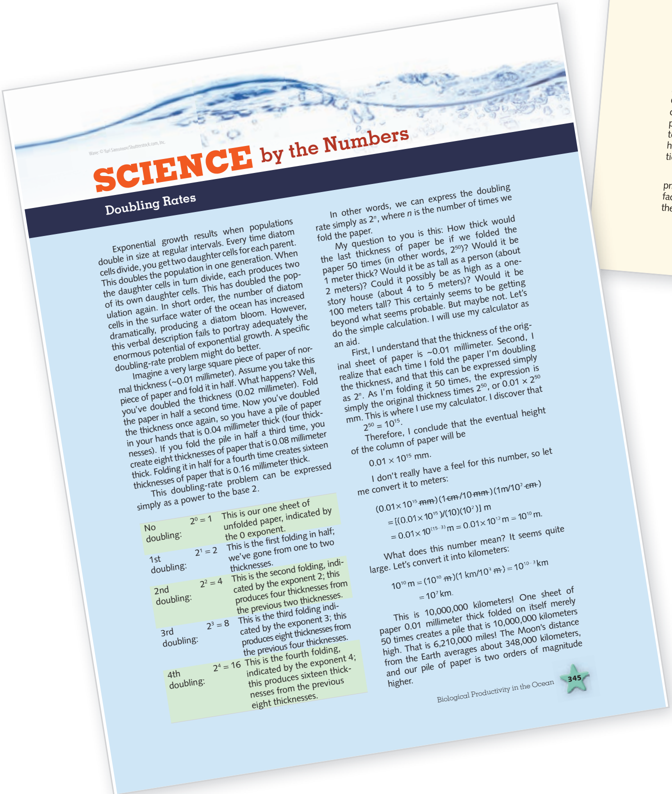
Depending on the results of tests, hypotheses may be verified, rejected, or modified. When a hypothesis is tested repeatedly in different ways and not disproved, scientists then assume that it is "correct" and the hypothesis becomes a theory, as new facts continue to support it. For example, Charles Darwin proposed his hypothesis of biological evolution by natural selection during the middle part of the nineteenth century. Today, after repeated tests and countless facts that support the idea, his hypothesis of biological evolution by natural selection has been elevated to the status of a theory.

In summary, scientists are not, as many believe, primarily concerned about discovering and gathering facts. Rather, researchers ask crucial questions about the natural world and then try to answer them by proposing hypotheses—creative insights about what the truthful responses to those questions might be. What really separates the scientific method from other ways of knowing is its reliance on the rigorous testing of each hypothesis by experimentation or by the gathering of additional observations; the explicit intent of the test is to determine whether the hypothesis is false or true. If the test results disagree with the prediction, then the hypothesis being evaluated is disproved, meaning that it cannot be a legitimate account of reality. Then it is either modified into a new hypothesis that is compatible with the test findings or discarded altogether and replaced by other, still-to-be-tested hypotheses. Keep in mind, however, that agreement between expected and experimental test results is not proof that the hypothesis is true. Rather, it means only that the hypothesis continues to be a valid version of reality for the time being. It may not survive the next test. If a hypothesis repeatedly avoids falsification, then scientists regard it as a close approximation of reality. A flow diagram of this version of the scientific method is presented as **Figure B2–1**.

In this text, we describe the results of a long-standing interest among scientists in answering questions about the workings of the oceans. It is a current update of the facts, hypotheses, and theories of ocean processes. Undoubtedly, as oceanographers continue to conduct scientific work in the world's oceans, some of these ideas will be disproved and replaced by other hypotheses. This is the way it must be; this is the scientific process.

Figure B2–1 The process of science. A version of the scientific method is presented as a simple flow diagram.

The Growth of Oceanography 19



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SCIENCE by the Numbers

Doubling Rates

Exponential growth results when populations double in size at regular intervals. Every time diatom cells divide, you get two daughter cells for each parent. This doubles the population in one generation. When the daughter cells in turn divide, each produces two of its own daughter cells. This has doubled the population again. In short order, the number of diatom cells in the surface water of the ocean has increased dramatically, producing a diatom bloom. However, this verbal description fails to portray adequately the enormous potential of exponential growth. A specific doubling-rate problem might do better.

Imagine a very large square piece of paper of normal thickness (~0.01 millimeter). Assume you take this piece of paper and fold it in half. What happens? Well, you've doubled the thickness (0.02 millimeter). Fold the paper in half a second time. Now you've doubled the thickness once again, so you have a pile of paper in your hands that is 0.04 millimeter thick (four thicknesses). If you fold the pile in half a third time, you create eight thicknesses of paper that is 0.08 millimeter thick. Folding it in half for a fourth time creates sixteen thicknesses of paper that is 0.16 millimeter thick.

This doubling-rate problem can be expressed simply as a power to the base 2.

No doubling:	$2^0 = 1$	This is our one sheet of unfolded paper, indicated by the 0 exponent.
1st doubling:	$2^1 = 2$	This is the first folding in half; we've gone from one to two thicknesses.
2nd doubling:	$2^2 = 4$	This is the second folding, indicated by the exponent 2; this produces four thicknesses from the previous two thicknesses.
3rd doubling:	$2^3 = 8$	This is the third folding indicated by the exponent 3; this produces eight thicknesses from the previous four thicknesses.
4th doubling:	$2^4 = 16$	This is the fourth folding, indicated by the exponent 4; this produces sixteen thicknesses from the previous eight thicknesses.

In other words, we can express the doubling rate simply as 2^n, where n is the number of times we fold the paper.

My question to you is this: How thick would the last thickness of paper be if we folded the paper 50 times (in other words, 2^{50})? Would it be 1 meter thick? Would it be as tall as a person (about 2 meters)? Could it possibly be as high as a one-story house (about 4 to 5 meters)? Would it be 100 meters tall? This certainly seems to be getting beyond what seems probable. But maybe not. Let's do the simple calculation. I will use my calculator as an aid.

First, I understand that the thickness of the original sheet of paper is ~0.01 millimeter. Second, I realize that each time I fold the paper I'm doubling the thickness, and that this can be expressed simply as 2^n. As I'm folding it 50 times, the expression is simply the original thickness times 2^{50}, or 0.01×2^{50} mm. This is where I use my calculator. I discover that

$$2^{50} = 10^{15}.$$

Therefore, I conclude that the eventual height of the column of paper will be

$$0.01 \times 10^{15} \text{ mm}.$$

I don't really have a feel for this number, so let me convert it to meters:

$$(0.01\times10^{15}\ \cancel{\text{mm}})(1\ \cancel{\text{cm}}/10\ \cancel{\text{mm}})(1\text{m}/10^2\ \cancel{\text{cm}})$$
$$= [(0.01\times10^{15})/(10)(10^2)]\text{ m}$$
$$= 0.01\times10^{(15-3)}\text{ m} = 0.01\times10^{12}\text{ m} = 10^{10}\text{ m}.$$

What does this number mean? It seems quite large. Let's convert it into kilometers:

$$10^{10}\text{ m} = (10^{10}\ \cancel{\text{m}})(1\text{ km}/10^3\ \cancel{\text{m}}) = 10^{10-3}\text{ km}$$
$$= 10^7\text{ km}.$$

This is 10,000,000 kilometers! One sheet of paper 0.01 millimeter thick folded on itself merely 50 times creates a pile that is 10,000,000 kilometers high. That is 6,210,000 miles! The Moon's distance from the Earth averages about 348,000 kilometers, and our pile of paper is two orders of magnitude higher.

Biological Productivity in the Ocean 345

- To assist students in understanding the basic mathematical concepts needed to study oceanography, **Science by the Numbers** provides a step-by-step solution to a specific problem. These boxes help improve students' math skills and provide the insights into ocean processes that only numerical calculations reveal.

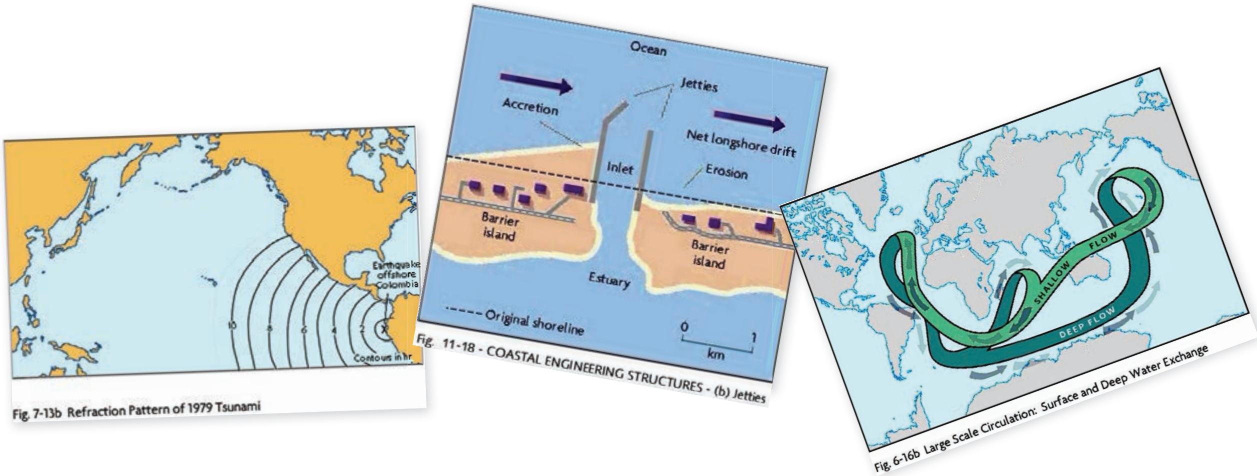
The boxes serve several purposes. Some review common research techniques employed by oceanographers to investigate the seas. Some flesh out a concept merely outlined in the text. Others spotlight case histories in which the oceanography of a specific place is presented in concrete terms from the standpoint of an idea introduced in the text. A few featured boxes review a concept that is simply interesting and that otherwise could not be integrated easily into the main text of the chapter. They are like eating dessert after finishing the main course of a meal. Enjoy them! Two new boxes have been added to this edition. Check the back of the book for a complete listing of the boxes, including the chapter in which each appears.

To ensure readers thoroughly grasp the important concepts, each chapter concludes with a detailed summary of the **Key Concepts**. Students can review the summary prior to diving into the chapter to guide their focus and can also use it as a study tool to prepare for course lectures and exams. It is important for students at this introductory level to be aware of and understand the terminology oceanographers use in their daily discourse. For this reason, a list of **Key Words** is also included at the end of every chapter. Furthermore, the key words in the chapter appear in bold to draw the reader's attention.

Most chapters conclude with a series of questions arranged into three groupings. The first set, the **Review of Basic Concepts**, is just that. The questions address the main notions developed in the chapter. The second set, the **Critical-Thinking Essays**, requires more thought because you must synthesize ideas, sometimes drawing from concepts developed in previous chapters. In other words, verbatim answers might not be found anywhere in the book. However, you can develop an answer by thinking deeply about the question posed and applying common sense and logic to the information provided in the book. The third set of questions, **Discovering with Numbers**, deals with making straightforward calculations about ocean processes. The questions rely on basic mathematics, the kind that any high school graduate has mastered. In order to assist you, the **Science by the Numbers** boxes teach the art of computation and are included in most chapters. The trick to answering math questions is to understand conceptually what it is you are trying to solve. These math boxes will help you upgrade your math skills and develop self-assurance about reasoning with numbers.

A reading list is provided at the end of each chapter and includes both classical, but still relevant, references and more recent writings on the ocean's dynamic processes and diverse habitats. Some are books; most are articles. They should prove valuable for delving deeper into an area of oceanography that intrigues you and for writing term papers. Also, the appendices at the end of the book provide important ancillary material, including conversion factors, a geologic time chart, map-reading techniques, a discussion of the Coriolis deflection, and the classification of marine organisms.

To visually assist readers in understanding key oceanographic processes, Jones & Bartlett Learning has developed **Interactive Oceanography Animations**. These engaging animations bring fascinating ocean science phenomena to life! Each interactive animation guides students through oceanographic processes and gauges students' understanding with exercises and assessment questions.



■ TEACHING TOOLS

To assist you in teaching this course and supplying your students with the best in teaching aids, Jones & Bartlett Learning has prepared a complete supplemental package available to all adopters. Additional information and review copies of any of the following items are available through your Jones & Bartlett Learning sales representative.

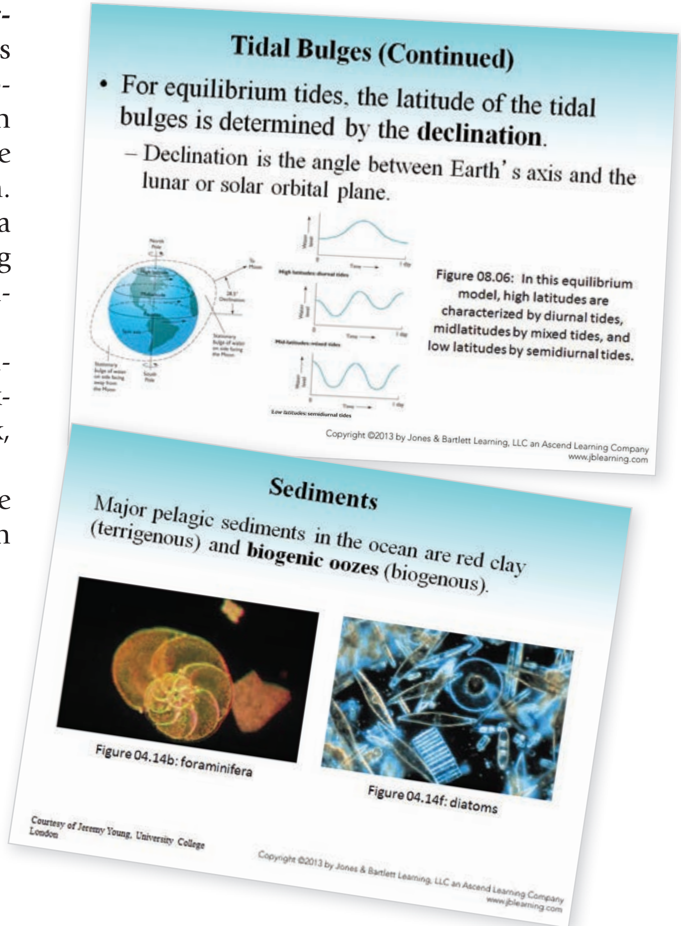
An **Image Bank** provides the illustrations, photographs, and tables (to which Jones & Bartlett Learning holds the copyright or has permission to reproduce digitally). These images are not for sale or distribution but may be used to enhance your existing lecture slides, tests and quizzes, or other classroom material.

The **Lecture Outline Slides in PowerPoint Format** presentation package provides lecture notes, graphs, and images for each chapter of *Invitation to Oceanography*. Instructors with Microsoft PowerPoint software can customize the outlines, images, and order of presentation.

The **Instructor's Manual** provided as a text file, includes chapter outlines, teaching tips, learning objectives, and additional concept and essay questions.

The **Additional Test Questions** are available as straight text files and contain approximately 750 multiple-choice, fill-in-the-blank, essay, and research questions.

A basic **sample syllabus** is also available to assist instructors who are beginning to plan their courses.



About the Author

Paul Pinet teaches geology, oceanography, and environmental studies courses at Colgate University, located in central New York state. He earned BA and MS degrees in geology from the University of New Hampshire and the University of Massachusetts, respectively, and a PhD in oceanography from the University of Rhode Island. His research has been focused on the geology of continental margins, coastal bluff erosion, estuarine sedimentation, and more recently, on the philosophical dimensions of deep time. At the moment, he is developing long-term (millennia) conservation strategies for barrier islands in response to rising sea level and for mitigating the ongoing extinction event in New England and its ocean. Pinet spent summers during much of his adult life either climbing mountains around the world or cruising on his small, gaff-headed catboat (*Taillefer*) off the New England coast. Though an oceanographer, Pinet admits that he fears water more than high, avalanche-prone mountains. At the moment, he is working on a book of essays entitled *Shadowed by Deep Time*.

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Jones & Bartlett Learning is committed to producing the finest introductory textbook in oceanography possible. This seventh edition of *Invitation to Oceanography* testifies to the staff's earnest commitment to that ideal. During my long association with these professionals, I was impressed by their patience, their creativity, their willingness to listen carefully and critically to my perspectives, and their attentive concern for visual and written aesthetics. The outcome of our collaborative effort is what you have in front of you. I am especially grateful to Matt Kane, Acquisitions Editor, Raven Heroux, Editorial Assistant, Leah Corrigan, Production Editor, and Lauren Miller, Manager of Photo Research, Rights & Permissions. A textbook of this ilk succeeds only if there is a dynamic balance among syntheses, coverage, and details, which was achievable because of our collaborative effort. The few remaining errors and unintentional misrepresentations in this seventh edition are my own alone. I am truly privileged to be working as an author with Jones & Bartlett Learning.

Paul R. Pinet
Hamilton, New York

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