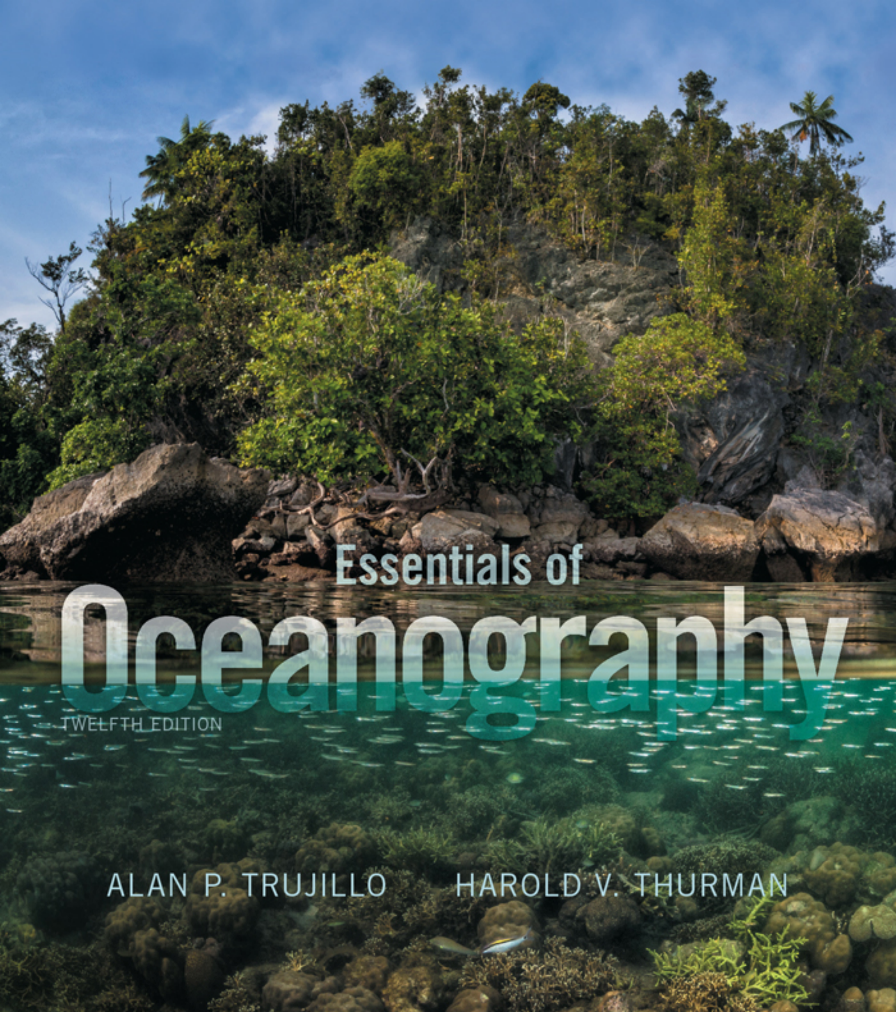
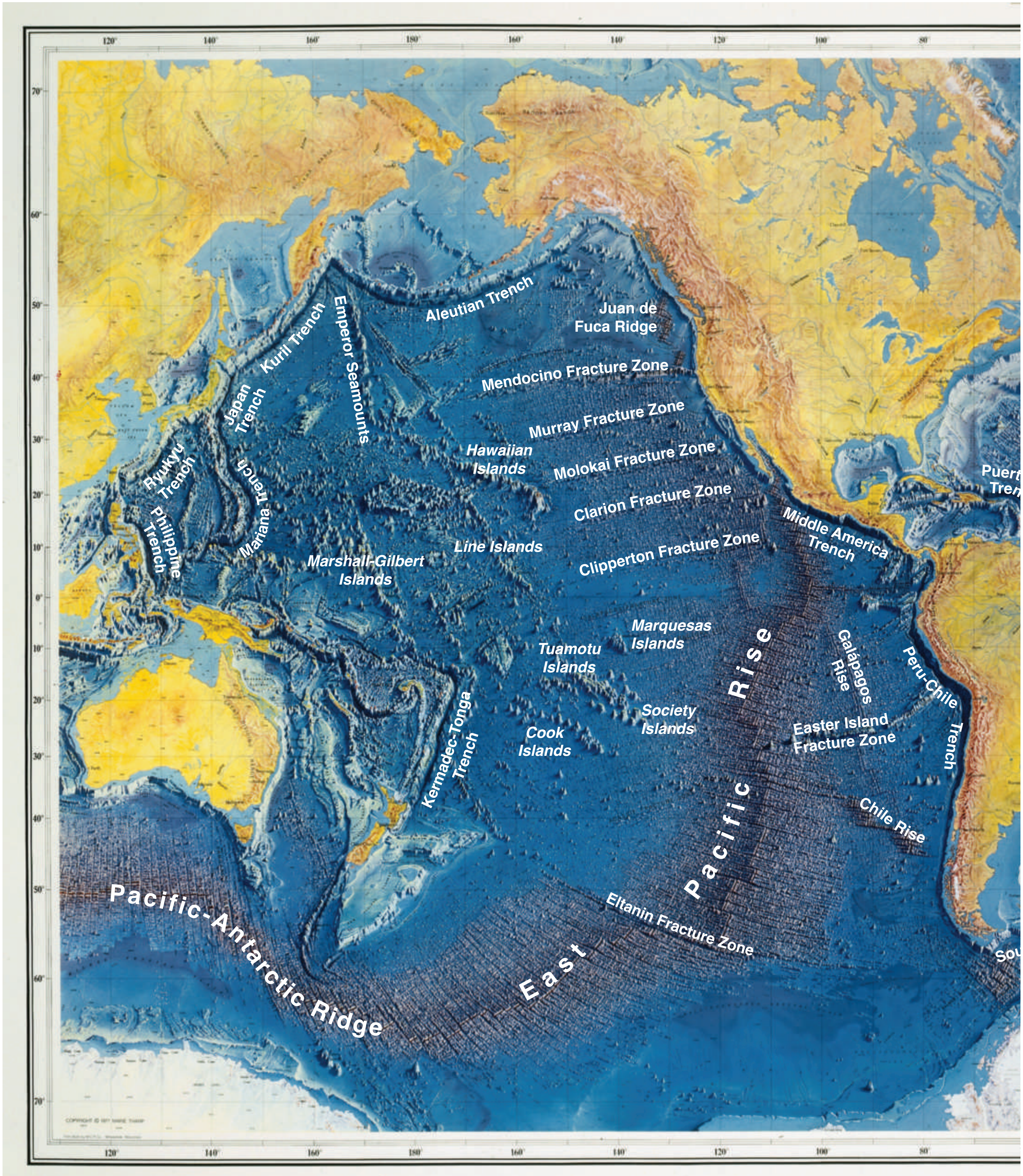


Essentials of Oceanography

TWELFTH EDITION

ALAN P. TRUJILLO HAROLD V. THURMAN


Aleutian Trench
Juan de Fuca Ridge
Kuril Trench
Emperor Seamounts
Mendocino Fracture Zone
Japan Trench
Murray Fracture Zone
Hawaiian Islands
Molokai Fracture Zone
Ryukyu Trench
Mariana Trench
Clarion Fracture Zone
Philippine Trench
Middle America Trench
Line Islands
Marshall-Gilbert Islands
Clipperton Fracture Zone
Marquesas Islands
Tuamotu Islands
Galápagos Rise
Peru-Chile Trench
Society Islands
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Cook Islands
Kermadec-Tonga Trench
Chile Rise
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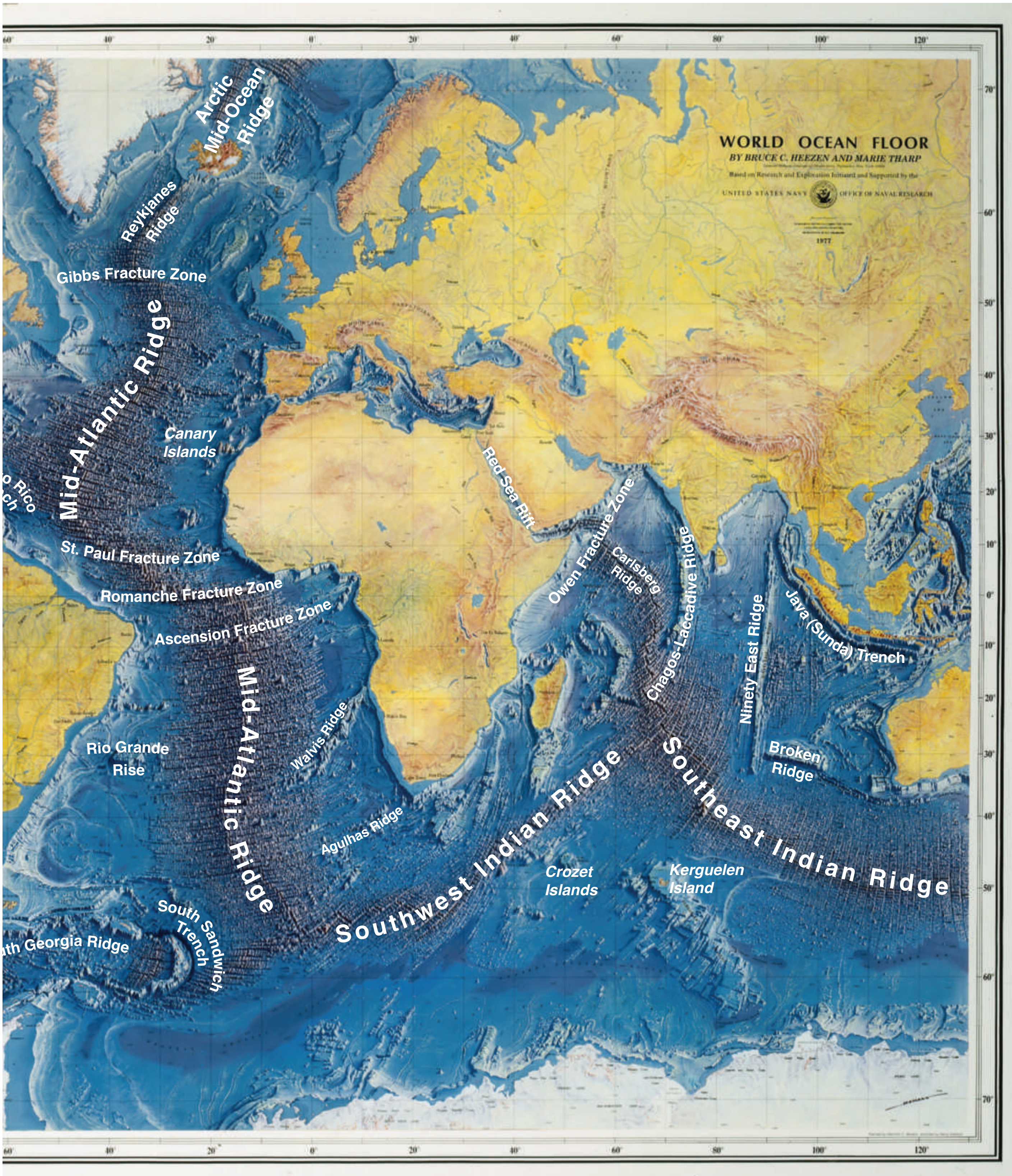
Eltanin Fracture Zone



The "map" that changed the world. This visualization, which shows what Earth's surface would look like if all the water in the oceans were emptied, was created by geologist Bruce Heezen and mapmaker Marie Tharp in 1977, based on ship soundings and sonar data. The representation exaggerates sea floor features for clarity; the vertical exaggeration is about 20 times. For the first time in the history of the world, the shape of Earth's sea floor could be observed, including its many diverse features.

Essentials of Oceanography

TWELFTH EDITION

Alan P. Trujillo

DISTINGUISHED TEACHING PROFESSOR

PALOMAR COLLEGE

Harold V. Thurman

FORMER PROFESSOR EMERITUS

MT. SAN ANTONIO COLLEGE

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Dedicated to my father Dr. Anthony P. Trujillo,
mentor, role model, teacher, and friend

—Al Trujillo

In memory of Hal Thurman (1934–2012)

ABOUT THE AUTHORS

ALAN P. TRUJILLO Al Trujillo is a Distinguished Teaching Professor in the Earth, Space, and Aviation Sciences Department at Palomar College in San Marcos, California. He received his bachelor's degree in geology from the University of California at Davis and his master's degree in geology from Northern Arizona University, afterward working for several years in industry. Al began teaching at Palomar in 1990. In 1997, he was awarded Palomar's Distinguished Faculty Award for Excellence in Teaching, and in 2005 he received Palomar's Faculty Research Award. He has coauthored *Introductory Oceanography* with Hal Thurman and is a contributing author for the textbooks *Earth* and *Earth Science*. In addition to writing and teaching, Al works as a naturalist and lecturer aboard natural history expedition vessels for Lindblad Expeditions/National Geographic in Alaska, Iceland, and the Sea of Cortez/Baja California. His research interests include beach processes, sea cliff erosion, and active teaching techniques. He enjoys photography, and he collects sand as a hobby. Al and his wife, Sandy, have two children, Karl and Eva.

HAROLD V. THURMAN Hal Thurman's interest in geology led to a bachelor's degree from Oklahoma A&M University, followed by seven years working as a petroleum geologist, mainly in the Gulf of Mexico, where his interest in the oceans developed. He earned a master's degree from California State University at Los Angeles. Hal began teaching at Mt. San Antonio College in Walnut, California, in 1968 as a temporary teacher and taught Physics 1 (a surveying class) and three Physical Geology labs. In 1970, he taught his first class of General Oceanography. It was from this experience that he decided to write a textbook on oceanography and received a contract with Charles E. Merrill Publishing Company in 1973. The first edition of his book *Introductory Oceanography* was released in 1975. Harold authored or coauthored over 20 editions of textbooks that include *Introductory Oceanography*, *Essentials of Oceanography*, *Physical Geology*, *Marine Biology*, and *Oceanography Laboratory Manual*, many of which are still being used today throughout the world. In addition, he contributed to the *World Book Encyclopedia* on the topics of "Arctic Ocean," "Atlantic Ocean," "Indian Ocean," and "Pacific Ocean." Hal Thurman retired in May 1994, after 24 years of teaching, and moved to be closer to family in Oklahoma, then to Florida. Hal passed away at the age of 78 on December 29, 2012. His writing expertise, knowledge about the ocean, and easy-going demeanor will be dearly missed.

BRIEF CONTENTS

CONTENTS

PREFACE

"The sea, once it casts its spell, holds one in its net of wonder forever."

—Jacques-Yves Cousteau, oceanographer, underwater videographer, and explorer (circa 1963)

To the Student

Welcome! You're about to embark on a journey that is far from ordinary. Over the course of this term, you will discover the central role the oceans play in the vast global system of which you are a part.

This book's content was carefully developed to provide a foundation in science by examining the vast body of oceanic knowledge. This knowledge includes information from a variety of scientific disciplines—geology, chemistry, physics, and biology—as they relate to the oceans. However, no formal background in any of these disciplines is required to successfully master the subject matter contained within this book. Our desire is to have you take away from your oceanography course much more than just a collection of facts. Instead, we want you to develop a fundamental understanding of how the oceans work and why the oceans behave the way that they do.

This book is intended to help you in your quest to know more about the oceans. Taken as a whole, the components of the ocean—its sea floor, chemical constituents, physical components, and lifeforms—comprise one of Earth's largest interacting, interrelated, and interdependent systems. Because human activities impact Earth systems, it is important to understand not only how the oceans operate but also how the oceans interact with Earth's other systems (such as its atmosphere, biosphere, and hydrosphere) as part of a larger picture. Thus, this book uses a systems approach to highlight the interdisciplinary relationships among oceanographic phenomena and how those phenomena affect other Earth systems.

DIVING DEEPER PREFACE.1

A USER'S GUIDE FOR STUDENTS: HOW TO READ A SCIENCE TEXTBOOK

Have you known someone who could scan a reading assignment or sleep with it under their pillow and somehow absorb all the information? Studies have shown that those people haven't really committed anything to long-term memory. For most of us, it takes a focused, concentrated effort to gain knowledge through reading. Interestingly, if you have the proper motivation and reading techniques, you can develop excellent reading comprehension. What is the best way to read a science textbook such as this one that contains many new and unfamiliar terms?

One common mistake is to approach reading a science textbook as one would read a newspaper, magazine, or novel. Instead, many reading instructors suggest using the SQ4R reading technique, which is based on research about how the brain learns. The SQ4R technique includes these steps:

1. **Survey:** Read the title, introduction, major headings, first sentences, concept statements, review questions, summary, and study aids to become familiar with the content in advance.
2. **Question:** Have questions in mind when you read. If you can't think of any good questions, use the chapter questions as a guide.
3. **Read:** Read flexibly through the chapter, using short time periods to accomplish the task one section at a time (not all in one sitting).
4. **Recite:** Answer the chapter questions. Take notes after each section and review your notes before you move on.
5. **(w)Rite:** Write summaries and/or reflections on what you've read. Write answers to the questions in Step 2.
6. **Review:** Review the text using the strategy in the survey step. Take the time to review your end-of-section notes as well as your summaries.

To help you study most effectively, this textbook includes many study aids that are designed to be used with the SQ4R technique. For example, each chapter includes a word cloud of key terms, a list of learning objectives that are tied to the Essential Concepts throughout the chapter, review Concept Check questions embedded at the end of each section, and an Essential Concepts Review that includes a chapter summary, study resources, and critical thinking questions.

Here are some additional reading tips that may seem like common sense but are often overlooked:

- Don't attempt to do your reading when you are tired, distracted, or agitated.
- Break up your reading into manageable sections. Don't save it all until the last minute.
- Take a short break if your concentration begins to fade. Listen to music, call a friend, have a snack, or drink some water. Then return to your reading.

Remember that every person is different, so experiment with new study techniques to discover what works best for you. In addition, being a successful student is hard work; it is not something one does in his/her spare time. With a little effort in applying the SQ4R reading technique, you will begin to see a difference in what you remember from your reading.

To that end—and to help you make the most of your study time—we focused the presentation in this book by organizing the material around three essential components:

1. **CONCEPTS:** General ideas derived or inferred from specific instances or occurrences (for instance, the concept of density can be used to explain why the oceans are layered)
2. **PROCESSES:** Actions or occurrences that bring about a result (for instance, the process of waves breaking at an angle to the shore results in the movement of sediment along the shoreline)
3. **PRINCIPLES:** Rules or laws concerning the functioning of natural phenomena or mechanical processes (for instance, the principle of sea floor spreading suggests that the geographic positions of the continents have changed through time)

Interwoven within these concepts, processes, and principles are hundreds of photographs, illustrations, real-world examples, and applications that make the material relevant and accessible (and maybe sometimes even *entertaining*) by bringing science to life.

Ultimately, it is our hope that by understanding how the oceans work, you will develop a new awareness and appreciation of all aspects of the marine environment and its role in Earth systems. To this end, the book has been written for you, a student of the oceans. So enjoy and immerse yourself! You're in for an exciting ride.

Al Trujillo

To the Instructor

This twelfth edition of *Essentials of Oceanography* is designed to accompany an introductory college-level course in oceanography taught to students who have no formal background in mathematics or science. As in previous editions, the goal of this edition of the textbook is to clearly present the relationships of scientific principles to ocean phenomena in an engaging and meaningful way.

This edition has greatly benefited from being thoroughly reviewed by hundreds of students who made numerous suggestions for improvement. Comments by former students about the book include, "*I have really enjoyed the oceanography book we've used this semester. It had just the right mix of graphics, text, and user-friendliness that really held my interest,*" and "*What I really liked about the book is that it's a welcoming textbook—open and airy. You could almost read it at bedtime like a story because of all the interesting pictures.*"

This edition has been reviewed in detail by a host of instructors from leading institutions across the country. Reviewers of the eleventh edition described the text as follows: "*Clean, sleek, easy-to-read text with engaging photos, figures, text features, and animations/videos that will "hook" students in and get them excited about the material,*" and "*I think the text is very well put together. It does a nice job presenting the material and supporting it with many pictures, illustrations, and graphs. The text is well-organized and laid out in an easy-to-use fashion. I would recommend this text to a colleague for teaching Introductory Oceanography.*"

In 2012, the tenth edition of *Essentials of Oceanography* received a Textbook Excellence Award, called a "Texty," from the Text and Academic Authors Association (TAA). The Texty award recognizes written works for their excellence in the areas of content, presentation, appeal, and teachability. The publisher, Pearson Education, nominated the book for the award, and the textbook was critically reviewed by a panel of expert judges.

The 16-chapter format of this textbook is designed for easy coverage of the material in a 15- or 16-week semester. For courses taught on a 10-week quarter system, instructors may need to select those chapters that cover the topics and concepts of primary relevance to their course. Chapters are self-contained and can thus be covered in any order. Following the introductory chapter (Chapter 1, which covers the general geography of the oceans; a historical perspective of oceanography; the reasoning behind the scientific method; and a discussion of the origin of Earth, the atmosphere, the oceans, and life itself), the

DIVING DEEPER PREFACE.2

OCEAN LITERACY: WHAT SHOULD PEOPLE KNOW ABOUT THE OCEAN?

The ocean is the defining feature of our planet. Accordingly, there is great interest in developing *ocean literacy*, which means understanding the ocean's influence on humans as well as humans' influence on the ocean. For example, scientists and educators agree that an ocean-literate person:

- Understands the essential principles and fundamental concepts about the functioning of the ocean.
- Can communicate about the ocean in a meaningful way.
- Is able to make informed and responsible decisions regarding the ocean and its resources.

To achieve this goal, ocean educators and experts have developed the **Seven Principles of Ocean Literacy**. The following ideas are what everyone—especially those who successfully pass a college course in oceanography or marine science—should understand about the ocean:

1. Earth has one big ocean with many features.
2. The ocean and life in the ocean shape the features of Earth.
3. The ocean is a major influence on weather and climate.
4. The ocean makes Earth habitable.
5. The ocean supports a great diversity of life and ecosystems.
6. The ocean and humans are inextricably interconnected.
7. The ocean is largely unexplored.

This book is intended to help all people achieve ocean literacy. For more information about the Seven Principles of Ocean Literacy, see **http://oceanliteracy.wp2.coexploration.org/**

https://goo.gl/eMPIXD

four major academic disciplines of oceanography are represented in the following chapters:

- Geological oceanography (Chapters 2–4 and Chapter 10)
- Chemical oceanography (Chapter 5 and Chapter 11)
- Physical oceanography (Chapters 6–9)
- Biological oceanography (Chapters 12–15)
- Interdisciplinary oceanography: Climate change (Chapter 16)

We strongly believe that oceanography is at its best when it links together several scientific disciplines and shows how they are interrelated in the oceans. Therefore, this interdisciplinary approach is a key element of every chapter, particularly Chapter 16, "The Oceans and Climate Change."

Reorganization of What's New in This Edition Section

Changes in this edition are designed to increase the readability, relevance, and appeal of this book. Major changes include the following:

1. *NEW! Hybridization of the Textbook*

- Inclusion of more than 70 Web Animations from Pearson's Geoscience Animations Library, which include state-of-the-art computer animations that have been created by Al Trujillo and a panel of geoscience educators
- Addition of seven new Geoscience Animations that have been specifically designed for this edition to help students visualize some of the most challenging oceanographic concepts:
    - Formation of Earth's Oceans (Chapter 1)
    - How Salt Dissolves in Water (Chapter 5)
    - Three Types of Breakers (Chapter 8)
    - Effects of Elliptical Orbits (Chapter 9)
    - Osmosis (Chapter 12)
    - Feeding in Baleen Whales (Chapter 14)
    - Latitude and Longitude on Earth (Appendix III)
- Inclusion of links to more than 50 hand-picked Web videos that show important oceanographic processes in action
- Addition of QR codes embedded in the text that allow students to use their mobile devices to link directly to MasteringOceanography Animations, SmartFigures, SmartTables, and Web Videos
- Select Diving Deeper features have been migrated online to MasteringOceanography as Bonus Web Content in an effort to reduce the length of the text
- The addition in each chapter of a series of new SmartFigures and SmartTables which provide a video explanation of difficult-to-understand oceanographic concepts and numerical data by an oceanography teaching expert

2. *NEW! Content/Art Revisions*

- A thoroughly updated Chapter 16 "The Oceans and Climate Change," including new information about ocean acidification, the most recent findings of the IPCC, five new "Students Sometimes Ask … " features that address student misconceptions and concerns regarding climate change, a new Diving Deeper Box about the father-son team of Charles David and Ralph Keeling who created and maintain the Keeling curve of atmospheric carbon dioxide, an expanded discussion on the role of orbital parameters in creating natural cycles of climate change, and a new section on the effect of aerosols on global warming
- A redesigned and updated Chapter 13, "Biological Productivity and Energy Transfer," including contributions by Dr. Angel Rodriguez of Broward College in Florida highlighting issues of fisheries sustainability
- A new name and focus for Chapter 11 "Marine Pollution," which reframes the chapter discussion along environmental themes
- Reorganization of Chapter 10, adding content about the properties of the coastal ocean from Chapter 11 and renaming the chapter "Beaches, Shoreline Processes, and the Coastal Ocean"
- Greater emphasis on the ocean's role in Earth systems
- Addition of a revised word cloud at the beginning of each chapter that uses different font sizes to show the most important vocabulary terms within the chapter and directs students to the glossary at the end of the book to discover the meaning of any terms they don't already know
- A detailed list of specific chapter-by-chapter changes is available at **www2.palomar.edu/users/atrujillo**.

3. *NEW! Pedagogical Enhancements*

- A stronger learning path that directly links the learning objectives listed at the beginning of each chapter to the end-of-section "Concept Checks," which allow and encourage students to pause and test their knowledge as they proceed through the chapter
- Addition of a new "Recap" feature that summarizes key points throughout the text that making studying easier
- A new active learning pedagogy that divides chapter material into easily digestible chunks, which makes studying easier and assists student learning (cognitive science research shows that the ability to "chunk" information is essential to enhancing learning and memory)
- The addition of one or more "Give It Some Thought" assessment questions to each "Diving Deeper" boxed feature
- The addition of a new "Climate Connection" icon that alerts students to topics that are related to the overarching theme of the ocean's importance to global climate change
- A new multidisciplinary icon that flags content related to two or more of the sub-disciplines in oceanography: geological oceanography, chemical oceanography, physical oceanography, and biological oceanography
- In all Essential Concept Review (end-of-chapter) materials, the revision of existing "Critical Thinking Questions" and the addition of new "Active Learning Exercise" questions that can be used for in-class group activities
- Updating of information throughout the text to include some of the most recent and critical developments in oceanography

- Addition of an array of new "Students Sometimes Ask … " questions throughout the book
- Diving Deeper features appearing in the book are organized around the following four themes:
    - **HISTORICAL FEATURES**, which focus on historical developments in oceanography that tie into chapter topics
    - **RESEARCH METHODS IN OCEANOGRAPHY**, which highlight how oceanographic knowledge is obtained
    - **OCEANS AND PEOPLE**, which illustrate the interaction of humans and the ocean environment
    - **FOCUS ON THE ENVIRONMENT**, which emphasizes environmental issues that are an increasingly important component of ocean studies
- All text in the chapters has been thoroughly reviewed and edited by students and oceanography instructors in a continued effort to refine the style and clarity of the writing
- In addition, this edition continues to offer some of the previous edition's most popular features, including the following:
- Scientifically accurate and thorough coverage of oceanography topics
- "Students Sometimes Ask … " questions, which present actual student questions along with the authors' answers
- Use of the international metric system (Système International [SI] units), with comparable English system units in parentheses
- Explanation of word etymons (*etumon* = sense of a word) as new terms are introduced, in an effort to demystify scientific terms by showing what the terms actually mean
- Use of **bold print** on key terms, which are defined when they are introduced and are described in the glossary
- A reorganized "Essential Concepts Review" summary at the end of each chapter
- **MasteringOceanography**, which features chapter-specific Essential Concepts, eText, Bonus Web Content, Geoscience Animations, Web Videos, Web Destinations, and two Test Yourself quiz modules

4. NEW! Squidtoons

- A new, comic-styled *Squidtoons* cartoon in each chapter; created by a team of graduate students at Scripps Institution of Oceanography in California, each *Squidtoons* highlights an important marine organism relevant to the chapter's content; the cartoon links to a poster-like presentation that uses engaging graphics and humor to discuss interesting aspects of each creature

For the Student

- **MASTERINGOCEANOGRAPHY** delivers engaging, dynamic learning opportunities—focused on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand difficult concepts. MasteringOceanography and MyLab & Mastering are customized learning resources that include:
    - **Student Study Area**, which is designed to be a one-stop resource for students to acquire study help and serve as a launching pad for further exploration. Content for the site was written by author Al Trujillo and is tied, chapter-by-chapter, to the text. The Student Study Area is organized around a four-step learning pathway:
        1. *Review*, which contains **Essential Concepts** as learning objectives
        2. *Read*, which contains the **eText** and **Bonus Web Content**
        3. *Visualize*, which contains **Geoscience Animations**, **Web Videos**, and **Web Destinations**. **Geoscience Animations** were created by a team of geoscience educators and include an array of more than 70 visualizations that help students understand complex oceanographic concepts and processes by allowing the user to control the action. For example, students can fully examine how an animation develops by replaying it, controlling its pace, and stopping and starting the animation anywhere in its sequence. In order to facilitate effective study, Al Trujillo has written an accompanying narration and assessment quiz questions including hints and specific wrong-answer feedback for each animation. **Web Videos** include more than 50 hand-selected short video clips of oceanographic processes in action. **Web Destinations** include links to some of the best oceanography sites on the Web.
        4. *Test Yourself*, which contains three **Test Yourself** modules, including multiple-choice and true/false, multiple-answer, and image-labeling exercises. Answers, once submitted, are automatically graded for instant feedback.
    - **RSS Feeds**, which allow students to subscribe and stay up-to-date on oceanographic discoveries
    - **Study Tools** such as flashcards and a searchable online glossary to help make the most of students' study time
- **THE PEARSON eTEXT** gives students complete access to a digital version of the text whenever and wherever you have access to the Internet. eText pages look exactly like the printed text, offering powerful new portability and functionality.

For the Instructor

- **MASTERINGOCEANOGRAPHY: CONTINUOUS LEARNING BEFORE, DURING, AND AFTER CLASS** MasteringOceanography is an online homework, tutorials, and assessments program designed to improve results by helping students quickly master oceanography concepts. Students will benefit from self-paced tutorials that feature immediate wrong-answer feedback and hints that emulate the office-hour experience to help keep them on track. With a wide range of interactive, engaging, and assignable activities, students will be encouraged to actively learn and retain tough course concepts:
    - **SmartFigures** and **SmartTables**, which are short instructional videos that examine and explain the most important concepts illustrated by the figure or data table. With nearly 100 of these SmartFigures/SmartTables inside the text, students can stop, pause, and replay the videos multiple times to help them learn about important concepts and real oceanographic data.

- **Mobile Interactive Geoscience Animations**, which include more than 70 Geoscience Animations of difficult-to-understand concepts that are embedded throughout the text using mobile-friendly QR codes
- **GeoTutors**, which coach students through difficult concepts
- **Encounter Oceans Activities**, which provide interactive explorations of oceanography concepts using Google Earth™. Students work through the activities in Google Earth and then test their knowledge by answering the assessment questions, which include hints and specific wrong-answer feedback.
- **Geoscience Animations**, which illuminate the most difficult-to-understand topics in oceanography and were created by an expert team of geoscience educators. The animation activities include audio narration, a text transcript, and assignable multiple-choice questions with specific wrong-answer feedback.
- **Dynamic Study Modules**, which help students study effectively on their own by continuously assessing their activity and performance in real time. Here's how it works: Students complete a set of questions with a unique answer format that also asks them to indicate their confidence level. Questions repeat until the student can answer them all correctly and confidently. Once completed, Dynamic Study Modules explain the concept using materials from the text. These are available as graded assignments prior to class, and accessible on smartphones, tablets, and computers.
- **Learning Catalytics™**, which are an interactive student response tool that uses students' smartphones, tablets, or laptops to engage them in more sophisticated tasks and thinking. Now included with MyLab & Mastering and eText, Learning Catalytics™ enables you to generate classroom discussion, guide your lecture, and promote peer-to-peer learning with real-time analytics.

- **STUDENT PERFORMANCE ANALYTICS** MasteringOceanography allows an instructor to gain easy access to information about student performance and their ability to meet student learning outcomes. Instructors can quickly add their own learning outcomes, or use publisher-provided ones, to track student performance.
- **INSTRUCTOR MANUAL (DOWNLOAD ONLY)** This resource contains learning objectives, chapter outlines, answers to embedded end-of-section questions, and suggested teaching tips to spice up your lectures.
- **TESTGEN® COMPUTERIZED TEST BANK (DOWNLOAD ONLY)** This resource is a computerized test generator that lets instructors view and edit *Test Bank* questions, transfer questions to tests, and print the test in a variety of customized formats. The *Test Bank* includes over 1200 multiple-choice, matching, and short-answer/essay questions. All questions are tied to the chapter's learning outcomes, include a rating based on Bloom's taxonomy of learning domains (Bloom's 1–6) and contain the section number in which each question's answer can be found.
- **INSTRUCTOR POWERPOINT® PRESENTATIONS (DOWNLOAD ONLY)** Instructor Resource Materials include the following three PowerPoint® files for each chapter so that you can cut down on your preparation time, no matter what your lecture needs:

1. **EXCLUSIVELY ART:** This file provides all the photos, art, and tables from the text, in order, loaded into PowerPoint® slides.
2. **LECTURE OUTLINE:** This file averages 50 PowerPoint® slides per chapter and includes customizable lecture outlines with supporting art.
3. **CLASSROOM RESPONSE SYSTEM (CRS) QUESTIONS:** Authored for use in conjunction with classroom response systems, this PowerPoint® file allows you to electronically poll your class for responses to questions, pop quizzes, attendance, and more.

For more information about these instructor resources, contact your Pearson textbook representative.

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Tony Barros, *Miami-Dade Community College*
Steven Benham, *Pacific Lutheran University*
Lori Bettison-Varga, *College of Wooster*
Thomas Bianchi, *Tulane University*
David Black, *University of Akron*
Mark Boryta, *Consumnes River College*
Laurie Brown, *University of Massachusetts*
Kathleen Browne, *Rider University*
Aurora Burd, *Green River Community College*
Nancy Bushell, *Kauai Community College*
Chatham Callan, *Hawaii Pacific University*
Mark Chiappone, *Miami-Dade College–Homestead Campus*
Chris Cirmo, *State University of New York, Cortland*
G. Kent Colbath, *Cerritos Community College*
Thomas Cramer, *Brookdale Community College*
Richard Crooker, *Kutztown University*
Cynthia Cudaback, *North Carolina State University*
Warren Currie, *Ohio University*
Hans Dam, *University of Connecticut*
Dan Deocampo, *California State University, Sacramento*
Richard Dixon, *Texas State University*
Holly Dodson, *Sierra College*
Joachim Dorsch, *St. Louis Community College*
Wallace Drexler, *Shippensburg University*
Walter Dudley, *University of Hawaii*
Iver Duedall, *Florida Institute of Technology*
Jessica Dutton, *Adelphi University*
Charles Ebert, *State University of New York, Buffalo*
Ted Eckmann, *University of Portland*
Charles Epifanio, *University of Delaware*
Jiasong Fang, *Hawaii Pacific University*
Diego Figueroa, *Florida State University*
Kenneth Finger, *Irvine Valley College*
Catrina Frey, *Broward College*
Jessica Garza, *MiraCosta College*
Benjamin Giese, *Texas A&M University*
Cari Gomes, *MiraCosta College*
Dave Gosse, *University of Virginia*
Carla Grandy, *City College of San Francisco*
John Griffin, *University of Nebraska, Lincoln*
Elizabeth Griffith, *University of Texas at Arlington*
Gary Griggs, *University of California, Santa Cruz*
Joseph Holliday, *El Camino Community College*
Mary Anne Holmes, *University of Nebraska, Lincoln*
Timothy Horner, *California State University, Sacramento*
Alan Jacobs, *Youngstown State University*
Ron Johnson, *Old Dominion University*
Uwe Richard Kackstaetter, *Metropolitan State University of Denver*
Charlotte Kelchner, *Oakton Community College*
Matthew Kleban, *New York University*
Eryn Klosko, *State University of New York, Westchester Community College*
M. John Kocurko, *Midwestern State University*
Lawrence Krissek, *Ohio State University*
Jason Krumholz, *NOAA/University of Rhode Island*
Paul LaRock, *Louisiana State University*
Gary Lash, *State University of New York, Fredonia*
Richard Laws, *University of North Carolina*
Richard Little, *Greenfield Community College*
Stephen Macko, *University of Virginia, Charlottesville*
Chris Marone, *Pennsylvania State University*
Jonathan McKenzie, *Edison State College–Lee Campus*
Matthew McMackin, *San Jose State University*
James McWhorter, *Miami-Dade Community College*
Gregory Mead, *University of Florida*
Keith Meldahl, *MiraCosta College*
Nancy Mesner, *Utah State University*
Chris Metzler, *MiraCosta College*
Johnnie Moore, *University of Montana*
P. Graham Mortyn, *California State University, Fresno*
Andrew Muller, *Millersville University*
Andrew Muller, *Utah State University*
Daniel Murphy, *Eastfield College*
Jay Muza, *Florida Atlantic University*
Jennifer Nelson, *Indiana University–Purdue University at Indianapolis*
Jim Noyes, *El Camino Community College*
Sarah O'Malley, *Maine Maritime Academy*
B. L. Oostdam, *Millersville University*
William Orr, *University of Oregon*
Joseph Osborn, *Century College*
Donald Palmer, *Kent State University*
Nancy Penncavage, *Suffolk County Community College*
Curt Peterson, *Portland State University*
Adam Petrusek, *Charles University, Prague, Czech Republic*
Edward Ponto, *Onondaga Community College*
Donald Reed, *San Jose State University*
Randal Reed, *Shasta College*
M. Hassan Rezaie Boroon, *California State University, Los Angeles*
Cathryn Rhodes, *University of California, Davis*
James Rine, *University of South Carolina*
Felix Rizk, *Manatee Community College*
Angel Rodriguez, *Broward College*
Diane Shepherd, *Shepherd Veterinary Clinic, Hawaii*
Beth Simmons, *Metropolitan State College of Denver*
Jill Singer, *State University of New York, Buffalo*
Arthur Snoke, *Virginia Polytechnic Institute*

Pamela Stephens, *Midwestern State University*
Dean Stockwell, *University of Alaska, Fairbanks*
Scott Stone, *Fairfax High School, Virginia*
Lenore Tedesco, *Indiana University–Purdue University at Indianapolis*
Shelly Thompson, *West High School*
Craig Tobias, *University of North Carolina, Wilmington*
M. Craig VanBoskirk, *Florida Community College at Jacksonville*
Paul Vincent, *Oregon State University*
George Voulgaris, *University of South Carolina*
Bess Ward, *Princeton University*
Jackie Watkins, *Midwestern State University*
Jamieson Webb, *Gulf Coast State College*
Arthur Wegweiser, *Edinboro University of Pennsylvania*
Diana Wenzel, *Seminole State College of Florida*
John White, *Louisiana State University*
Katryn Wiese, *City College of San Francisco*
Raymond Wiggers, *College of Lake County*
John Wormuth, *Texas A&M University*
Memorie Yasuda, *Scripps Institution of Oceanography*

Although this book has benefited from careful review by many individuals, the accuracy of the information rests with the authors. If you find errors or have comments about the text, please contact me.

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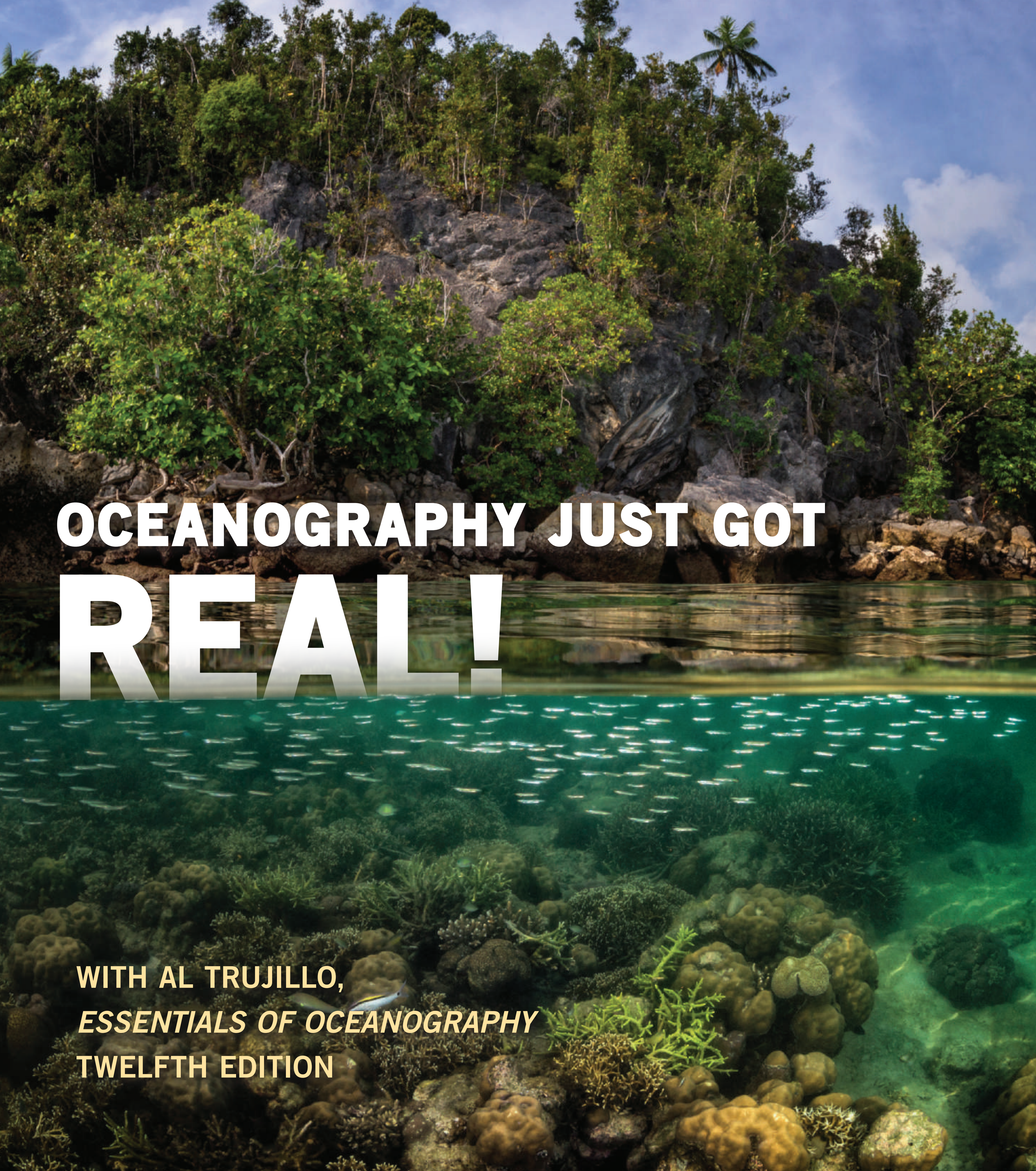
"If there is magic on this planet, it is contained in water."

—Loren Eiseley, American educator and natural science writer (1907–1977)

SmartFigures

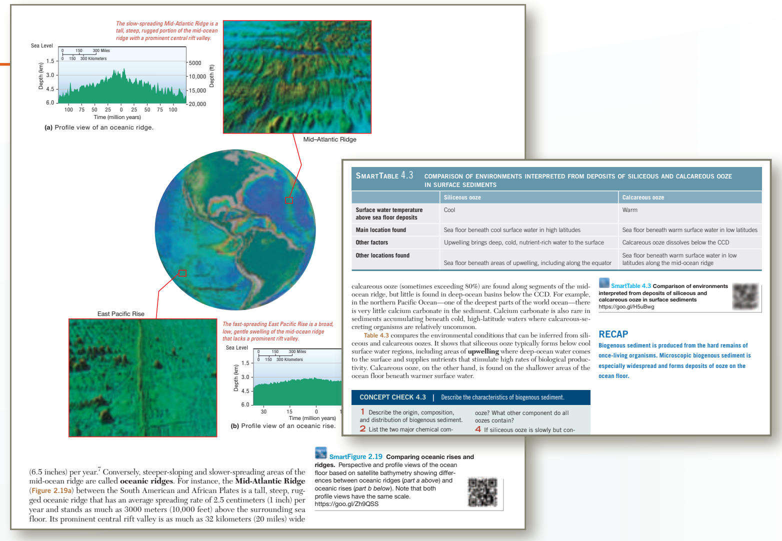
SmartTables

New Geoscience Animations Specifically Designed for this Edition


OCEANOGRAPHY JUST GOT
REAL!
WITH AL TRUJILLO,
ESSENTIALS OF OCEANOGRAPHY
TWELFTH EDITION

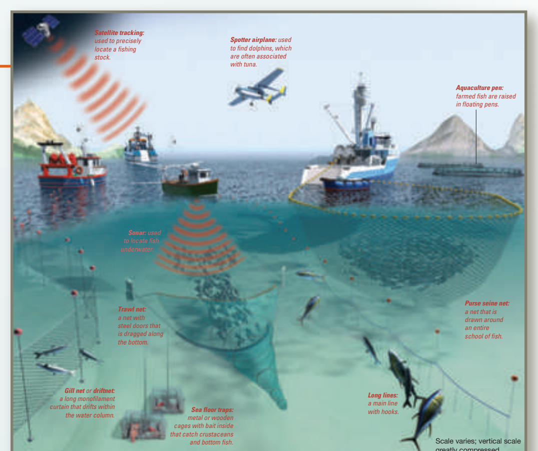
DYNAMIC VISUALS AND **INTEGRATED MEDIA** BRING OCEANOGRAPHY TO LIFE

Highly visual and interactive tools make oceanography approachable, enabling students to see oceanographic processes in action.

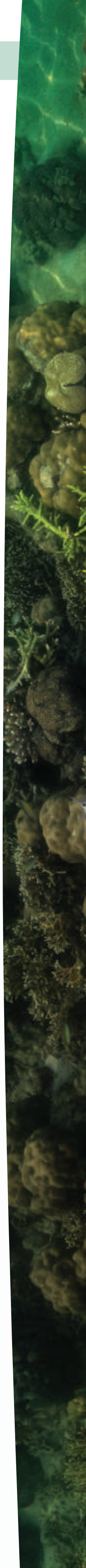


NEW! **SmartFigures** and **SmartTables** are 3- to 4-minute mini video lessons containing explanations of difficult-to-understand oceanographic concepts and numerical data directed by an oceanography teaching expert and NASA Science Communicator. By scanning the accompanying QR code, or typing in the short URL, students now have a multitude of ways to learn from art and data tables, all designed to teach.

NEW! **Squidtoons**, a comic-styled call-out created by a team of graduate students at Scripps Institution of Oceanography in California, are featured in each chapter. These infographics highlight an important marine organism related to each chapter's content using graphical representation to display recent discoveries by researchers in an interesting and captivating manner. By scanning the associated QR code or typing in the short URL in the text, students will be taken to the digital space to view the full cartoon.



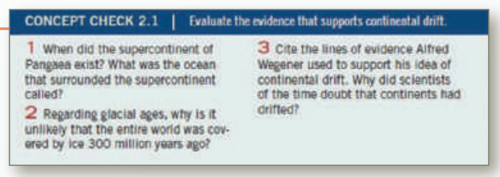
NEW! **Enhanced illustration program**, with new art incorporating the research-proven technique of strategically placing annotations and labels within the key figures, allows students to focus on the most relevant visual information and helps them interpret complex art. Overall, nearly 90% of the entire book's artwork has been updated or is new, including new figures that provide visual summaries of essential processes and concepts.



ESSENTIAL ELEMENTS FORM A PATH TO SUCCESSFUL LEARNING

Each chapter is organized into easily digestible chunks, making studying easier and assisting student learning. Chapter material begins with learning goals and ends with assessment questions tied to those learning goals. The end-of-chapter material is also organized by the chapter's sections, helping students remain focused on the essential concepts throughout the chapter.

Each chapter opens with a list of learning objectives called **Essential Learning Concepts**, which provide a roadmap to the chapter. Each chapter section focuses on one main Essential Concept.



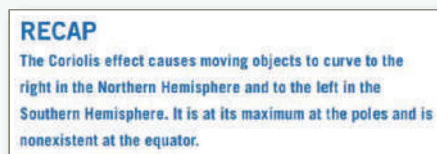
CONCEPT CHECK 2.1 | Evaluate the evidence that supports continental drift.

1 When did the supercontinent of Pangaea exist? What was the ocean that surrounded the supercontinent called?

2 Regarding glacial ages, why is it unlikely that the entire world was covered by ice 300 million years ago?

3 Cite the lines of evidence Alfred Wegener used to support his idea of continental drift. Why did scientists of the time doubt that continents had drifted?

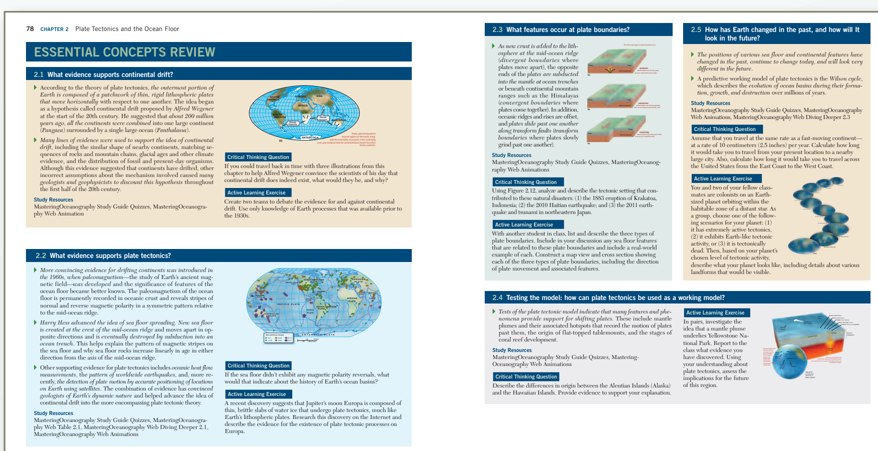
Concept Check questions at the end of each section are designed to let students check their understanding of the Essential Learning Concept. By stopping and answering questions, students ensure that they have a thorough understanding of key points before moving on to the next section.



RECAP

The Coriolis effect causes moving objects to curve to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. It is at its maximum at the poles and is nonexistent at the equator.

NEW! A **Recap** feature now appears throughout each chapter, summarizing essential concepts. This is a great tool for directing students' study and review.



Each chapter ends with the **Essential Concepts Review**, which simplifies the study process. Also organized by section, this review highlights a key figure from the chapter and provides a summary of the chapter's key concepts. It also includes study resources, Critical Thinking Questions, and NEW! Active Learning Exercises.

TURNING INTEREST **INTO ENGAGEMENT**

Everyday topics in a real world context help students relate oceanography to their lives while engaging them in how oceanography is studied.

NEW! **Climate Connection:** This icon shows how various sections of the text relate to the overarching theme of the importance of Earth's oceans to global climate change.

Climate Connection

Interdisciplinary Relationship

NEW! **Interdisciplinary Relationship:** This icon shows how various sections of the text relate to two or more sub-disciplines in oceanography: geological oceanography, biological oceanography, physical oceanography, and chemical oceanography.

The new edition includes a variety of **Diving Deeper** features, including Historical Features, Research Methods in Oceanography, Oceans and People, and Focus on the Environment. These features foster multi-dimensional understanding with captivating examples and stories. Each Diving Deeper feature now includes one or more "Give It Some Thought" assessment questions.

The popular **Students Sometimes Ask** features answer often entertaining questions posed by real students.

STUDENTS SOMETIMES ASK . . .

What happened to the recent Malaysian Airlines flight that vanished after takeoff?

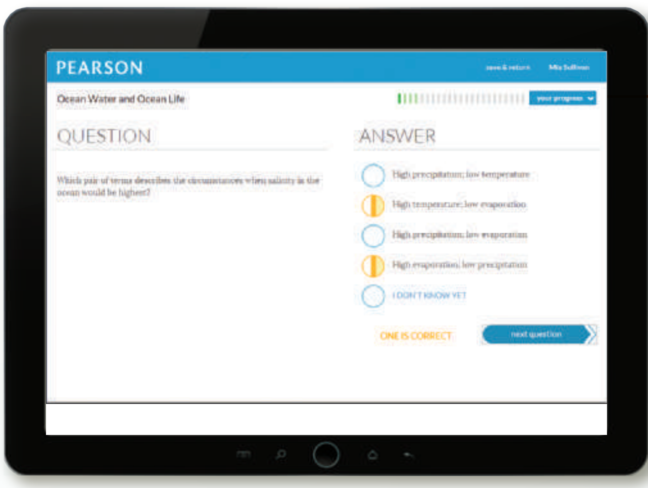
It's still a mystery. Malaysian Airlines flight MH370 went missing on March 8, 2014, while in route from Kuala Lumpur, Malaysia to Beijing, China. Satellite communications suggest that the flight veered south and ended up running out of fuel and crash-landing in the Indian Ocean west of Australia. Unfortunately, the suspected area of the crash is large, remote, and deep, and the region's rugged sea floor is very poorly explored, all of which has hampered recovery efforts. In the days followi

CONTINUOUS LEARNING **BEFORE**, **DURING**, AND **AFTER** CLASS WITH MasteringOceanography™

MasteringOceanography delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student's progress—that are proven to help students absorb oceanography course materials and understand challenging physical processes and oceanography concepts.

BEFORE CLASS

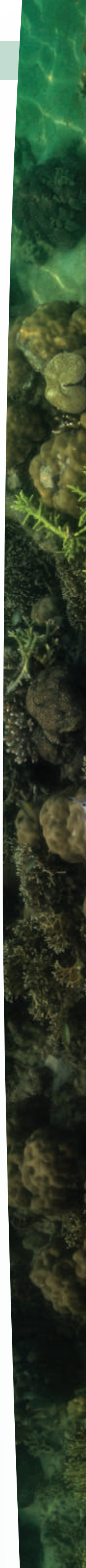
DYNAMIC STUDY MODULES AND ETEXT 2.0 PROVIDE STUDENTS WITH A PREVIEW OF WHAT'S TO COME.



NEW! **Dynamic Study Modules** enable students to study effectively on their own in an adaptive format. Students receive an initial set of questions with a unique answer format asking them to indicate their confidence. Once completed, Dynamic Study Modules include explanations using material taken directly from the text.

NEW! **Interactive eText 2.0** comes complete with embedded media and is both mobile friendly and ADA accessible.

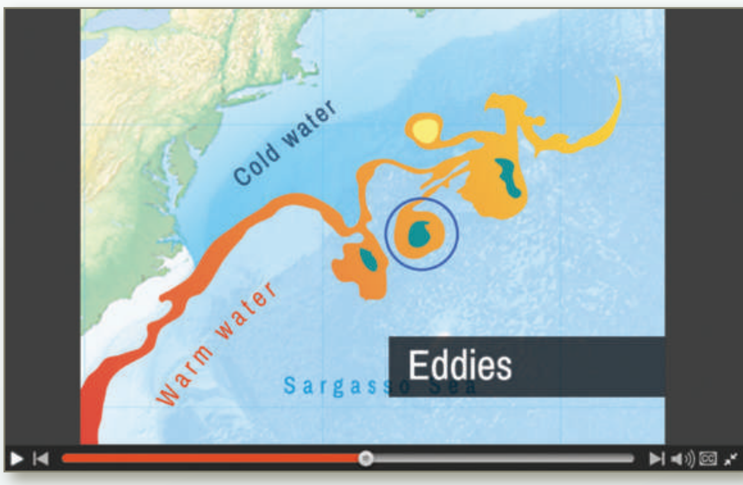
- Now available on smartphones and tablets.
- Seamlessly integrated videos and other rich media.
- Fully accessible (screen-reader ready).
- Configurable reading settings, including resizable type and night reading mode.
- Facilitates instructor and student note-taking, highlighting, bookmarking, and search.



DURING CLASS ENGAGE STUDENTS WITH LearningCatalytics

NEW! **LearningCatalytics,** a "bring your own device" student engagement, assessment, and classroom intelligence system (PRS), allows students to use their smartphone, tablet, or laptop to respond to questions in class without the need for a "clicker."

AFTER CLASS HELPING STUDENTS VISUALIZE OCEANOGRAPHY CONCEPTS THAT CAN BE EASILY ASSIGNABLE.

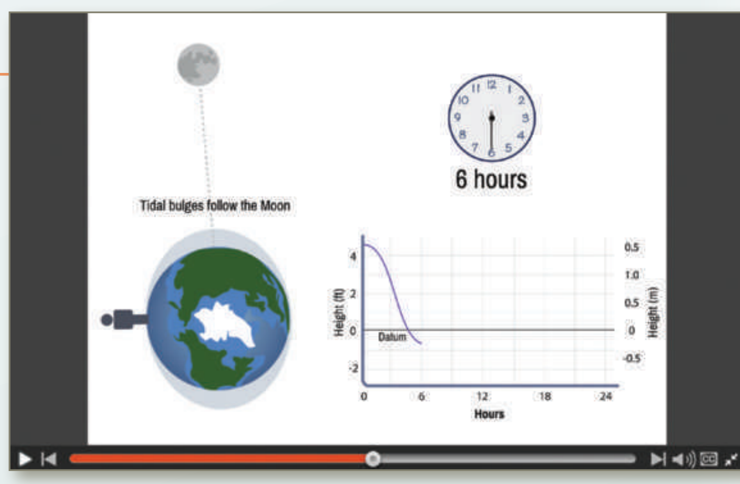


NEW! The following 7 **geoscience animations** have been specifically designed for this edition:

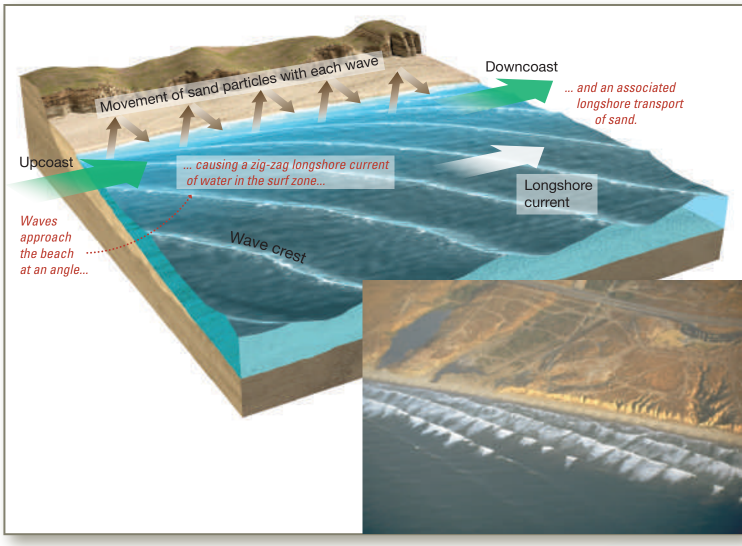
- Formation of Earth's Oceans
- How Salt Dissolves in Water
- Three Types of Breakers
- Effects of Elliptical Orbits
- Osmosis
- Feeding in Baleen Whales
- Latitude and Longitude on Earth

More than 70 geoscience animations are associated with the text, and all include audio narration, a text transcript, and assignable multiple-choice questions with specific wrong-answer feedback in Mastering.

Select key animations have been refreshed and made compatible for Mastering and mobile devices.



MasteringOceanography™ HELPS STUDENTS LEARN...



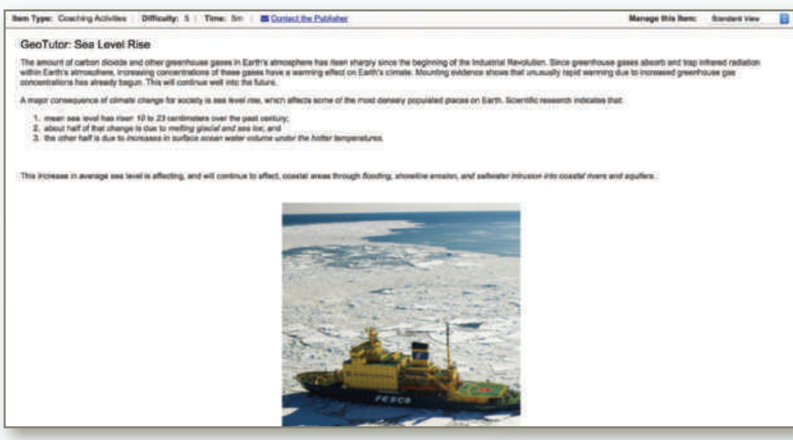
NEW! **SmartFigures** bring key chapter illustrations to life! These videos are accessible on mobile devices via scannable Quick Response (QR) codes printed in the text and through the Study Area in MasteringOceanography. Paired with other assessments in Mastering, these videos become assignable and assessable learning objects that can either prepare students for lecture or assess what they have learned.

NEW! **SmartTables** are engaging tutorial videos that explain the relevance of the real data found in tables within the textbook. Paired with other assessments in Mastering, these become assignable and assessable learning objects that allow students to interpret real data sets.

TABLE 2.1 CHARACTERISTICS, TECTONIC PROCESSES, FEATURES, AND EXAMPLES OF PLATE BOUNDARIES

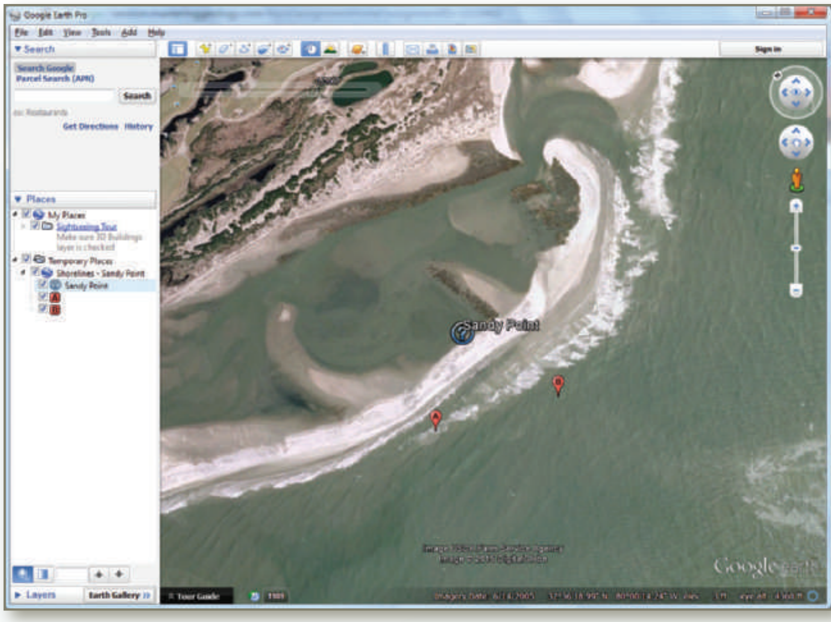
Plate boundary	Plate movement	Crust types	Sea floor created or destroyed?	Tectonic process	Sea floor feature(s)	Geographic examples
Divergent plate boundaries	Apart	Oceanic–oceanic	New sea floor is created	Sea floor spreading	Mid-ocean ridge; volcanoes; young lava flows	Mid-Atlantic Ridge, East Pacific Rise
		Continental–continental	As a continent splits apart, new sea floor is created	Continental rifting	Rift valley; volcanoes; young lava flows	East Africa Rift Valleys, Red Sea, Gulf of California
Convergent plate boundaries	Together	Oceanic–continental	Old sea floor is destroyed	Subduction	Trench; volcanic arc on land	Peru–Chile Trench, Andes Mountains
		Oceanic–oceanic	Old sea floor is destroyed	Subduction	Trench; volcanic arc as islands	Mariana Trench, Aleutian Islands
		Continental–continental	N/A	Collision	Tall mountains	Himalaya Mountains, Alps
Transform plate boundaries	Past each other	Oceanic	N/A	Transform faulting	Fault	Mendocino Fault, Eltanin Fault (between mid-ocean ridges)
		Continental	N/A	Transform faulting	Fault	San Andreas Fault, Alpine Fault (New Zealand)

An excellent study guide!



GeoTutor Coaching Activities are based on data collected from educators across the country and address the topics most frequently ranked as tough for students to understand. These activities guide students towards mastery of these topics, using highly visual, kinesthetic, and interactive activities.

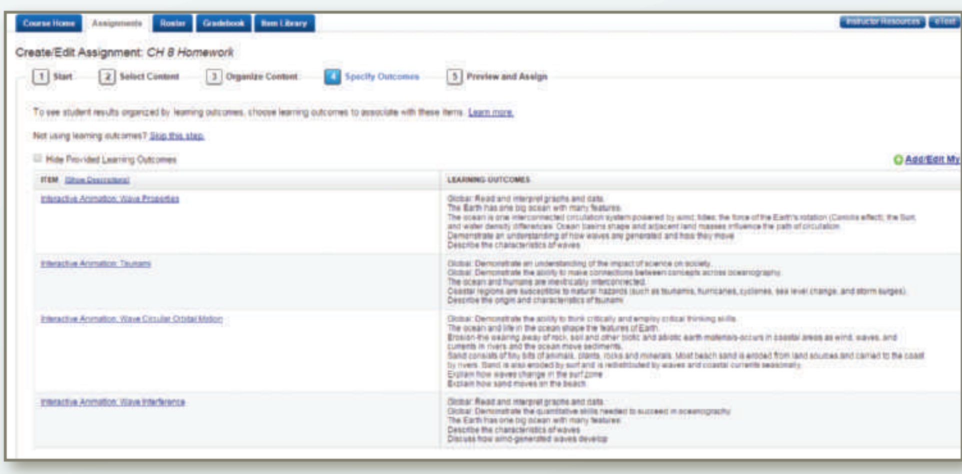
…AND MASTER THE SCIENCE OF OCEANOGRAPHY



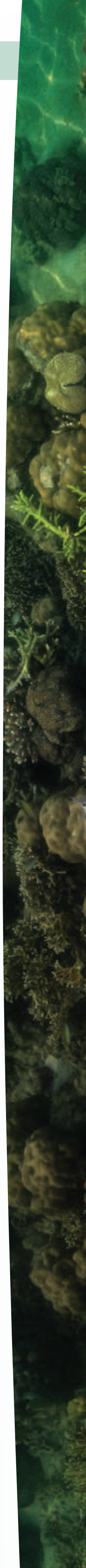
Encounter Activities provide rich, interactive explorations of Oceanography concepts using the dynamic features of Google Earth™ to visualize and explore Earth's Oceans. Dynamic assessment includes multiple-choice and short-answer questions related to core geology concepts. All explorations include corresponding media files, and questions include hints and specific wrong-answer feedback to help coach students towards mastery of the concepts.

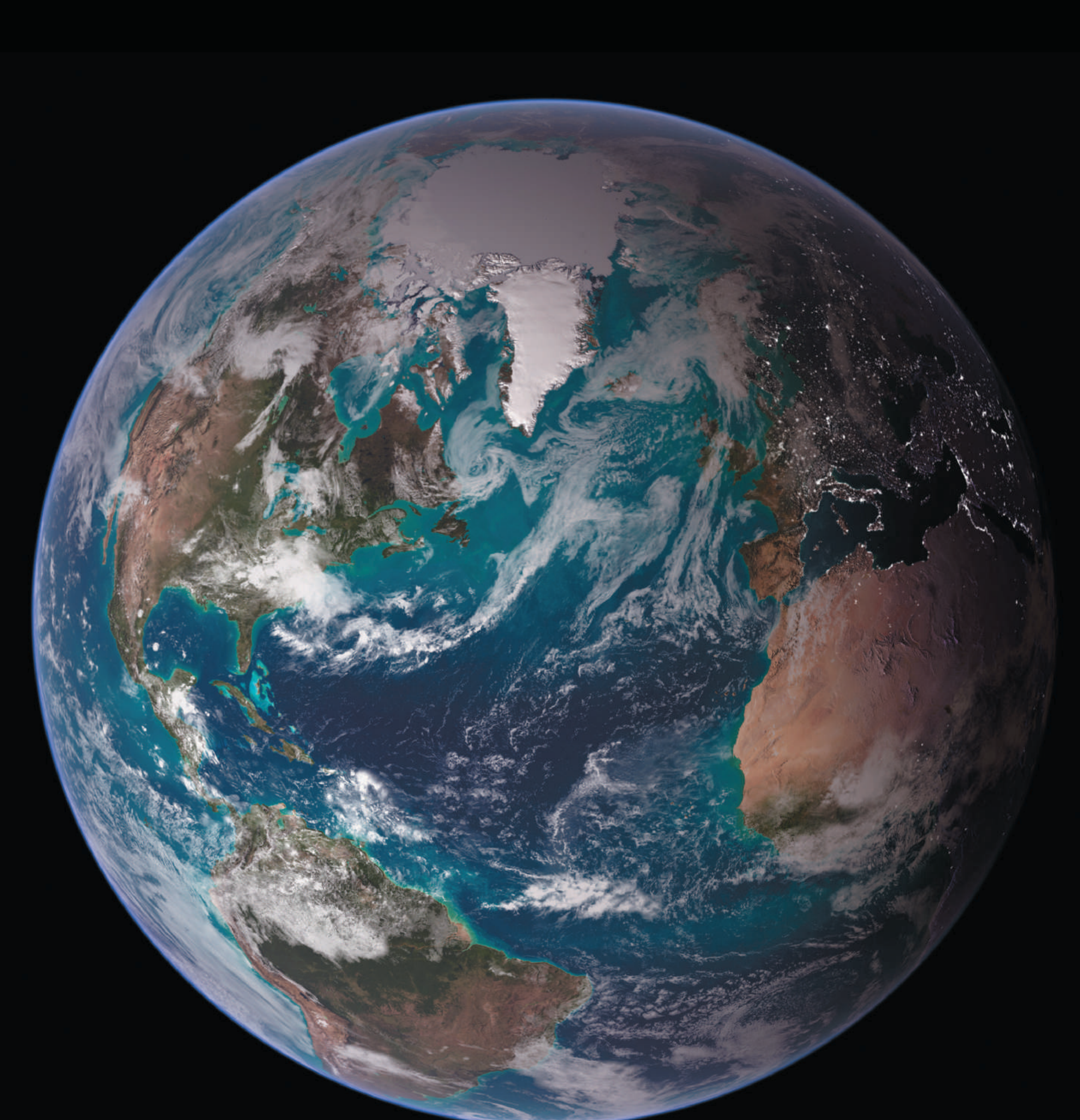
Student Study Area Resources in MasteringOceanography include:

- Practice quizzes
- Interactive Animations
- Oceanography Videos–*A series of studio demo and field segment videos created by author Al Trujillo; most of the studio demos were created as 2-part interactive videos and the field segments show real oceanographic processes in action.*
- Web Video links
- RSS Feeds from ScienceDaily and Scientific American



Learning Outcomes: All of the MasteringOceanography assignable content is tagged to book content. Instructors also have the ability to add their own learning outcomes to assessments and keep track of student performance relative to those learning outcomes. Mastering offers a data-supported measure to quantify students' learning gains and to share those results quickly and easily with colleagues and administrators.

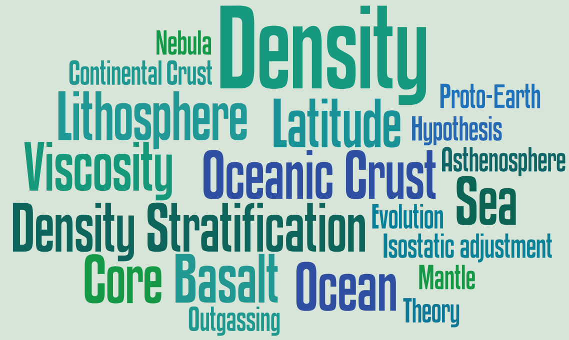




The blue marble, next generation. This composite image of satellite data shows Earth's interrelated atmosphere, oceans, and land—including human presence. Its various layers include the land surface, sea ice, ocean, cloud cover, city lights, and the hazy edge of Earth's atmosphere.

1

Introduction To Planet "Earth"



Before you begin reading this chapter, use the glossary at the end of this book to discover the meanings of any of the words in the word cloud above you don't already know.[1]

ESSENTIAL LEARNING CONCEPTS

At the end of this chapter, you should be able to:

- **1.1** Compare the characteristics of Earth's oceans.
- **1.2** Discuss how early exploration of the oceans was achieved.
- **1.3** Explain why oceanography is considered an interdisciplinary science.
- **1.4** Describe the nature of scientific inquiry.
- **1.5** Explain how Earth and the solar system formed.
- **1.6** Explain how Earth's atmosphere and oceans formed.
- **1.7** Discuss why life is thought to have originated in the oceans.
- **1.8** Demonstrate an understanding of how old Earth is.

"When you're circling the Earth every 90 minutes, what becomes clearest is that it's mostly water; the continents look like they're floating objects."

—Loren Shriver, NASA astronaut (2008)

The **oceans**[2] are the largest and most prominent feature on Earth. In fact, they are the single most defining feature of our planet. As viewed from space, our planet is a beautiful blue, white, and brown globe (see this chapter's opening photo). The abundance of liquid water on Earth's surface is a distinguishing characteristic of our home planet.

Yet it seems perplexing that our planet is called "Earth" when 70.8% of its surface is covered by oceans. Many early human cultures that lived near the Mediterranean (*medi* = middle, *terra* = land) Sea envisioned the world as being composed of large landmasses surrounded by marginal bodies of water. From their viewpoint, landmasses—not oceans—dominated the surface of Earth. How surprised they must have been when they ventured into the larger oceans of the world. Our planet is misnamed "Earth" because we live on the land portion of the planet. If we were marine animals, our planet would probably be called "Ocean," "Water," "Hydro," "Aqua," or even "Oceanus" to indicate the prominence of Earth's oceans. Let's begin our study of the oceans by examining some of the unique geographic characteristics of our watery world.

1.1 How Are Earth's Oceans Unique?

In all of the planets and moons in our solar system, Earth is the only one that has oceans of liquid water on its surface. No other body in the solar system has a confirmed ocean, but recent satellite missions to other planets have revealed some tantalizing possibilities. For example, the spidery network of fluid-filled cracks on Jupiter's moon Europa (**Figure 1.1**) almost certainly betrays the presence of an ocean of liquid water beneath its icy surface. In fact, a recent analysis of the icy blocks that cover Europa's surface indicates that the blocks are actively being reshaped in a process analogous to plate tectonics on Earth. Two other moons of Jupiter, Ganymede and Callisto, may also have liquid oceans of water beneath their cold, icy crust. Yet another possibility for a nearby world with an ocean beneath its icy surface is Saturn's tiny moon Enceladus, which displays geysers of water vapor and ice that have

[1] The most commonly used words in this chapter are shown by larger font sizes in this *word cloud*, which is a visual aid for identifying important terms. Look for word clouds of important vocabulary terms on the opening page of each chapter throughout this book.

[2] Note that all **bolded** words are key vocabulary terms that are defined in the glossary at the end of this book.

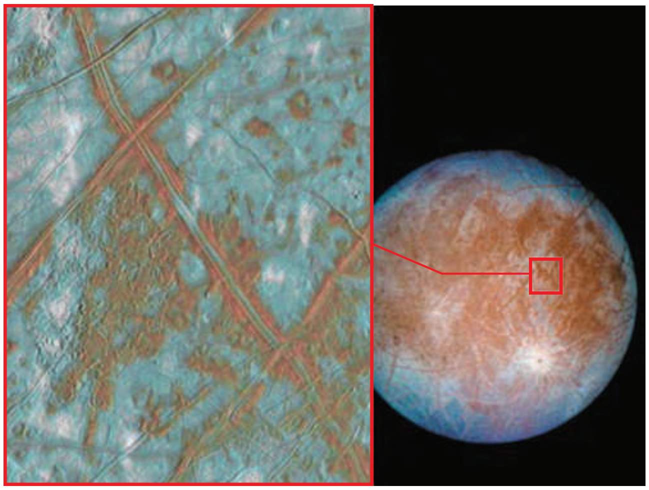


Figure 1.1 Jupiter's moon Europa. Europa's network of dark fluid-filled cracks suggests the presence of an ocean beneath its icy surface.

recently been analyzed and, remarkably, contain salt. Recent analysis of the gravity field of Enceladus suggests the presence of a 10-kilometer (6.2-mile) deep saltwater ocean beneath a thick layer of surface ice. Also contained in the geysers' icy spray are tiny mineral grains, and in 2015 analysis of these particles indicated that the dust-sized grains likely form when hot, mineral-laden water from the moon's rocky interior travels upward, coming into contact with cooler water. This evidence of subsurface hydrothermal activity is reminiscent of underwater hot springs in the deep oceans on Earth, a place that may have been key to the development of life on Earth. And evidence continues to mount that Saturn's giant moon Titan has small seas of liquid hydrocarbons, suggesting that Titan may be the only other body in the solar system besides Earth known to have stable liquid at its surface. All these moons are enticing targets for space missions to search for signs of extraterrestrial life. Still, the fact that our planet has so much water, *and in the liquid form,* is unique in the solar system.

STUDENTS SOMETIMES ASK . . .

I've heard of the discovery of other planets outside of our solar system. Could any of them contain life?

Outside our solar system, more than 2000 exoplanets have been discovered orbiting other star systems, including a few rocky exoplanets that are Earth-sized and may be orbiting their Sun-like stars at just the right distance for water to remain liquid, potentially sustaining life. Astronomers are able to detect if these exoplanets have water or not by analyzing specific frequencies of light. New discoveries of exoplanets are a frequent occurrence, suggesting that there could be hundreds to billions of Earth-like worlds in the vastness of the galaxy. However, most of these exoplanets are many light-years away, so we may never know if any of them harbor life.

Earth's Amazing Oceans

Earth's oceans have had a profound effect on our planet and continue to shape our planet in critical ways. The oceans are essential to all life-forms and are in large part responsible for the development of life on Earth, providing a stable environment in which life could evolve over billions of years. Today, the oceans contain the greatest number of living things on the planet, from microscopic bacteria and algae to the largest life-form alive today (the blue whale). Interestingly, water is the major component of nearly every life-form on Earth, and our own body fluid chemistry is remarkably similar to the chemistry of seawater.

The oceans influence climate and weather all over the globe—even in continental areas far from any ocean—through an intricate pattern of currents and heating/cooling mechanisms, some of which scientists are only now beginning to understand. The oceans are also the "lungs" of the planet, taking carbon dioxide gas out of the atmosphere and replacing it with oxygen gas. Scientists have estimated that the oceans supply as much as 70% of the oxygen that humans breathe.

The oceans determine where our continents end and have thus shaped political boundaries and human history. The oceans conceal many features; in fact, the majority of Earth's geographic features are on the ocean floor. Remarkably, there was once more known about the surface of the Moon than about the floor of the oceans! Fortunately, our knowledge of both has increased dramatically over the past several decades.

The oceans also hold many secrets waiting to be discovered, and new scientific discoveries about the oceans are made nearly every day. The oceans are a source of food, minerals, and energy that remains largely untapped. More than half of the world population lives in coastal areas near the oceans, taking advantage of the mild climate, an inexpensive form of transportation, proximity to food resources, and vast recreational opportunities. Unfortunately, the oceans are also the dumping ground for many of society's wastes. In fact, the oceans are currently showing alarming changes caused by pollution, overfishing, invasive species, and climate change, among other things. All of these and many other topics are contained within this book.

1.1 Squidtoons

https://goo.gl/xwUwNX

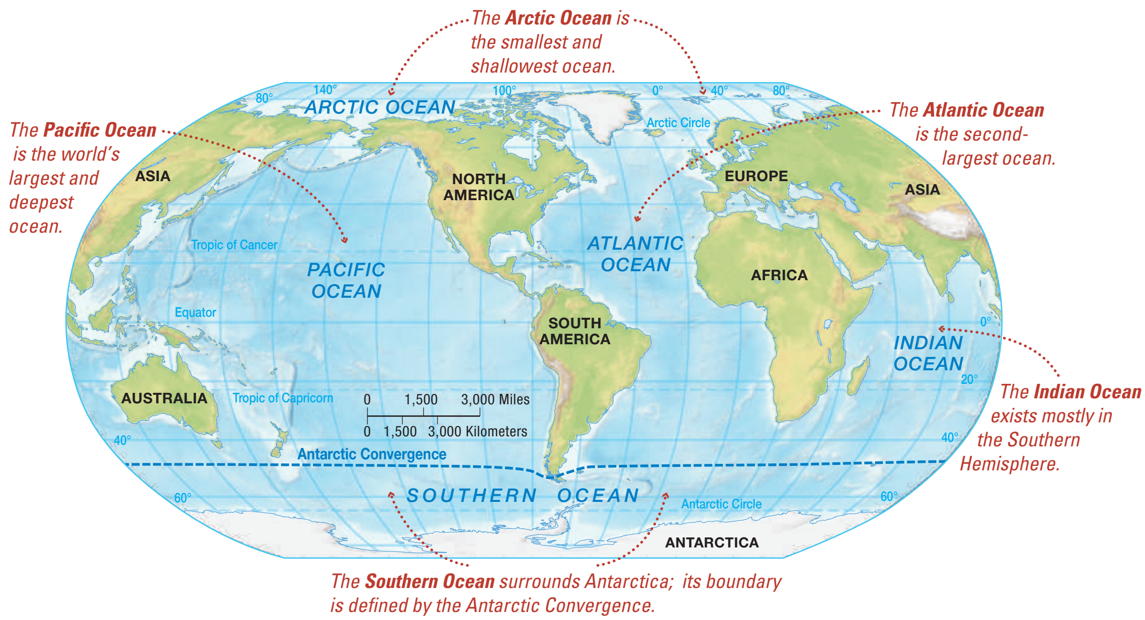
How Many Oceans Exist on Earth?

The oceans are a common metaphor for vastness. When one examines a world map (**Figure 1.2**), it's easy to appreciate the impressive extent of Earth's oceans. Notice that *the oceans dominate the surface area of the globe.* For those people who have traveled by boat across an ocean (or even flown across one in an airplane), the one thing that immediately strikes them is that the oceans are enormous. Notice, also, that *the oceans are interconnected* and form a single continuous body of seawater, which is why the oceans are commonly referred to as a "world ocean" (singular, not plural).

For instance, a vessel at sea can travel from one ocean to another, whereas it is impossible to travel on land from one continent to most others without crossing an ocean. In addition, *the volume of the oceans is immense*. For example, the oceans comprise the planet's largest habitat and contain 97.2% of all the water on or near Earth's surface (**Figure 1.3**).

The Four Principal Oceans, Plus One

Our world ocean can be divided into four principal oceans plus an additional ocean, based on the shape of the ocean basins and the positions of the continents (Figure 1.2).



SmartFigure 1.2 Earth's oceans. Map showing the four principal oceans plus the Southern Ocean, or Antarctic Ocean.
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PACIFIC OCEAN The **Pacific Ocean** is the world's largest ocean, covering more than half of the ocean surface area on Earth (**Figure 1.4b**). The Pacific Ocean is the single largest geographic feature on the planet, spanning more than one-third of Earth's entire surface. The Pacific Ocean is so large that *all* of the continents could fit into the space occupied by it—with room left over! Although the Pacific Ocean is also the deepest ocean in the world (**Figure 1.4c**), it contains many small tropical islands. It was named in 1520 by explorer Ferdinand Magellan's party in honor of the fine weather they encountered while crossing into the Pacific (*paci* = peace) Ocean.

ATLANTIC OCEAN The **Atlantic Ocean** is about half the size of the Pacific Ocean and is not quite as deep (Figure 1.4c). It separates the Old World (Europe, Asia, and Africa) from the New World (North and South America). The Atlantic Ocean was named after Atlas, who was one of the Titans in Greek mythology.

INDIAN OCEAN The **Indian Ocean** is slightly smaller than the Atlantic Ocean and has about the same average depth (Figure 1.4c). It is mostly in the Southern Hemisphere (south of the equator, or below 0 degrees latitude in Figure 1.2). The Indian Ocean was named for its proximity to the subcontinent of India.

ARCTIC OCEAN The **Arctic Ocean** is about 7% the size of the Pacific Ocean and is only a little more than one-quarter as deep as the rest of the oceans (Figure 1.4c). Although it has a permanent layer of sea ice at the surface, the ice is only a few meters thick. The Arctic Ocean was named after its location in the Arctic region, which exists beneath the northern constellation Ursa Major, otherwise known as the Big Dipper, or the Bear (*arktos* = bear).

SOUTHERN OCEAN, OR ANTARCTIC OCEAN Oceanographers recognize an additional ocean near the continent of Antarctica in the Southern Hemisphere (Figure 1.2). Defined by the meeting of currents near Antarctica called the Antarctic Convergence, the **Southern Ocean**, or **Antarctic Ocean**, is really the portions of the Pacific, Atlantic, and Indian Oceans south of about 50 degrees south latitude. This ocean was named for its location in the Southern Hemisphere.

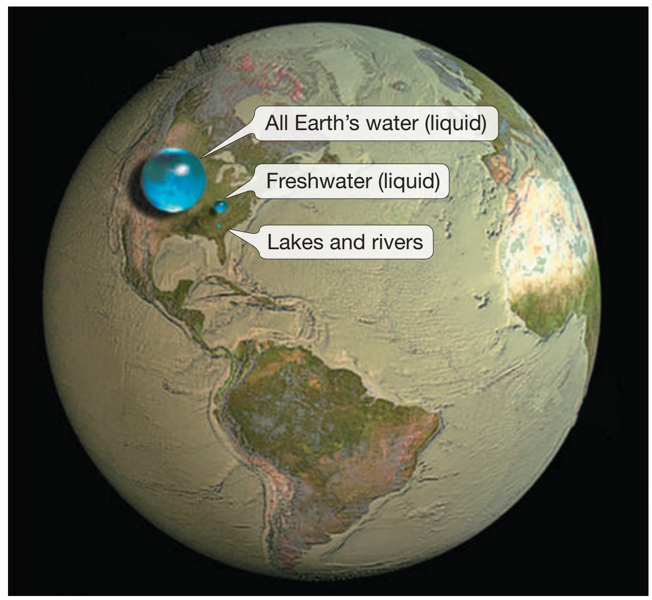
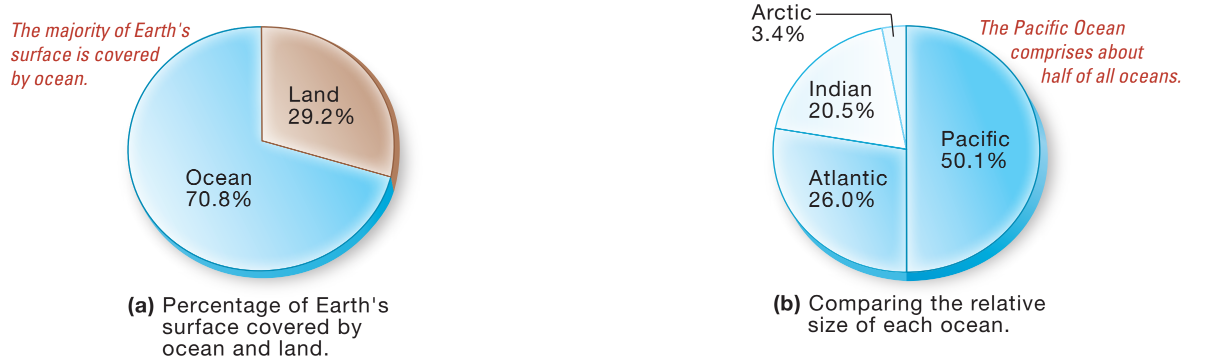


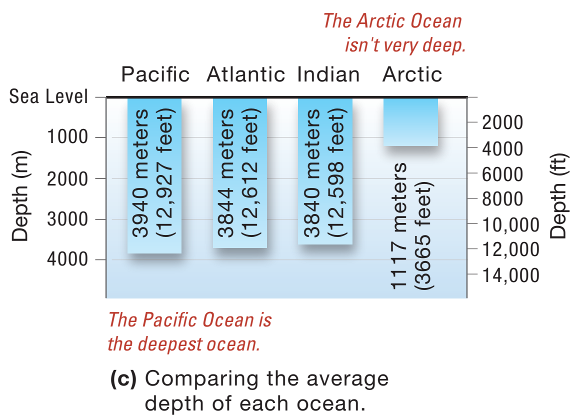
Figure 1.3 Relative sizes of the spheres of water on Earth. This image shows all of Earth's liquid water using three blue spheres of proportional sizes. The big sphere is all liquid water in the world, 97% of which is seawater. The next smallest sphere represents a subset of the larger sphere, showing freshwater in the ground, lakes, swamps, and rivers. The tiny speck below it represents an even smaller subset of all the water—just the freshwater in lakes and rivers.

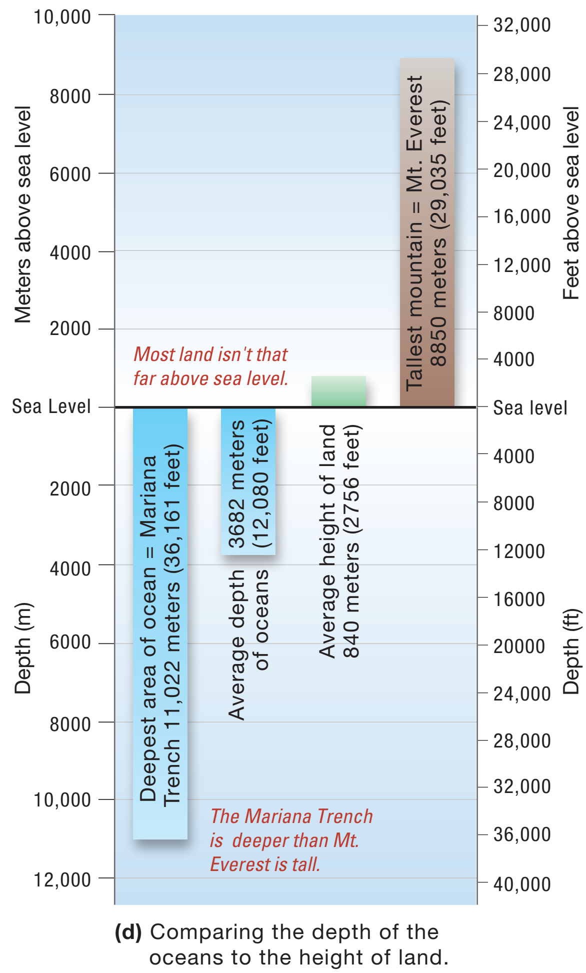
RECAP

The four principal oceans are the Pacific, Atlantic, Indian, and Arctic Oceans. An additional ocean, the Southern Ocean, or Antarctic Ocean, is also recognized.

Figure 1.4 Ocean size and depth. **(a)** Relative proportions of land and ocean on Earth's surface. **(b)** Relative size of the four principal oceans. **(c)** Average ocean depth. **(d)** Comparing average and maximum depth of the oceans to average and maximum height of land.







Web Animation
Earth's Water and the Hydrologic Cycle
http://goo.gl/kAo8FC

Oceans versus Seas

What is the difference between an ocean and a sea? In common use, the terms *sea* and *ocean* are often used interchangeably. For instance, a *sea* star lives in the *ocean*, the *ocean* is full of *sea* water, *sea* ice forms in the *ocean*, and one might stroll the *sea* shore while living on *ocean*-front property. Technically, however, a *sea* is defined as follows:

- Smaller and shallower than an ocean (this is why the Arctic Ocean might be more appropriately considered a sea)
- Composed of salt water (although some inland "seas," such as the Caspian Sea in Asia, are actually large lakes with relatively high salinity)

Figure 1.5 Map of the ancient seven seas. This map represents the extent of the known world to Europeans before the 15th century.

- Somewhat enclosed by land (although some seas, such as the Sargasso Sea in the Atlantic Ocean, are defined by strong ocean currents rather than by land)
- Directly connected to the world ocean

COMPARING THE OCEANS TO THE CONTINENTS Figure 1.4d shows that the average depth of the world's oceans is 3682 meters[3] (12,080 feet). This means that there must be some extremely deep areas in the ocean to offset the shallow areas close to shore. Figure 1.4d also shows that the deepest depth in the oceans (the Challenger Deep region of the Mariana Trench, which is near Guam) is a staggering 11,022 meters (36,161 feet) below sea level.

How do the continents compare to the oceans? Figure 1.4d shows that the average height of the continents is only 840 meters (2756 feet), illustrating that the average height of the land is not very far above sea level. The highest mountain in the world (the mountain with the greatest height above sea level) is Mount Everest in the Himalaya Mountains of Asia, at 8850 meters (29,035 feet). Even so, Mount Everest is a full 2172 meters (7126 feet) shorter than the Mariana Trench is deep. The mountain with the *greatest total height* from base to top is Mauna Kea on the island of Hawaii in the United States. It measures 4206 meters (13,800 feet) above sea level and 5426 meters (17,800 feet) from sea level down to its base, for a total height of 9632 meters (31,601 feet). The total height of Mauna Kea is 782 meters (2566 feet) higher than Mount Everest, but it is still 1390 meters (4560 feet) shorter than the Mariana Trench is deep. Therefore, no mountain on Earth is taller than the Mariana Trench is deep.

[3]Throughout this book, metric measurements are used (and the corresponding English measurements follow in parentheses). See Appendix I, "Metric and English Units Compared," for conversion factors between the two systems of units.

STUDENTS SOMETIMES ASK . . .

Where are the seven seas?

"Sailing the seven seas" is a familiar phrase in literature and song, but the origin of the saying is shaded in antiquity. To the ancients, the term "seven" often meant "many," and before the 15th century, Europeans considered these the main seas of the world (Figure 1.5):

1. The Red Sea
2. The Mediterranean Sea
3. The Persian Gulf
4. The Black Sea
5. The Adriatic Sea
6. The Caspian Sea
7. The Indian Ocean (notice how "ocean" and "sea" are used interchangeably)

Today, however, more than 100 seas, bays, and gulfs are recognized worldwide, nearly all of them smaller portions of the huge interconnected world ocean.

STUDENTS SOMETIMES ASK ...

Have humans ever explored the deepest ocean trenches? Could anything live there?

Humans have indeed visited the deepest part of the oceans—where there is crushing high pressure, complete darkness, and near-freezing water temperatures—and they first did so over half a century ago! In January 1960, U.S. Navy Lt. Don Walsh and explorer Jacques Piccard descended to the bottom of the Challenger Deep region of the Mariana Trench in the *Trieste*, a deep-diving bathyscaphe (*bathos* = depth, *scaphe* = a small ship) (**Figure 1.6**). At 9906 meters (32,500 feet), the men heard a loud cracking sound that shook the cabin. They were unable to see that a 7.6-centimeter (3-inch) Plexiglas viewing port had cracked (miraculously, it held for the rest of the dive). More than five hours after leaving the surface, they reached the bottom, at 10,912 meters (35,800 feet)—a record depth for human descent. They did observe some small organisms that are adapted to life in the deep: a flatfish, a shrimp, and some jellies.

In 2012, film icon James Cameron made a historic solo dive to the Mariana Trench in his submersible *DEEPSEA CHALLENGER* (**Figure 1.7**). On the seven-hour round-trip voyage, Cameron spent about three hours at the deepest spot on the planet to take photographs and collect samples for scientific research. Other notable voyages to the deep ocean in submersibles are discussed in MasteringOceanography **Web Diving Deeper 1.3**.

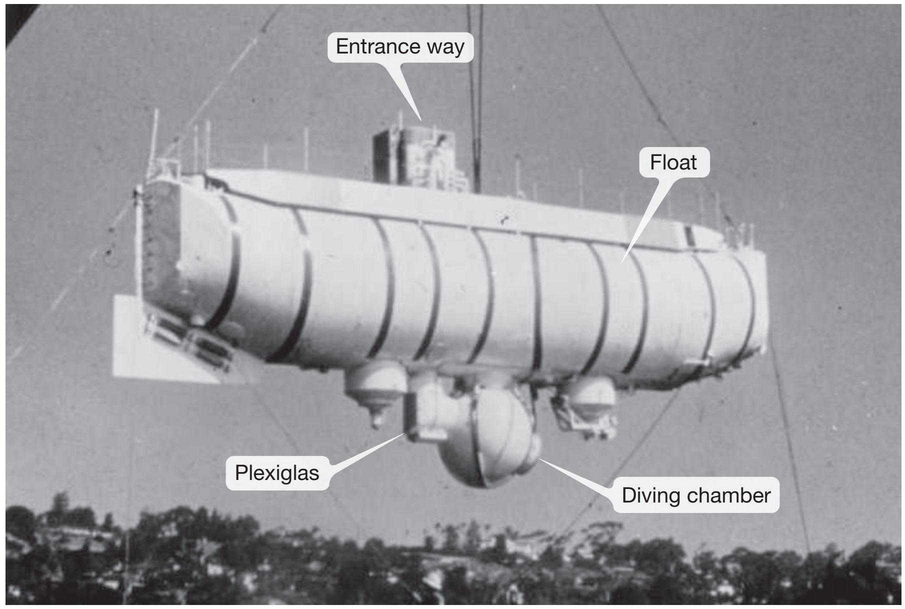


Figure 1.6 The U.S. Navy's bathyscaphe Trieste. The *Trieste* suspended on a crane before its record-setting deep dive in 1960. The 1.8-meter (6-foot) diameter diving chamber (the round ball below the float) accommodated two people and had steel walls 7.6 centimeters (3 inches) thick.

Figure 1.7 James Cameron emerges from the submersible *DEEPSEA CHALLENGER* after his solo dive to the Mariana Trench. In 2012, famous moviemaker James Cameron completed a record-breaking solo dive to the bottom of the Mariana Trench, becoming only the third human to visit the deepest spot on Earth.

RECAP

The deepest part of the ocean is the Mariana Trench in the Pacific Ocean. It is 11,022 meters (36,161 feet) deep and has been visited only twice by humans: once in 1960 and more recently in 2012.

CONCEPT CHECK 1.1 | Compare the characteristics of Earth's oceans.

1 How did the view of the ocean by early Mediterranean cultures influence the naming of planet Earth?

2 Although the terms *ocean* and *sea* are sometimes used interchangeably, what is the technical difference between an ocean and a sea?

3 Where is the deepest part of the ocean? How deep is it, and how does it compare to the height of the tallest mountain on Earth?

1.2 How Was Early Exploration of the Oceans Achieved?

The ocean's huge extent over the surface area of Earth has not prevented humans from exploring its furthest reaches. Since early times, humans have developed technology that has allowed civilizations to travel across large stretches of open ocean. Today, we can cross even the Pacific Ocean in less than a day by airplane. Even so, much of the deep ocean remains out of reach and woefully unexplored. In fact, the surface of the Moon has been mapped more accurately than most parts of the sea floor. Yet satellites at great distances above Earth are being used to gain knowledge about our watery home.

Early History

Humankind probably first viewed the oceans as a source of food. Archeological evidence suggests that when boat technology was developed about 40,000 years ago, people probably traveled the oceans. Most likely, their vessels were built to move upon the ocean's surface and transport oceangoing people to new fishing grounds. The oceans also provided an inexpensive and efficient way to move large and heavy objects, facilitating trade and interaction between cultures.

PACIFIC NAVIGATORS The peopling of the Pacific Islands (Oceania) is somewhat perplexing because there is no evidence that people actually evolved on these islands. Their presence required travel over hundreds or even thousands of kilometers of open ocean from the continents (probably in small vessels of that time—double canoes, outrigger canoes, or balsa rafts) as well as remarkable navigation skills (**Diving Deeper 1.1**). The islands in the Pacific Ocean are widely scattered, so it is likely that only a fortunate few of the voyagers made landfall and that many others perished during voyages. **Figure 1.8** shows the three major inhabited island regions in the Pacific Ocean: Micronesia (*micro* = small, *nesia* = islands), Melanesia (*mela* = black, *nesia* = islands), and Polynesia (*poly* = many, *nesia* = islands), which covers the largest area.

No written records of Pacific human history have been found prior to the arrival of Europeans in the 16th century. Nevertheless, the movement of Asian peoples into Micronesia and Melanesia is easy to imagine because distances between islands are relatively short. In Polynesia, however, large distances separate island groups, which must have presented great challenges to ocean voyagers. Easter Island, for example, at the southeastern corner of the triangular-shaped Polynesian Islands region, is more than 1600 kilometers (1000 miles) from Pitcairn Island, the next nearest island. Clearly, a voyage to the Hawaiian Islands must have been one of the most difficult because Hawaii is more than 3000 kilometers (2000 miles) from the nearest inhabited islands, the Marquesas Islands (Figure 1.8).

Figure 1.8 **The peopling of the Pacific islands.** The major island groups of the Pacific Ocean are Micronesia (*brown shading*), Melanesia (*peach shading*), and Polynesia (*green shading*). The "Lapita people" present in New Ireland 5000–4000 B.C. can be traced to Fiji, Tonga, and Samoa by 1100 B.C. (*yellow arrow*). Green arrows show the peopling of distant islands throughout Polynesia. The route of Thor Heyerdahl's balsa raft *Kon Tiki* is also shown (*red arrow*).

Archeological evidence suggests that humans from New Guinea may have occupied New Ireland as early as 4000 or 5000 B.C. However, there is little evidence of human travel farther into the Pacific Ocean before 1100 B.C. By then, the *Lapita people*,[4] a group of early settlers who produced a distinctive type of

[4]In recent years, a combination of genetic, linguistic, and archaeological evidence has suggested that the forebears of the Lapita people—and thus Polynesians—originated in Taiwan, just off the coast of China.