



OCEANOGRAPHY

AN INVITATION TO MARINE SCIENCE

TOM GARRISON

FOURTH EDITION

Oceanography

An Invitation to Marine Science

FOURTH EDITION

TOM GARRISON

*Orange Coast College
University of Southern California*

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*To my family and my students:
My hope for the future.*

Preface for Students and Instructors

This book was written to provide an *interesting*, clear, current, and reasonably comprehensive overview of the marine sciences. It was designed for college and university students who are curious about Earth's largest feature, but who may have little formal background in science. Oceanography is broadly interdisciplinary; students are invited to see the *connections* between astronomy, economics, physics, chemistry, history, meteorology, geology, and ecology—areas of study they once considered separate. It's no surprise that oceanography courses have become increasingly popular in the last decade.

Students bring a natural enthusiasm to their study of this field. Even the most indifferent reader will perk up when presented with stories of encounters with huge waves, photos of giant squids, tales of exploration under the best and worst of circumstances, evidence that vast chunks of Earth's surface slowly move, news of Earth's past battering by asteroids, micrographs of glistening diatoms, and data showing the growing economic importance of seafood and marine materials. If pure spectacle is required to generate an initial interest in the study of science, oceanography wins hands down!

In the end, however, it is subtlety that triumphs. Studying the ocean reinstills in us the sense of wonder we felt as children when we first encountered the natural world. There is much to tell. The story of the ocean is a story of change and chance—its history is written in the rocks, the water, and the genes of the millions of organisms that have evolved here.

The Fourth Edition

My aim in writing this book was to produce a text that would enhance students' natural enthusiasm for the ocean. My students have been involved in this book from the very beginning—indeed, it was their request for a readable, engaging, and thorough text that initiated the project a long time ago. Through the 20 years I have been writing textbooks, my enthusiasm for oceanic knowledge has increased (if that is possible), forcing my patient reviewers and editors to weed out an excessive number of exclamation points, but enthusiasm does shine through. One student reading the final manuscript of the first edition commented, "At last, a textbook that does not read like stereo instructions." Good!

This fourth edition builds on its predecessors. As before, a great many students have participated alongside professional marine scientists in the writing and review process. In response to their recommendations, as well as those of instructors who have adopted the book and the many specialists and reviewers who contributed suggestions for strengthening the earlier editions, we have

- Emphasized the *process* of science throughout. Underlying assumptions and limitations are discussed as appropriate in all sections of the book.
- Rearranged the chapters on the physics and chemistry of seawater to present the physical properties before discussing chemistry.
- Enhanced the visual program for increased clarity and accuracy, adding and modifying illustrations to make ideas easier to grasp.
- Expanded discussions of physical oceanography, marine geology, environmental issues, and the ocean's contribution to world economics.
- Covered communities more thoroughly, emphasizing community ecology in the sections of the text on marine biology.
- Refined every chapter to reflect current thought and recent research.
- Produced an interactive CD-ROM to be included with each copy of the text. Students can see oceanography in action.
- Generated a new Web site specific to this textbook. The Web site is open to all without cost or subscription.

The Plan

The plan of the book is straightforward: Because all matter on Earth—except hydrogen and some helium—was generated in stars, our story of the ocean starts with stars. Have oceans evolved elsewhere? We continue with a brief look at the history of marine science (with additional historical information sprinkled through later chapters). The theories of Earth structure and plate tectonics are presented next as a base on which to build the explanation of bottom features that follow. A survey of ocean physics and chemistry prepares us for

discussions of atmospheric circulation, classical physical oceanography, and coastal processes. Our look at marine biology begins with an overview of the problems and benefits of living in seawater, continues with a discussion of the production and consumption of food, and ends with taxonomic and ecological surveys of marine organisms. The last chapters address marine resources and environmental concerns.

Connections between disciplines are emphasized throughout. Marine science draws on several fields of study integrating the work of specialists into a unified whole. For example, a geologist studying the composition of marine sediments on the deep seabed must be aware of the biology and life histories of the organisms in the water above, the chemistry that affects the shells and skeletons of the creatures as they fall to the ocean floor, the physics of particle settling and water density and ocean currents, and the age and underlying geology of the study area. This book is organized to make those connections from the first.

Organization

A broad view of marine science is presented in 18 chapters, each free-standing (or nearly so) to allow an instructor to assign chapters in any order he or she finds appropriate. Each chapter begins with a **vignette**—a short illustrated tale, observation, or sea story to whet your appetite for the material to come—followed by **What to Watch For**, a survey of the chapter's content. Some vignettes spotlight scientists at work; others describe the experiences of people or animals in the sea.

The chapters are written in an **engaging style**. Terms are defined and principles developed in a straightforward manner. Some complex ideas are initially outlined in broad-brush strokes, then discussed again in greater depth after you have a clear view of the overall situation. When appropriate to their meanings, the derivations of words are shown. **Measurements** are given in both metric (S.I.) and American systems. At the request of a great many students, the units are spelled out (that is, we write *kilometer* rather than *km*) to avoid ambiguity and for ease of reading.

The photos, charts, graphs, and paintings in the **extensive illustration program** have been chosen for their utility, clarity, and beauty. **Boxes** in each chapter present commentaries of special interest on unique topics or controversies. **Internet icons** are provided at nearly all of the subheads, boxes, and essays, indicating that text-specific Web links provide additional information.

Concluding each chapter is a **Questions from Students** section. These questions are ones that students have asked me over the years. This material is an important extension of the chapters and occasionally contains key words and illustrations. Each chapter ends with an array of study materials for students, beginning with a new feature called **Key Concepts to Review**. Important **Terms** are listed next. These are also defined in an extensive **Glossary** in the back of the book. **Study Questions** are also included in each chapter. Writing the answers to these questions will cement your understanding of the concepts presented. The **annotated bibliography**

at the book's Web site will be helpful when you wish to know more about a particular topic.

Appendixes will help you master measurements and conversions, geological time, latitude and longitude, chart projections, the mathematics of the Coriolis effect and tidal forces, and the taxonomy of marine organisms. In case you'd like to join us in our life's work, the last appendix discusses **jobs in marine science**.

This book has been thoroughly **student tested**. You need not feel intimidated by the concepts—this material has been mastered by students just like you. Read slowly and go step-by-step through any parts that give you trouble. Your predecessors have found the ideas presented here to be useful, inspiring, and applicable to their lives. Best of all, they have found the subject to be *interesting!*

The Web Site

This book is fully Internet integrated. You'll find its dedicated Web site at:



www.brookscole.com/product/053437557xs

Internet icons at each head and subhead, and at the ends of Vignettes and Boxes, indicate text-specific information is available on the site. References, bibliography entries, chapter outlines, sample quizzes, flashcards, links, exercises, animations, and tutorial assistance are also accessible at the site. We will periodically update the Web site to add features and announce important advances in marine science. *The site is open to anyone without cost or subscription.*

Suggestions for Using This Book

1. *Begin with a preview.* Scout the territory ahead: Read "What to Watch For" after each vignette, flip through the assigned pages reading only the headings and sub-headings, look at the figures and read captions that catch your attention.
2. *Keep a pen and paper handy.* Jot down a few questions—any questions—that this quick glance stimulates. *Why* is the deep ocean cold if the inside of the Earth is so hot? *What* makes storm conditions like those seen in 1997–98? *Where* did sea salt come from? *Will* global warming actually be a problem? *Does* anybody still hunt whales? Writing questions will help you focus when you start studying.
3. *Now read in small but concentrated doses.* Each chapter is written in a sequence and tells a story. The logical progression of ideas is going somewhere. Follow the organization of the chapter. Stop occasionally to review what you've learned. Flip back and forth to review and preview.
4. *Strive to be actively engaged.* Write marginal notes, underline occasional passages (underlining whole sections is seldom useful), write more questions, draw on the diagrams, check off subjects as you master them, make

flashcards while you read (if you find them helpful), *use your book!*

5. *Monitor your understanding.* If you start at the beginning of the chapter, you will have little trouble understanding the concepts as they unfold. But if you find yourself at the bottom of the page having only scanned (rather than understood) the material, stop there and start that part again. Look ahead to see where we're going. Remember, students have been here before, and I have listened to their comments to make the material as clear as I can. This book was written for you.
6. *Use the Internet sites.* We have placed more than 1,500 Internet links throughout the text. If you have access to a computer, fire it up and scan the designated site as you read the associated passage of the book.
7. *Enjoy the journey.* Your instructor would be glad to share his or her understanding and appreciation of marine science with you—you need only ask. Students, instructors, and authors all work together toward a common goal—an appreciation of the beauty and interrelationships a growing understanding of the ocean can provide.

Acknowledgments

Jack Carey at Thomson Learning, the grand master of college textbook publishing, willed the first edition of this book into being. His suggestions have been combined with those of more than 750 undergraduate students and 118 reviewers to contribute to my continuously growing understanding of marine science. Donald Lovejoy, Stanley Ulanski, Richard Yuretich, Ronald Johnson, and John Mylroie deserve special recognition for many years of patient direction. For the fourth edition, I have especially depended on the expert advice of Ernest Knowles at North Carolina State University, Hans-Peter Bunge of Princeton, William Cochlan of San Francisco State University, James Ingle at Stanford, Richard Murray at Boston University, Morris Sotonoff at Chicago State University, Kent Syverson of the University of Wisconsin, Michelle Kominz at Western Michigan University, Lawrence Krissek at Ohio State, Scott King at Purdue, Brian McAdoo at Vassar, James Stratton of Eastern Illinois University, Michael Lyle at Tidewater Community College, and Bruce Fouke at the University of Illinois, Urbana.

My long-suffering departmental colleagues Dennis Kelly, Jay Yett, and Robert Profeta again should be awarded medals for putting up with me, answering hundreds of my questions, and being so forbearing through the book's lengthy gestation period. Thanks again to our dean, Stanley Johnson, and our college president, Margaret Gratton, for supporting this project and encouraging our faculty to teach, conduct research, and be involved in community service. Our department teaching assistants deserve praise as well, especially Timothy Riddle and Matthew Bollen, the Internet wizards responsible for the Web site and extensive links.

Yet another round of gold medals should go to my family for being patient (well, *relatively* patient) during those years

of days and nights when dad was holed up in his dark reference-littered cave, listening to really loud Glenn Gould Bach recordings, working late on *The Book*. Thank you Marsha, Jeanne, Greg, and John for your love and understanding.

The people who provided pictures and drawings have worked miracles to obtain the remarkable images in these pages. To mention just a few: Gerald Kuhn sent classics taken by his late SIO colleague Francis Shepard, Vincent Courtillot of the University of Paris contributed the remarkable photo of the Aden Rift, Catherine Devine at Cornell provided time-lapse graphics of tsunami propagation, Jian Lin of Woods Hole sent a photo of Iceland's Thingvellir Graben, Robert Headland of the Scott Polar Research Institute in Cambridge searched out prints of polar subjects, Charles Hollister at Woods Hole kindly provided seafloor photos from his important books, Andreas Rechnitzer and Don Walsh recalled their exciting days with *Trieste*, and Bruce Hall, Pat Mason, Ron Romanoski, Ted Delaca, William Cochlan, Christopher Ralling, Mark McMahon, John Shelton, Alistair Black, Howard Spero, Eric Bender, Ken-ichi Inoue, and Norman Cole contributed beautiful slides. Seran Gibbard provided the highest-resolution images yet made of the surface of Titan, and Michael Malin forwarded truly beautiful images of erosion on Mars. Herbert Kawainui Kane again allowed us to reprint his magnificent paintings of Hawaiian subjects. Deborah Day and Cindy Clark at Scripps Institution, Jutta Voss-Diestelkamp at the Alfred Wegener Institut in Bremerhaven, and David Taylor at the Centre for Maritime Research in Greenwich dug through their archives one more time. Don Dixon, William Hartmann, Ron Miller, and William Kaufmann provided paintings, Dan Burton sent photos, and Andrew Goodwillie printed customized charts. Wim van Egmond contributed striking photomicrographs of diatoms, forams, and copepods. Bill Haxby at Lamont provided truly beautiful seabed scans. Karen Riedel helped with DSDP core images. James Ingle offered me a desk at Stanford whenever I needed it. NOAA, NASA, USGS, the Smithsonian Institution, the Royal Geographical Society, the U.S. Navy, and the U.S. Coast Guard came through time and again, as did private organizations like Alcoa Aluminum, Cunard, Shell Oil, The Maersk Line, Grumman Aviation, Breitling-SA, CNN, Associated Press, Oakley, and the *Los Angeles Times*. The Woods Hole team was also generous: Philip Richardson, William Schmitz, Susumu Honjo, Doug Webb, James Broda, Albert Bradley, and Kathy Patterson all provided photographs, diagrams, and advice. Individuals with special expertise have also been willing to share: Hank Brandli processed satellite digital images of storms, Peter Sloss at the National Geophysical Data Center helped me sort through computer-generated seabed images, Steven Grand of the University of Texas provided a descending deep-slab image, Hans-Peter Bunge of Princeton patiently explained mantle-core dynamics, Michael Gentry again mined the archives of the Johnson Space Center for Earth images, Jurrie van der Woude at JPL helped with images of oceans elsewhere, John Maxtone-Graham of New York's Ocean Liner Museum found me a rogue wave picture, Ed Ricketts, Jr., contributed a portrait of his father,

and professor Lynton Land of the University of Texas sent a rare photo of a turbidity current.

The Brooks/Cole team performed the customary miracles. The charge was again led from her redwood forest keep by Joan Keyes, production editor and champion of every known means of digital communication. The text was polished by Mary Arbogast, the best developmental editor in the Orion arm of the galaxy, and Cathy Baehler and Mary Roybal the copy editors who saved me from many errors. Myrna Engler worked tirelessly on photo research and permissions. Project manager Teri Hyde kept us all running in the same direction. And Nina Horne, my excellent editor, gave birth to this book and a baby daughter simultaneously. What skill!

My thanks to all.

A Goal and a Gift

The goal of all this effort: *To allow you to gain an oceanic perspective.* “Perspective” means being able to view things in terms of their relative importance or relationship to one an-

other. An oceanic perspective lets you see this misnamed planet in a new light, and helps you plan for its future. You will see that water, continents, seafloors, sunlight, storms, seaweeds, and society are connected in subtle and beautiful ways.

The ocean’s greatest gift to humanity is intellectual—the constant challenge its restless mass presents. Let yourself be swept into this book and the class it accompanies. Give yourself time to ponder: “Meditation and water are wedded forever,” wrote Herman Melville in *Moby Dick*. Take pleasure in the natural world. Ask questions of your instructors and teaching assistants, read the references, try your hand at the questions at the ends of the chapters.

Be optimistic. Take pleasure in the natural world. Please write to me when you find errors or if you have comments. Above all, *enjoy yourself!*

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