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# OCEANOGRAPHY

*An Invitation to Marine Science*

Second Edition

**TOM GARRISON**

*Orange Coast College*



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# PREFACE FOR STUDENTS AND INSTRUCTORS

In recent years, the systematic study of the ocean—marine science—has become increasingly popular with college and university students. They could hardly make a better choice. Inevitably, a general marine science course is interdisciplinary; students are invited to see the *connections* bridging astronomy, physics, chemistry, meteorology, geology, biology, ecology, history, and economics—areas of study they once considered separate. Together, teachers and students learn to see that the rise of a wave is linked to the twinkle of distant starlight, that a soft summer breeze is shaped by the chemistry of a billion microscopic plants, that the slow drift of a continent molds the evolution of countless organisms.

Studying the ocean awakens in us the sense of wonder we all felt as children when we first encountered the natural world. Students in marine science classes often find themselves immersed in wonderful stories and spectacular pictures and surrounded by teachers and technicians whose barely contained enthusiasm for their subject overtakes the clock. 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.

This comprehensive book is designed to tell that story in a clear and interesting way.

## The Second Edition

My aim in writing this book was to produce a compelling, visually exciting 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, interesting, and thorough text that initiated the project. Through the fifteen 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 second edition builds on the first. As before, a great many students have read and commented on the manuscript. In response to their recommendations, as well as those of professors who have adopted the book and the many reviewers who contributed suggestions for strengthening the first edition, we have produced the book in full color, improved and expanded the illustration program, and incorporated many recent advances in oceanography. Major changes in the text include a greater dependence on satellite data and images (especially those from *TOPEX/Poseidon*), an overview of the objectives and funding levels of large new marine science programs, changes in the organization and presentation of the material on continental margins and ocean basins, combining nearly all El Niño information in one chapter (Ocean Circulation), reporting the effects of recent storms, tsunamis, and earthquakes, noting the recent collapse of some fisheries, and extensively rewriting the chapter on coasts and most of the material on tides.

Oceanography is surely the most visual of the natural sciences, and we have incorporated some truly wonderful images. Among the many new and noteworthy illustrations, you will find a remarkable photo of a mid-ocean rift above sea level (Figure 3.20), a U.S. Navy nuclear submarine being used as an oceanographic research vessel (Box 4.1e and Figure 18.27), the first comprehensive image of the world ocean floor derived from gravimetric and sound sampling data (Figure 4.21), Calvin and Hobbes pondering the Coriolis effect (Figure 8.6), a particularly attractive sea monster (Box 13.1), yellowfin tuna swimming at high speed (Chapter 16's opener), a feeding blue whale (Figure 16.26), and the newest double-hulled tanker (Figure 19.21).

The organization 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. 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 follows. A survey of ocean chemistry and physics 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. A special chapter

comparing and contrasting the polar and tropical regions precedes the last chapters on 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. An oceanographer needs to be acquainted with a broad and beautiful array of information. This book is organized to make those connections from the first.

## How This Book Is Organized

A broad view of marine science is presented in 20 chapters, each free-standing (or nearly so) to allow an instructor to assign chapters in any order he or she finds appropriate. Each chapter is preceded by an **overview**, a quick survey of the chapter's content. The overview shows you the topics to be covered and previews the most important points. The chapter itself begins with an attractive **vignette**, a short illustrated tale, observation, or sea story to whet your appetite for the material to come. 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 of the more complex ideas are initially outlined in broad brush strokes, then the same concepts are 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 and English systems. At the request of a great many students, the units are written 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.

Concluding each chapter is a **Q-and-A section**. The Q-and-A items are interesting questions, with their answers, 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 a list of important **terms and con-**

**cepts**, which 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 end of each chapter 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, 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**.

The 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!*

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Many people have helped with this book. Sally Beaty at the Southern California Consortium for Community College Television began the whole thing in 1979 when she asked Ruth Lebow and me to write the study guide for the *Oceanus* telecourse. That led to a great many magazine and newspaper articles, student guides, supplements, and, ultimately, the first edition of this textbook. Jack Carey at Wadsworth, with whom I have worked for 25 years, encouraged me to continue writing through thick and thin, and Cecie Starr at Wadsworth, the best textbook author I know, sent suggestions and encouragement at appropriate intervals. The 74 reviewers have contributed to my continuously growing understanding of marine science, but Donald Lovejoy, Stanley Ulanski, Richard Yuretich, Ronald Johnson, and John Mylroie deserve special recognition for their expert direction. My long-suffering departmental colleagues Dennis Kelly, Jay Yett, Robert Profeta, and Joyce Kai-Mott 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, David Grant, for supporting this project and encouraging our faculty to teach, conduct research, and be involved in community service. 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 working on The Book. Thanks to all.

The people who provided pictures and drawings have worked miracles to obtain the remarkable images in

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The Wadsworth production team for this book has been ideal in every respect. Mary Arbogast, the world's

best developmental editor, is more co-author and friend than editor. Her clear, linear writing style has been my guide for years. Production editor Mary Douglas, invariably optimistic and always on top of everything, has kept production flowing smoothly. Myrna Engler-Forkner, art editor, has a filing system that would be the envy of a medium-sized governmental agency. Jeanne Bosschart, permissions editor, has been able to make sense out of my very large permissions and acquisitions file. Kristin Milotich looks after supplements and ancillary details with enthusiasm. Gary McDonald, production services coordinator, made sure we were all running in the same direction. And Jack Carey helped me focus on the Big Picture when I was submerged in a thousand details. What pleasure to work with such professionals as these!

## 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 another. 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. Take pleasure in the natural world. Ask questions of your instructors, read some of the references, try your hand at the questions at the ends of the chapters. Be optimistic. Please write to me when you find errors or if you have comments. Above all, enjoy yourself!

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