## Oceanography

An Introduction to the Planet Oceanus

PAULR. PINET

# Oceanography



An Introduction to the Planet Oceanus

PAUL R. PINET COLGATE UNIVERSITY

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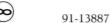
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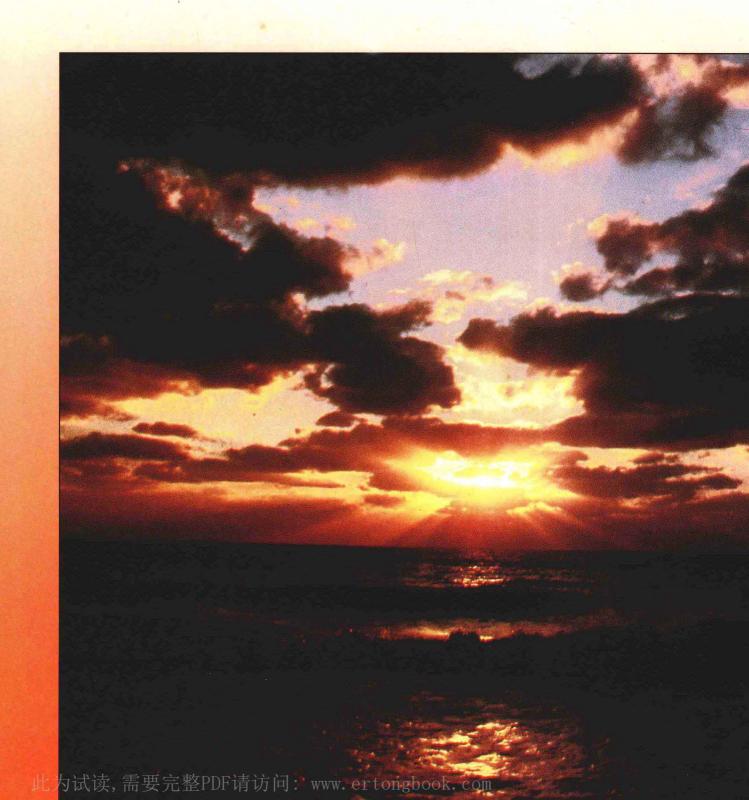
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## THE PLANET OCEANUS

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### \* DEDICATION

Robert L. McMaster Annette B. Pinet Margery A. Pinet

Unique individuals who, in their own special ways, taught me about the world and about myself.

#### PREFACE

OCEANOGRAPHY: AN INTRODUCTION TO THE PLANET OCEANUS is an introductory college textbook written for students who wish to improve their understanding of science in general and of oceanography in particular. My principal motivation in writing this book has been to acquaint readers with the marine processes, both physical and biological, that typify our planet—phenomena not at all obvious or familiar to most of us air-breathing land dwellers. My hope is that a deliberate, careful reading of this book will, at the very least, alter people's human-centered perspective of the earth, broaden their understanding of science, and enrich their aesthetic appreciation of nature. The ideas and concepts in each chapter are developed systematically, logically, and rigorously; their comprehension requires no more than a good dose of common sense and a rudimentary knowledge of a few basic scientific principles. I have tried hard to infuse the book with my genuine reverence for the ocean and with my enthusiasm for its varied dimensions and qualities. I can only hope that this feeling is infectious and that each reader of this book will continue to explore the various dimensions of the ocean environment actively and seriously for a lifetime.

The material in the book is organized into three parts. Part I (Chapters 1–2) provides an historical account of ocean exploration and the science of oceanography. It also reviews some of the more essential physical properties of the earth, focusing on a few critical interactions among the ocean, the atmosphere, and the biosphere. For me the highlight of Part I was envisioning the Atlantic Ocean without any water and writing about an imaginary trek from New Jersey eastward across the dry sea bed to the summit of a submarine mountain chain called the Mid-Atlantic Ridge. I hope readers will enjoy this flight of fancy as much as I delighted in writing it.

Part II (Chapters 3–14) describes and explains the scientific nature of marine processes. This part represents the heart of the book; in it, basic geologic, chemical, physical, and biological principles are clearly explained and applied to the study of the ocean. A careful

reading of this material will teach you not only about oceanography but about scientific methodology as well. Two of the chapters in Part II (Chapter 9, "The Dynamic Shoreline," and Chapter 13, "Coral Reefs and Mangrove Forests") provide an expanded treatment of coastal environments—areas where many readers can come in direct contact with the ocean. The use of coastal habitats has sparked conflicts between preservationists and developers. Because readers of this book may be in a position to vote and influence the management and regulation of these dynamic environments, it is imperative that you be well-informed and acquainted with the nature of the fragile ecosystems of the shoreline.

Part III (Chapters 15–18) amplifies, refines, and rounds out the ideas developed in Part II. In one sense, the case histories in these chapters describe the oceanography of discrete geographic areas located at the shoreline, on the continental shelf, in the open ocean, and within seas and gulfs. This material can be used as supplementary reading to reinforce your understanding of the oceanographic concepts developed in Part II, or they may be studied later during a second-semester course in oceanography.

One of the more valuable aspects of the book are the figures, maps, and photographs, many of which are newly rendered and in color. All the diagrams and photos are tied intimately to the narration of the text; the two go hand in hand and together provide a clearer elucidation of the ideas discussed. Furthermore, extended figure captions are included. These should be read and pondered carefully and critically, because many are designed to deepen your understanding of an oceanographic concept.

A variety of pedagogical devices are used throughout the book to help you learn more about oceanography. Each chapter begins with a preview, which outlines its organizational format and content and relates material in the chapter to material in preceding chapters. Each chapter in Parts I and II concludes with a summary of key concepts, which can help you determine if you understand the main points of the chapter. Also, key terms are highlighted when they are first introduced in the text and are listed at the end of each chapter. To understand any area of science, including oceanography, you must be acquainted with the technical vocabulary used by researchers and scientists in the field. The definitions and figure references in the extensive glossary at the back of the book provide thorough and accurate clarification of the oceanographer's words.

Other features of the book designed to help you learn about the field of oceanography include a reading list, questions, and appendixes. The books and journal articles listed at the end of most chapters will allow you to delve more deeply into or locate more information about key oceanographic topics. A series of review and discussion questions are included to help you think about the material and assess your understanding of the concepts developed in each chapter. Some of the discussion questions require you to apply ideas in ways that go a bit beyond their treatment in the text; the application of familiar ideas to novel situations will help you to acquire a better understanding of these ideas. Finally, the appendixes summarize simple mathematical concepts, data plotting, conversion factors, a geologic time scale and a rock-classification scheme, the construction of maps and topographic profiles, and important chemical reactions.

In many respects, the writing of this book has been a frustrating four-year-long endeavor as I strove to shape my ideas about the teaching of oceanography into a concrete written document. I drew extensively from the comments and suggestions of many students at Colgate University, who thought about and criticized what I was saying in class and how I was saying it. Two personal friends at Colgate University, Bonnie DeGroat and Dyann Curtis, transcribed my words to the page, coping amiably with my urgent requests for work that needed their "immediate" attention and striving gallantly to juggle their heavy workload and responsibilities to accommodate my incessant entreatments. I am indebted to both of them.

I was encouraged repeatedly and assisted immeasurably by the professional expertise of the entire staff at West Educational Publishing. Each editor and everyone involved contributed generously and enduringly to the book. At all stages of manuscript and book production, the West staff strove to remain faithful to my visionary concept and to balance my wishes with the reality and expense of publishing a book. Pat Fitzgerald, in particu-

lar, is responsible for initiating and stimulating my interest in this project; his encouragement, nurturing, and prodding were essential in my early struggles to write. I am also indebted to Jay Ricci, who helped me refine my crude and naïve ideas and guided me ably in the actual planning and organization of the manuscript; in fact, many important features of the book reflect his vision, not mine. Special thanks are extended to Pam Mc-Clanahan and Nancy Roth, two unique individuals who lightened my load tremendously by patiently listening to my suggestions and criticisms of galleys, artwork, and figure preparation; they also searched diligently and tirelessly across the United States for sources of photographs. The final stages in converting the manuscript to a book were guided aptly by Ron Pullins, an acquisition editor at West who moved the production of my book along smoothly and without delays.

Many of my colleagues at numerous institutions reviewed and made constructive suggestions during the developmental stages of the manuscript. Those who were particularly helpful and generous with their time and insights include Leo Berner, Texas A & M University; William Busch, University of New Orleans; Roseanne Carlson, Tidewater Community College; Richard Dame, University of South Carolina at Coastal Carolina; Larry Doyle, University of South Florida; Iver Duedall, Florida Institute of Technology; Herbert Frolander, Oregon State University; Anne Gardulski, Tufts University; Paul Hargraves, University of Rhode Island, Bay Campus; William Hoyt, University of Northern Colorado; Ronald Johnson, Old Dominion University; Robert King, San Jose City College; John Klasik, California State Polytechnic University, Pamona; C. Ernest Knowles, North Carolina State; William Kohland, Middle Tennessee University; Stephen Lebsack, Lin-Benton Community College; Michael Lyle, Tidewater Community College; Nancy Marcus, Florida State University; Jim McWorter, Miami Dade Community College; Paul Nelson, St. Louis Community College at Forest Park; Bob Presley, Texas A & M University; William Prothero, University of California, Santa Barbara; Lee Somers, University of Michigan; William Stephenson, Diablo Valley College; Harold Stonehouser, Michigan State University; Edward Stroup, University of Hawaii; Kathleen Sullivan, University of Miami; Keith Sverdrup, University of Wisconsin, Milwaukee; Detlef Warnke, California State University, Hayward; John Winchester, Florida State University.

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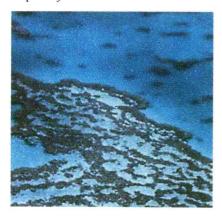
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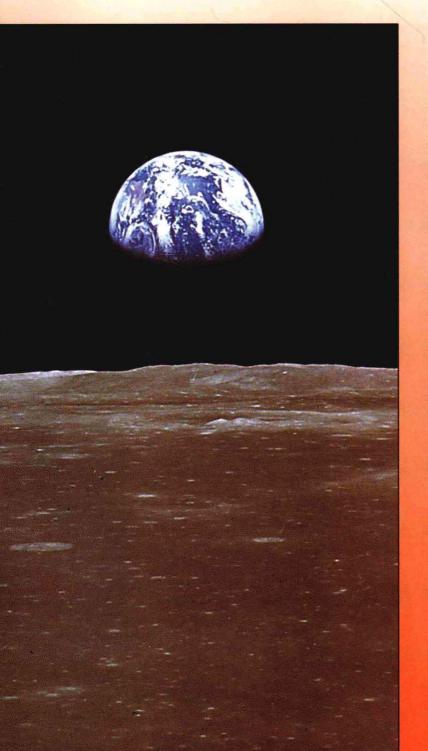
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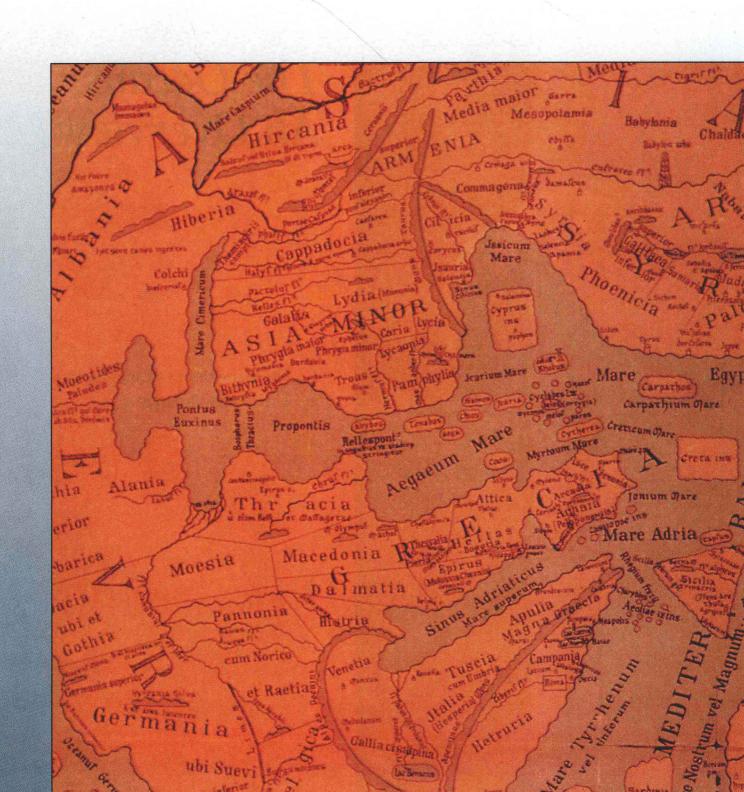


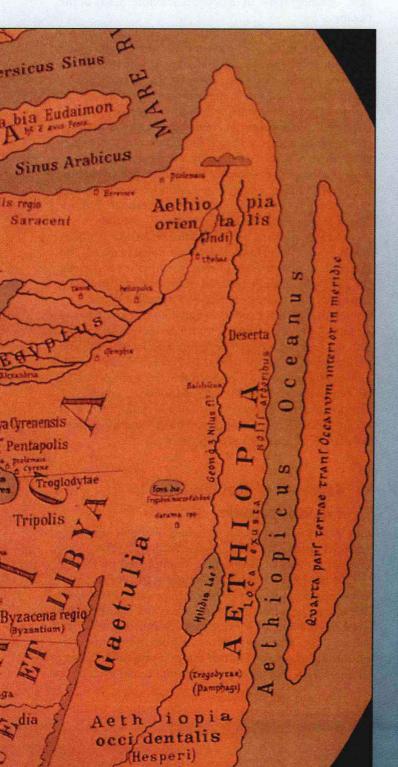
## The Oceans: An Overview

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Why upon your first voyage as a passenger, did you yourself feel such a mystical vibration, when first told that you and your ship were now out of sight of land? Why did the old Persians hold the sea holy? Why did the Greeks give it a separate deity, and make him the own brother of Jove? Sureley all this is not without meaning.

HERMAN MELVILLE, MOBY DICK





# The Growth of Oceanography

Oceanography: What Is It? Historical Review of Oceanography Future Oceanographic Research

#### PREVIEW

An historical account of oceanographic exploration and research is a massive undertaking. The record stretches back over several millenia to the time when ancient mariners constructed vessels and ventured boldly into the sea to explore the unknown. A brief sketch of this rich maritime history is needed in a book that deals with the physical, chemical, geological, and biological processes of the ocean in a scientifically rigorous manner.

The reason for this is that, first and foremost, it reminds us that people in the field of oceanography have always possessed an insatiable intellectual appetite for conquering the unknown and making it into the familiar. The world that is familiar to us today had to be investigated painstakingly by numerous seafarers throughout centuries of exploration. These people were lured by the unknown and by the opportunity to discover and unravel the mysteries of the earth and its seas.

Many details regarding the accomplishments of these earlier sea adventurers have been blurred by time. Yet we can still admire the courage and vision of these mariners as they strove, by slow increments, to replace ignorance and myth with knowledge. Today, the saga continues, as oceanographers (modern sea explorers) carry forward this quest as they strive to satisfy humankind's need to know about the earth's oceans.

As George Miller comments in his story "Oyster River" about discovery on the water, "Then what is the sense of owning a good boat if you hang around in home waters?" Let us embark on a voyage across the wet plains of the earth, away from home waters, using our good minds and good imaginations to search for and explore the private workings and imposing beauty of the oceans.

#### Oceanography: What Is It?

Before delving into the science of oceanography, we should have some clear sense of exactly what the word "oceanography" means. The term is coined from the Greek "Okeanos," meaning Oceanus, who was the Titan son of Uranus and Gaea and the father of the ocean nymphs (Oceanids). Eventually, "oceanus" was applied to the sea beyond the Pillars of Hercules, the North Atlantic Ocean. The Greek word "graphia" refers to the act of recording and describing. In some ways, the word oceanography does not appropriately describe the science of the seas. Scientists do much more than merely provide accounts of the oceans' physical, chemical, geological, and biological characteristics. Oceanographers investigate, interpret, and model all aspects of the ocean processes, using the most modern and sophisticated techniques of scientific and mathematical inquiry. As such, the term oceanology (derived from the root "ology," meaning "the science of") is etymologically

more accurate than "oceanography." The distinction between oceanography and oceanology is similar to that made between geography (the physical description of the world and its biota) and geology (the scientific study of the earth and its processes). However, the word "oceanology" has not displaced "oceanography" because the latter term is solidly entrenched in the minds of the laypeople as well as western practitioners of the science. Hence, I will follow convention throughout this book, using—and feeling very much at ease with—the expression "oceanography" to denote the scientific study of the oceans.

A common misconception is that oceanography is a pure science in its own right, practiced by women and men who are specifically and narrowly instructed in its investigative methods. The vast majority of oceanographers, in fact, are trained in one of the traditional sciences (physics, chemistry, biology, or geology) or a related field (engineering, meteorology, mathematics, statistics, or computer science) and choose to apply their research expertise to the study of the oceans. Hence, most oceanographers prepare for their careers by obtaining undergraduate training in a traditional science and then gaining experience conducting oceanographic research in graduate school or at a marine institute.

Oceans are vast physical domains. Their complex arrays of intertwined processes are coupled to events and materials in nonoceanic spheres, notably the solid earth, the atmosphere, and terrestrial environments. Therefore, marine studies commonly rely on a multidisciplinary approach that involves collaboration among many types of scientists. It is customary to subdivide oceanography into the four fields of physical, geological, chemical, and biological oceanography (Fig. 1–1); each of these fields embraces a number of subdisciplines as well. Although this breakdown is useful, the distinctions among the four broad areas can become quite blurry in practice, as illustrated by the fields of geochemistry and biochemistry and of geophysics and biophysics.

#### Historical Review of Oceanography

Our perception and understanding of the oceans have changed markedly over time. Although this book stresses the most current ideas championed by marine scientists, these attitudes and impressions did not suddenly appear out of an intellectual vacuum. They grew out of—and evolved from—the ideas and deductions of prior generations of ocean explorers and scientists. Reviewing the accomplishments of your predecessors is useful in many ways. For one thing, it places the present in a proper temporal perspective, reminding each of us