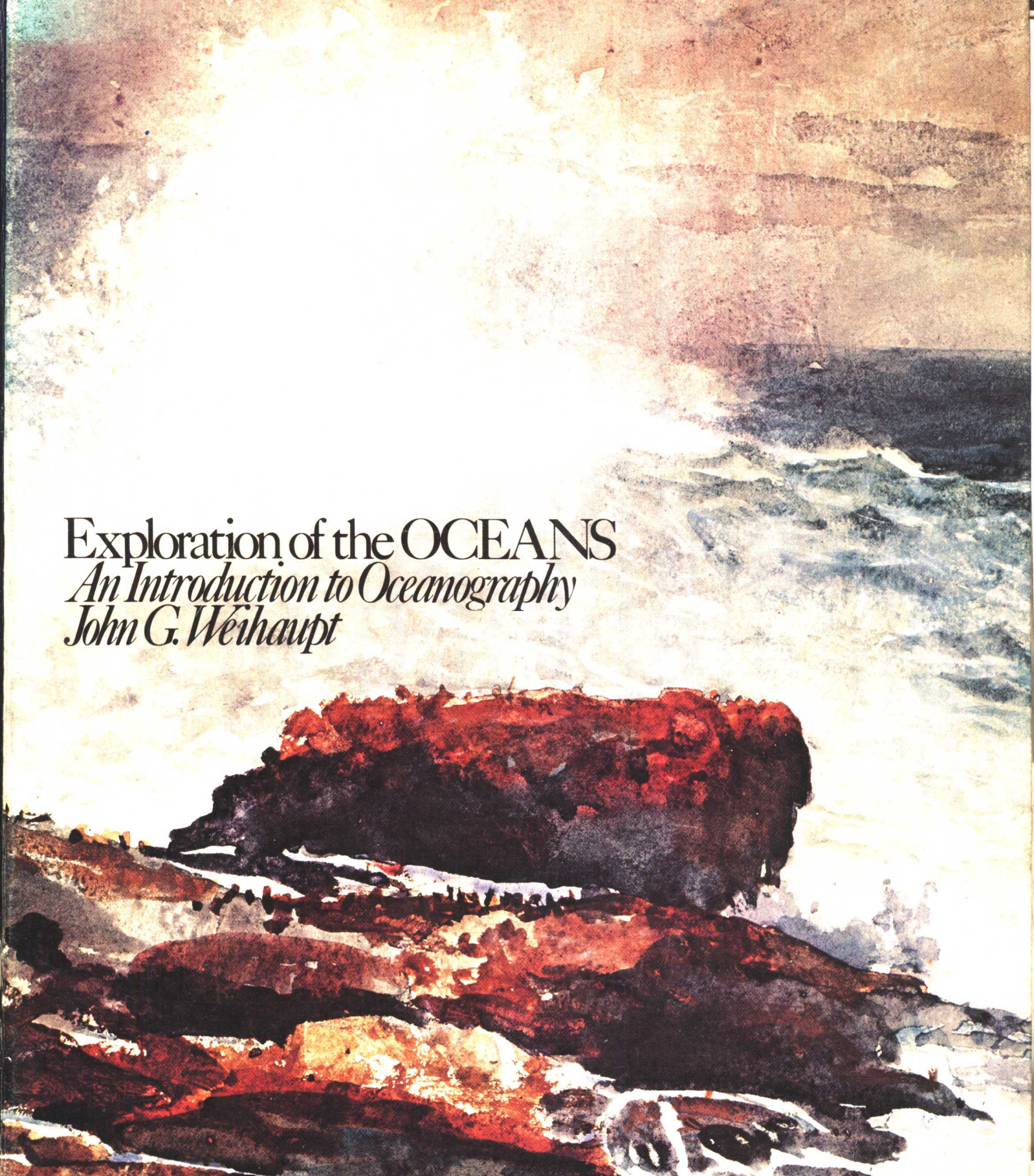

Exploration of the OCEANS

An Introduction to Oceanography

John G. Weihaupt

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Preface

Like all of nature, the sea is a vast and wonderful thing. Like all of science, the study of the oceans is a lesson in fascination.

For some, enchantment with science and nature emerges in childhood; for others, it is dependent upon time and the assimilation of fundamental knowledge. Contemporary science has evolved to its present form through the development and eventual merging of exclusive studies until, at present, almost all sciences have become mutually dependent in one way or another. One of the most multidisciplinary of the sciences is oceanography. As such, the study of the oceans offers challenge and opportunity to those who choose it as a profession; however, for others, oceanography provides a glimpse of the natural sciences and of the nature of the oceans as we know them today.

The preparation of this book was based upon the strong conviction that the subject of the oceans is one of almost universal interest, and upon the equally strong conviction that the elementary principles of oceanography can be successfully offered to the general college student at the early and middle undergraduate level. Furthermore, oceanography may be developed in its introductory aspects for both the general student and the beginning professional alike. Therefore, the book is designed to provide a broad, but comprehensive, introduction to oceanography. It assumes no previous knowledge of the subject, and presents descriptions, principles, and concepts in nontechnical language. Where technical terms are used, they are defined as introduced, and repeated once again in a glossary at the end of the book. The mathematics are minimal.

The treatment of topics is both descriptive and theoretical. Because the student must have a firm grasp of the physical nature of the oceans and of the tangible features that define it, these are provided before the related theoretical concepts are introduced. I have attempted to strike a proper balance between the descriptive and theoretical in this way, and to supplement theory by offering the more important supporting and contradictory evidence in each case. No firm answers are provided for the important unsolved problems in oceanography; rather, the

student is offered the alternative explanations along with the available evidence. The leading hypotheses are stressed, however.

Regarding the emphasis placed upon the various subdisciplines and discrete topics of the science, I have also attempted to maintain a balance insofar as that is possible. In a science as dynamic as oceanography, some branches have been investigated or developed to a greater extent than others. *Exploration of the Oceans* is divided into three main parts, and is designed for a one-semester or two-quarter course in general oceanography.

My approach has been to provide the reader with a view of the history and origin of the oceans in Part I. The physical setting of the oceans is introduced in chapters on marine geology and geophysics, where the student learns about the great ocean basins, their major features, and origin. Part II treats the water of the ocean basins, including such topics as its physical and chemical properties, oceanic circulation, and ocean-atmosphere interactions. Marine biology constitutes Part III of the book, which deals with the sea as a biological environment and describes the organisms that live in and near the water of the ocean basins. Marine biology constitutes something of a special case in that many volumes of descriptive literature have been produced since the *Challenger* Expedition. Therefore, only the broad features of the biologic environment are stressed along with a historical treatment of marine life from its ancient origins to the plankton, nekton, and benthos of today.

To my wife goes the greatest single measure of gratitude for her understanding, energy, and diligence in accomplishing so much of the administration attendant to this kind of undertaking, including typing of the entire original manuscript. It is to her and *The Wees* that this work is fondly dedicated. To Mrs. Carol Creasey, who labored long and loyally in the tasks prior to and during production, I am also immensely grateful.

I am also grateful to Dr. Robert W. Patenaude, University of Wisconsin—Madison, Dr. R. Gordon Pirie, University of Wisconsin—Milwaukee, and the reviewers selected by Macmillan who read the original manuscript and who made a variety of very helpful criticisms and suggestions.

Because occasional errors in both fact and composition are inescapable in such a publication, I shall be grateful to considerate colleagues who are kind enough to call these to my attention.

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There is, one knows not what
sweet mystery about the sea,
whose gently awful stirrings seem
to speak some hidden soul.
MELVILLE

Prologue

The History and Scope of Oceanography

The history of oceanography is a history of challenges, of successes, and of the evolution of man's thoughts about the marine world. The scope of oceanography encompasses—in one way or another—a vast number of the facets of the life of modern man.

The Early History of Oceanography

The study of oceanography is an old one. Long ago people looked at the sea and wondered. As they became more familiar with it, they learned. They studied the seasons of the sea for fishing and the currents of the sea for navigating. To very ancient observers the sea was huge and perplexing; to the more imaginative it was a living entity; still others saw it as the home of gods. People knew little of the depths, little of the details of these great water-filled basins and the vast assortment of life they hold. Yet there seems little doubt that in many of its aspects the sea was well known to these early observers.

The first evidence we have of scientific knowledge of the sea is contained in maps and ballads dating from about the tenth century B.C. By the eighth century B.C. ancient Phoenicia and the Hellenic civilization, through their seagoing commerce, had acquired a broad knowledge of the coasts of the Mediterranean Sea and of its currents and seasons. These people knew nothing of the scientific method, but, as a matter of course and in response to the practical matters of war and economics, their acquaintance with the marine environment grew.

Where it passed beyond the Straits of Gibraltar the sea was thought to wrap closely around the island continent to the south (Figure P-1). Herodotus (484–425 B.C.) considered the ocean to be a great ring that

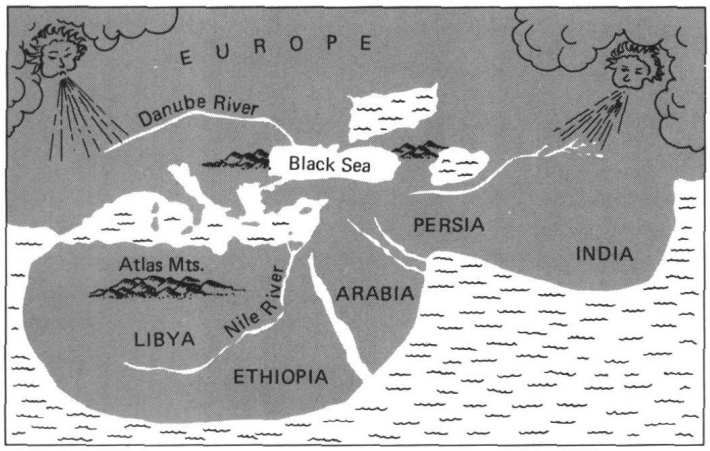


Figure P–1 The world of Herodotus (fifth century B.C.). (Courtesy Macmillan Publishing Company.)

surrounded the world, and in his writings he spoke of the spherical shape of the earth. Although he was correct in this, Herodotus was deceived, like most of the Greek scholars, by his great love of symmetry. Reports of mariners and his own understanding of the world caused him to draw a map (Figure P-1) on which such features as the Nile appear symmetrical with others, such as the Danube.

Aristotle traveled to Athens in the fourth century B.C. where, at the age of seventeen, he joined Plato's academy to learn from the master. Aristotle's main love was biology, which accounts for his meticulous observation and classification of animal species, particularly those of the sea. He was the first, for example, to note that the dolphin brought forth its young alive. He therefore correctly classed it not with fish, but with the creatures of the land. In his study of the habitats and hierarchy of living things, he constantly skirted the philosophy of organic evolution. However, it was more than 2,000 years later that Charles Darwin finally accomplished what Aristotle had begun.

By the third century B.C. the Hellenistic view of the world ocean and the land world had become somewhat more refined and detailed (Figure P-2), although it still remained very incomplete. Eratosthenes (276–194 B.C.) was the first to construct a map of the known world with grid lines of latitude and longitude so that locations could be identified. Eratosthenes's lines of latitude and longitude were not equally spaced and were not numbered; instead they were drawn so that they passed through places of importance and they were identified by these names (for example, the longitude of the pillars of Hercules and the meridian of Alexandria). Eratosthenes also acknowledged the spherical shape of the earth and was the first to calculate its approximate size (page 22).

In the second century B.C. the philosophy of science was pursued by Poseidonius (135–50 B.C.) of Apamea, Syria, a Stoic philosopher who had great influence upon the Romans, including Cicero. Like Pytheas (about 325 B.C.), Poseidonius recognized the moon as the source of

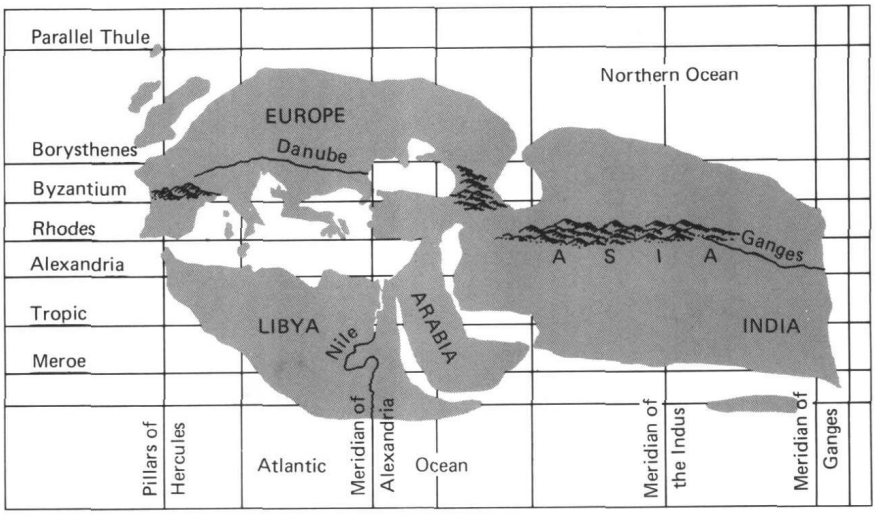


Figure P–2 The world of Eratosthenes (*third century* B.C.). (Courtesy Macmillan Publishing Company.)

tides in the sea and was able to correlate the tides and phases of the moon. Much of his importance stems from the erroneous calculations of the earth's circumference, however, which he computed to be about 72% of the nearly correct value determined by Eratosthenes.

By the first century A.D. the limits of the world ocean had been pushed farther from the heart of the ancient world with the discovery of land contiguous to but beyond the civilization of the Greeks and Romans. The limits of Europe were by now broadly defined, and the land of Africa and Asia was known to extend far beyond its earlier imagined limits (Figure P-3). The world of Ptolemy (A.D. 107–170) was much larger than that of Eratosthenes, and the world ocean was somewhat smaller and in some respects more remote. A Greek astronomer born in Egypt, Ptolemy produced the first atlas of maps ever made. Un-

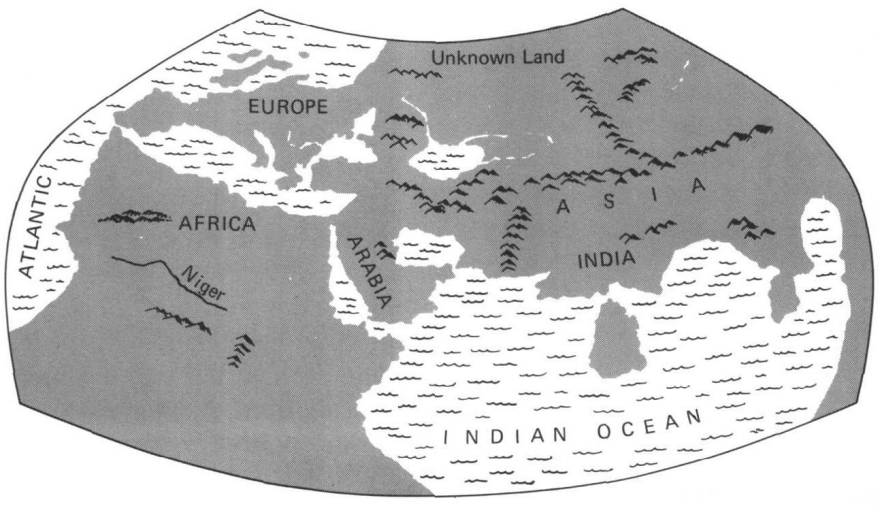


Figure P–3 The world of Ptolemy (second century B.C.). (Courtesy Macmillan Publishing Company.)

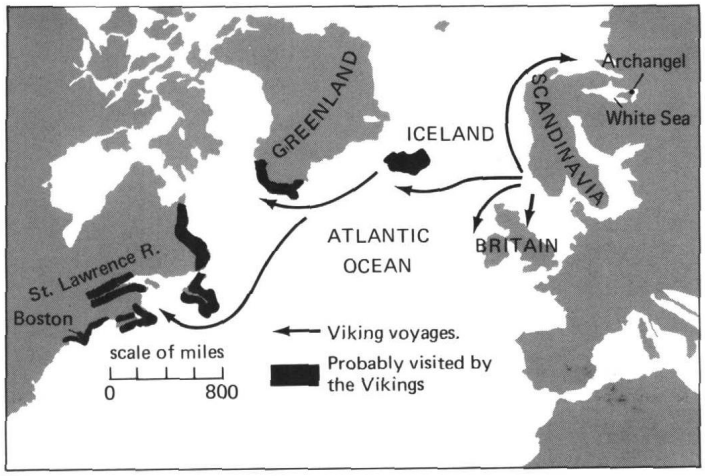


Figure P–4 Regions thought to have been discovered by the Vikings.

fortunately, he had been taught Poseidonius's incorrect circumference of the earth by his teacher Marinus rather than Eratosthenes' correct value; thus, the length of Ptolemy's degree at the equator was in error by about 20%. For this reason many of his locations and distances were inaccurate. However, he was the first to show that, like the Mediterranean Sea, the Indian Ocean was surrounded on many sides by land. His work suggested, furthermore, that it was enclosed to the south, thus confusing early European sailors who never found land south of the Indian Ocean. But with Ptolemy's death the science of the Greeks also died. The cloak of stagnation began to fall; the Romans reverted to an earth flat from horizon to horizon; and through the dark and middle ages science slumbered.

This period brought almost total neglect of the early works that were the foundations for intellectual scientific thought. Except for the largely unrecorded discoveries of the Vikings (A.D. 700–1000; Figure P-4), progress related to the oceans ceased because of scriptural interpretations of the world. The dethronement of dogma, particularly sacred dogma, is very difficult. Consequently intellectual progress in science remained dormant until the years following the tenth and eleventh centuries.

In the twelfth century a reawakening of intellectual activity caused the rediscovery of the works of such men as Aristotle and Ptolemy, and at the end of the thirteenth century the spirit of exploration, science, and interest in the oceans was rekindled. The Genoese brothers Ugolino and Vadino Vivaldi sailed through the Straits of Gibraltar in 1291 in the hope of reaching India. Although they did not return, the era of discovery had begun. The medieval conception of the world ocean was more detailed but still incomplete (Figure P-5) and did not differ essentially from that suggested by Ptolemy. It was with a copy of some version of Ptolemy's maps and in the belief that the earth was only 29,000 kilometers (km) or 18,000 miles (mi) in circumference that

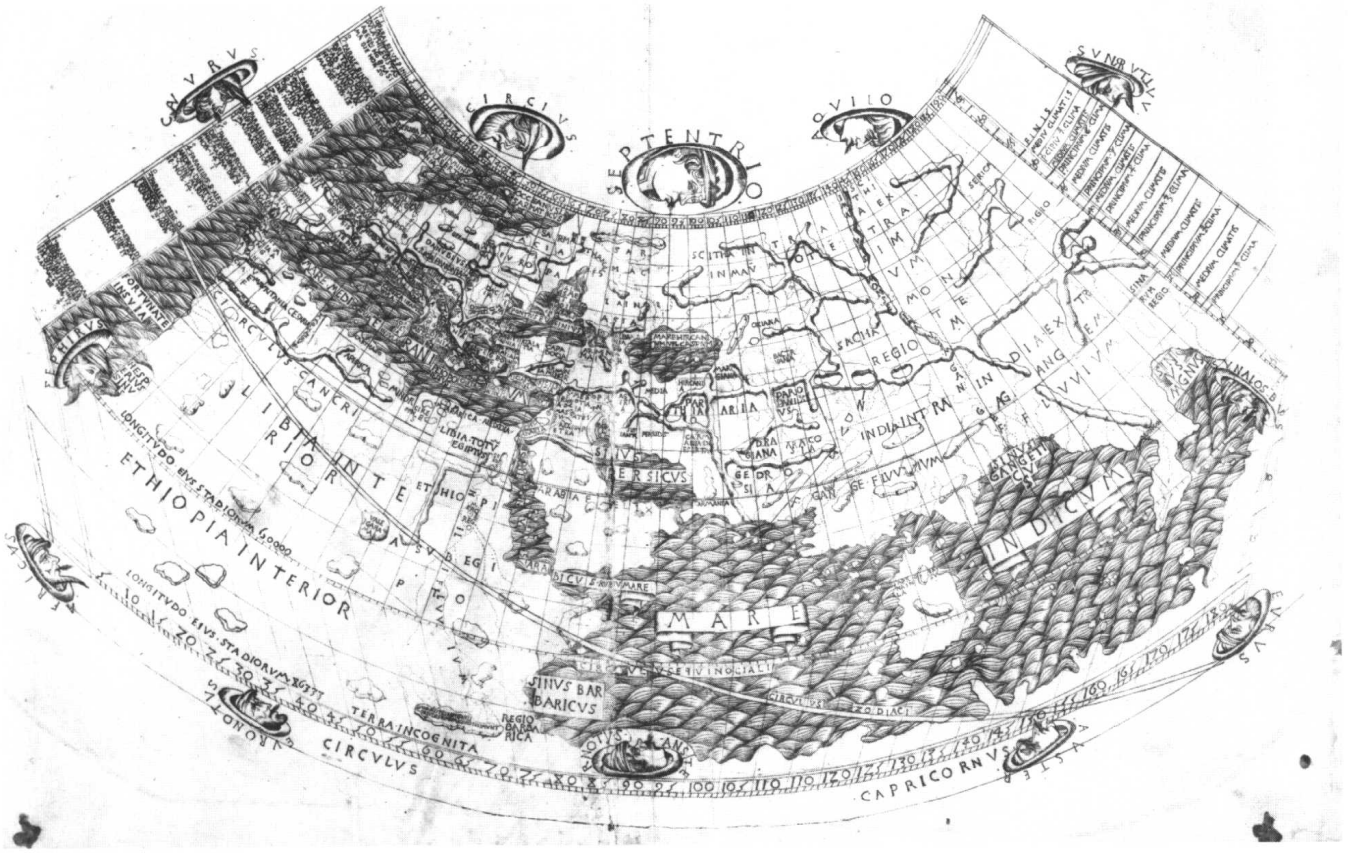


Figure P–5 The medieval world (first through fifteenth centuries). (Courtesy the Pierpont Morgan Library, 33 East Thirty-sixth Street, New York.)

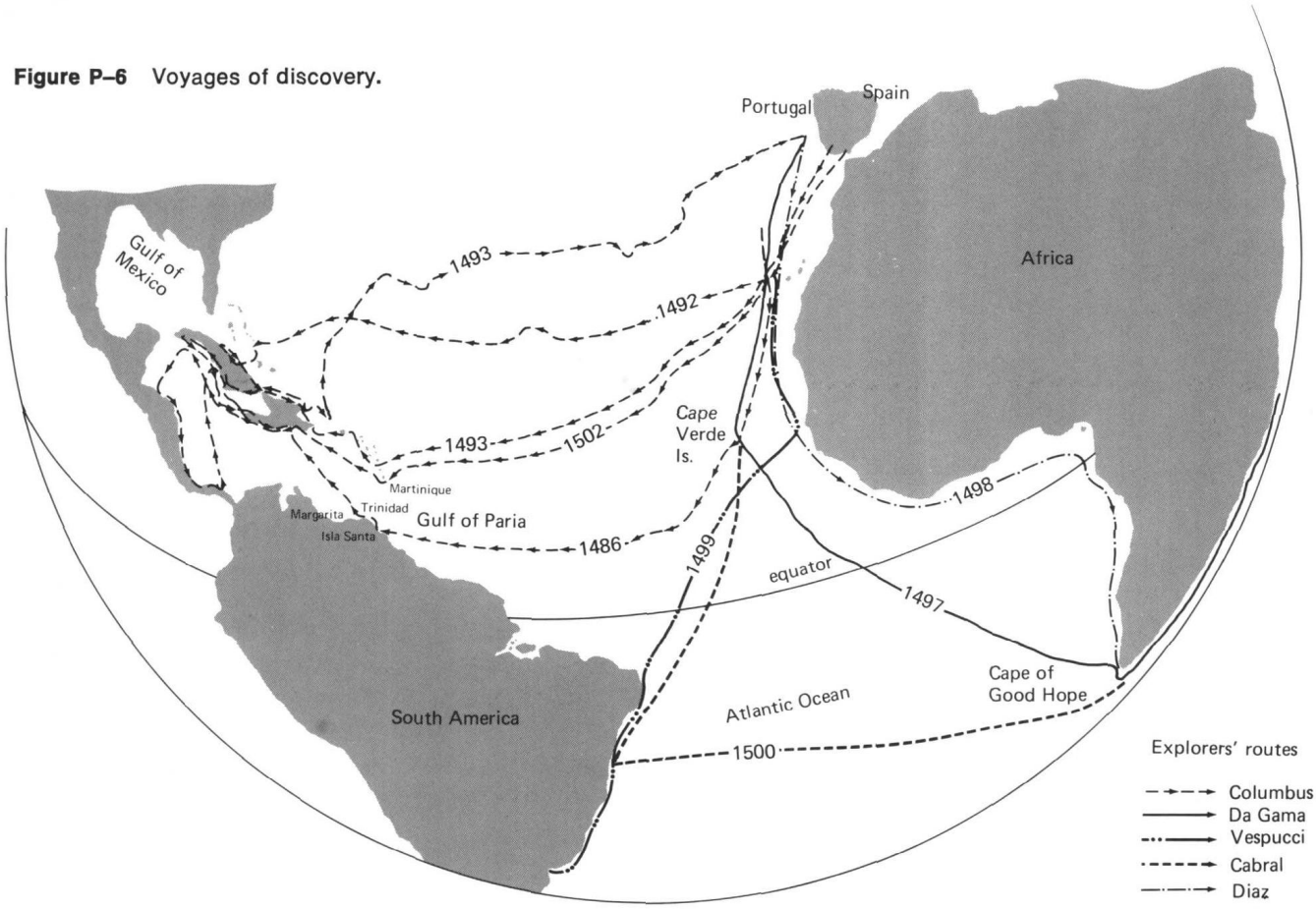
Columbus was encouraged to sail west in search of India. Had he known the true size of the earth, as calculated by Eratosthenes, it is almost certain he would not have undertaken that first voyage of discovery.

The Age of Discovery

The oceanography of the ancients was restricted largely to the Mediterranean Sea. However, the new age of discovery, ushered in by the Vivaldis, was a period entirely different from that of the Greeks and Egyptians. In contrast to the detailed examination and cataloging of species of marine animals by Aristotle, the period of discovery was marked by the expeditions of sailing ships to all of the major oceans of the world. It was a time of geographic discovery, and the products were maps and reports of new worlds. Little attention was given to the biology of these oceans or the scientific aspects of what these explorers found.

One of the first important voyages was the rounding of the Cape of Good Hope from the west by Bartholomew Diaz in 1487. Then followed the four voyages of discovery by Christopher Columbus, the first in 1492 with his crossing of the Atlantic Ocean to the Bahamas, and thence to Cuba and Hispaniola. His later crossings in 1493, 1498, and

Figure P–6 Voyages of discovery.



1502 (Figure P-6) widened his geographic discoveries of what he thought were the lands of Cathay until his death in 1506.

In 1499 and 1501 Amerigo Vespucci sailed southwest from Cadiz, and following Pedro Alvares Cabral's discovery of Brazil in 1500, identified the new land of the Western Hemisphere as continental in nature. These discoveries were accompanied by others of geographic importance, such as Vasco da Gama's journey south around the Cape of Good Hope to India, followed by the discovery in 1513 of the Pacific Ocean by Balboa on his expedition from the Spanish settlement at Darien across the Isthmus of Panama. In the same year Ponce de Leon reported the discovery of the Florida Current portion of the Gulf Stream. By this time interest in the New World had stimulated others to sail west. Magellan in 1520 and 1521 inspired and was responsible for the first crossing of the Pacific Ocean and circumnavigation of the globe, which were completed in 1522, although Magellan died in the Phillipines before the end of the voyage. He is perhaps the first to try to sound the depths of the Pacific Ocean. Using hand lines 365 meters

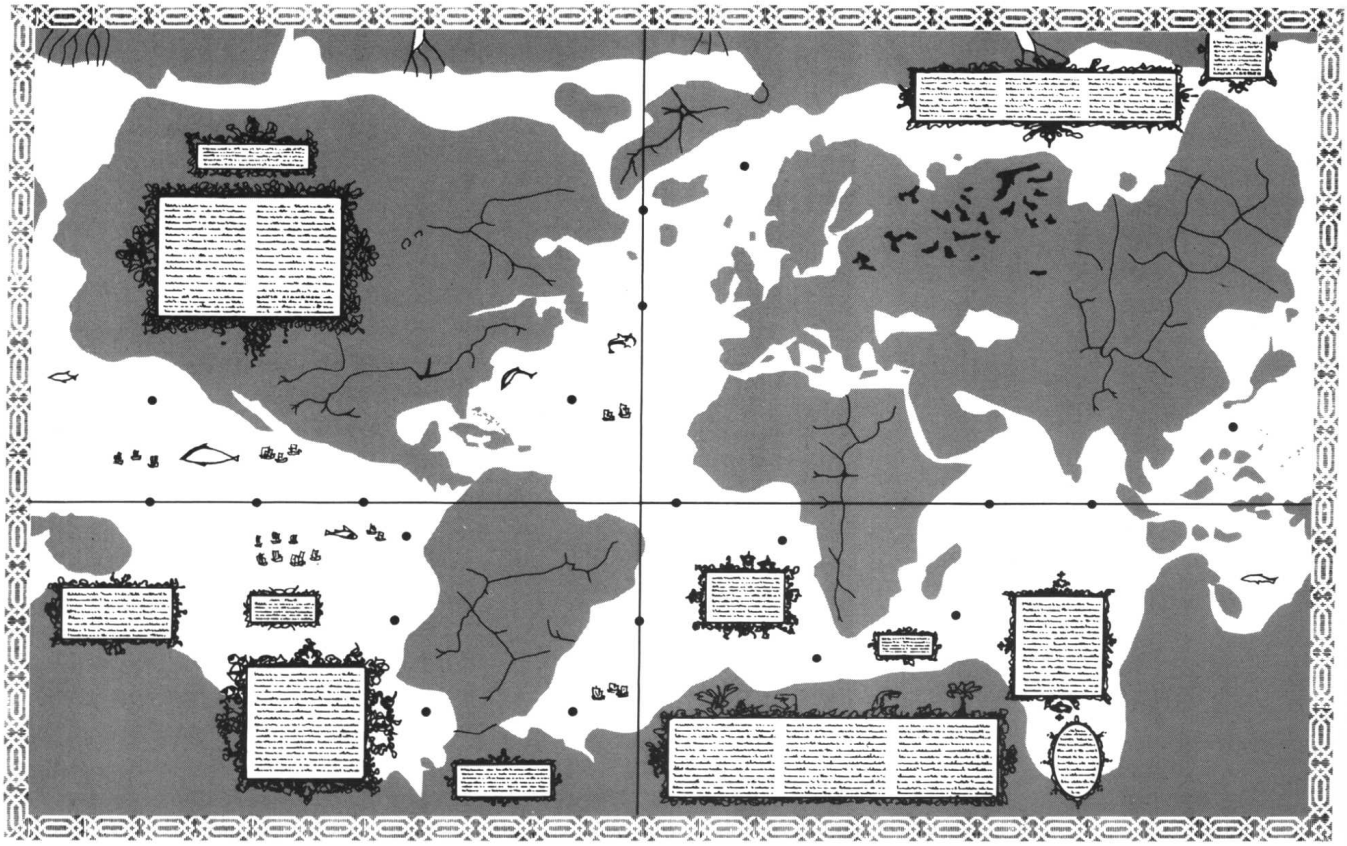


Figure P–7 The world of Mercator (sixteenth century). (Courtesy of the Map Division, The New York Public Library. Astor, Lenox, and Tilden Foundations.)

(m) or 1200 feet (ft) long, he failed to reach the bottom, which was shown much later to be more like 3650 m (12,000 ft) deep.

In spite of Magellan's rounding Cape Horn, in 1569 Mercator's map of the world (Figure P-7) showed a continuous land mass from the top of North America to the Antarctic, with a narrow passage at the end of South America. This view of the world ocean and its island continents was far different, however, from that of the mid-fifteenth century (Figure P-5), which was derived from the works of Ptolemy.

In the latter half of the sixteenth century the emphasis of exploration on the high seas shifted. The search for a northwest passage to the Orient had begun. During the years 1576–1578, Sir Martin Frobisher sought a route from the Atlantic Ocean westward in the Northern Hemisphere. He was followed in 1585–1587 by Davis, and in the early part of the next century by Hudson and Baffin, much later by Bering, Cook, Ross, Parry, Franklin, and finally by McClure, who is credited with a successful passage in 1853.

The continuation of the age of discovery did not end with Frobisher