Essentials of Oceanography

EDITION

THURMAN

ESSENTIALS OF OCEANOGRAPHY

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PREFACE

Essentials of Oceanography was initially written to provide for the needs of general oceanography courses in quarter-system colleges and community colleges. It contained eighteen chapters covering the full breadth of topics usually covered in such a course.

Because the book was very well received, we have made few changes in the content for this second edition. We have clarified the content wherever possible to help the reader. For example, all entries for distance, temperature, pressure, and rates of motion were given in metric units in the first edition. British equivalents have been added parenthetically in the second edition. All of the topics have been updated to reflect the latest knowledge, and much attention has been given to improving illustrations and passages in the text that were not as clear as they could have been.

A short introduction has been added to give students a feel for the marine problems facing us, and to explain what I hope they may gain from taking a course in oceanography.

Chapters 1 and 2 have been reversed so that "History of Oceanography" now precedes "The Origin of the Earth, Its Oceans, and Life in the Oceans."

Chapter 3, "Marine Provinces," is a short discussion that provides a framework for the presentation of plate tectonics in chapter 4 and marine sediments in chapter 5.

The study of physical oceanography begins with chapter 6, "The Nature of Water," summarizing these properties in table 6–1 for those who do not wish to consider them in depth, but also providing an in-depth discussion of each property. Physical phenomena are discussed in the following chapters: 7, "Air-Sea Interaction," 8, "Ocean Circulation," 9, "Waves," and 10, "Tides." The boundary between land and sea is discussed in chapters 11, "The Shore," and 12, "The Coastal Ocean."

Marine biology is first considered in chapter 13, "The Marine Environment," which provides an ecological overview. Chapter 14, "Biological Productivity—Energy Transfer," introduces marine algae and continues the discussion of broad ecological concepts related to biological energy transfer.

An ecological presentation of the variety of marine life is contained in chapters 15, "Life in the Open Ocean," and 16, "Life on the Ocean Floor." These chapters are in reverse of what they were in the first edition because many believed that it is more logical to discuss the pelagic organisms before the benthos. For those wishing to discuss the taxonomic relationships among phyla, a phylogenetic tree with a brief discussion of relationships is provided in figure 14–2, and a more complete listing of taxonomy is presented in appendix V.

Finally, the practical problems resulting from human interaction with the ocean are covered in chapters 17, "Food from the Sea," and 18, "Marine Pollution."

I wish to express my gratitude to the following persons for reviewing the text and illustrations during the development of the second edition: Laurie Brown of the University of Massachusetts at Amherst; Tom S. Garrison of Orange Coast College; Charles Ebert of the State University of New York at Buffalo; Bernard W. Pipkin of the University of Southern California; Donald G. Klim of the University of Hawaii, Leeward Community College; and James C. Kelley of San Francisco State University. They made many valuable suggestions for the improvement of the text and illustrations.

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INTRODUCTION

We hope the world will be a better place for our having been here. As good world citizens we have that responsibility. If you approach the study of the oceans with such a goal in mind, I'm sure the oceans and the world will benefit from your presence.

When I first began writing texts in the early 1970s, I wanted to help students develop an appreciation for the oceans by learning about oceanic processes, both physical and biological. I think now that in the 1980s appreciation means an ecological awareness. Some of you may even find a life-long interest in the ocean and continue to study it formally or informally.

I'd like to impart to you what I feel are the basic facts behind oceanic science. First, the physical nature of the ocean and its life forms are dramatically interrelated, a mystery that we are only now beginning to unravel. Second, people are migrating to the coasts, and this trend will have a negative impact on coastal ecology. Third, our technology can be used to increase the threat to our oceans or lessen lethal damage, as we dictate.

INTERRELATIONSHIPS OF THE OCEAN

Let me begin discussing these concerns by saying that since prehistoric times, people have used the ocean as a means of transportation and as a source of food, but the importance of its processes has been studied technically only since 1930. The impetus for this study began then in a search for petroleum, continued with the emphasis on ocean warfare during World War II, and more recently has been expressed in the concern for ocean ecology. Of course, fishermen have always known to go where the physical processes of the ocean offer good fishing. But how life interrelates with ocean chemistry, geology, and physics was more or less a mystery until scientists in these disciplines began to look at the ocean and use high technology.

For example, a group of geologists investigating global plate tectonics decided in 1977 to research hot water anomalies in the deep eastern Pacific Ocean. (The process of tectonics, confirmed in 1968, involves the creation of new ocean floor along underwater mountain ranges.) When they searched the hot water vents along a range, they discovered many large tube worms, clams, mussels, and crabs. Normally the ocean floor supports relatively few, small forms of life because there isn't much food. But the vents provided energy for bacteria to support abundant life. This is a striking example of how the physical nature of the ocean determines the distribution of life within it.

Scientists have always been interested in how the atmosphere and the water affect each other. Our present technology uses satellites to view ocean circulation and life distribution. Within the next decade we will be gathering data from every ocean, every day. Such simultaneous data will show how the water reacts to wind speed and air temperature and how the air responds to oceanic changes.

POPULATION IMPACTS ON COASTAL ECOLOGY AND THE OPEN OCEAN

Population studies now show that by 1990 three-fourths of all Americans will live within 80 kilometers (50 miles) of the coast or the Great Lakes. This migration to the coasts will further mar a delicate balance between the ocean and the shore, resulting in more harbor and channel dredging; sea disposal of sewage, industrial waste, and dredge spoils; the use of ocean water for cooling of power plants and industries; and the filling in of marshes. But the marshes are vital to the cleansing of runoff waters and the maintenance of coastal fisheries. In the open ocean, deep ocean mining and nuclear waste disposal are planned. How do we deal with the increased demands on the environment; how do we regulate the ocean's use?

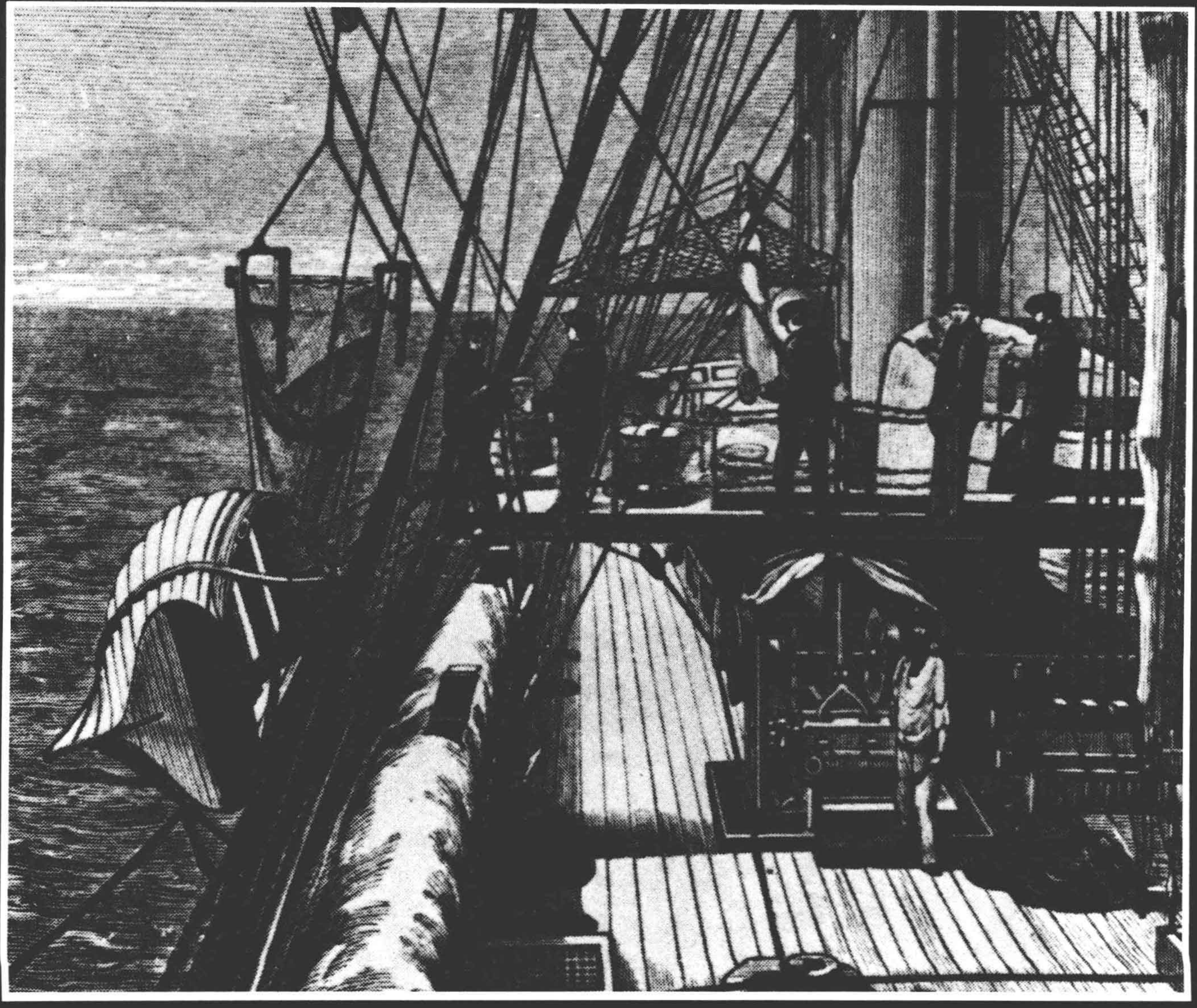
Further, the National Academy of Sciences in 1980 predicted a rise in sea level. Even considering present erosion and deposition, geologists would like to have us move back from the shore as much as possible and leave it to nature. Engineers, on the other hand, say any coastal region can be stabilized for the lifetime of a development; in that case much public money will be spent stabilizing the coastal property of a few. Perhaps if the sea level does rise, engineers will be too busy protecting present development and will abandon plans to develop new areas!

RATIONAL USE OF TECHNOLOGY

We look at these issues and see a cause for concern, but certainly not despair. We have a vast resource that hasn't yet been lethally damaged. We have been able to inflict only minor damage here and there along its margin. But as our technology makes us more powerful, the threat of irreversible harm becomes greater—or less, depending on how we use our tools.

Which path will we take? All of you will need to evaluate carefully those you elect to public office, and some of you will have direct responsibility for making the decisions that affect our environment. It is my hope that you, as a new student of the marine environment, will gain enough knowledge from your teacher and this course to help our nation make rational use of the oceans in your lifetime.

CHAPTER ONE



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CONTENTS

HISTORY OF OCEANOGRAPHY

With each passing year, human interaction with the ocean increases. The fishing effort is stepped up, and the search for petroleum and minerals intensifies. With this increasing rate of ocean exploitation, we are obliged to increase our knowledge of its effect on the marine environment. The following is a summary of events that have brought us to our present state of knowledge and a discussion of how the pressing need for increased knowledge of the oceans may be met through the application of newly developed technology.

THE CONCEPT OF GEOGRAPHY DEVELOPS

Early History

If human beings evolved in Africa some two million years ago, as present evidence indicates, it is obvious that the vast extent of the ocean was no barrier to their movement from this early home to all parts of the habitable world. When the European explorers set out at the end of the 15th century to see what lay beyond the horizon, they discovered that cultures unknown to them had preceded them to many of these far-off places, from Tierra del Fuego in the south to the island of Greenland in the north. Explorers found that not only were the newly discovered continents of the world inhabited, but also the small islands in the Pacific Ocean separated from the mainlands by perhaps thousands of kilometers of ocean expanse. We know little of how the inhabitants reached these islands or by what routes their migrations were made. However, they surely did arrive on the islands by traveling across the ocean.

From the *Challenger* report, Great Britain, 1895.

In the islands of Micronesia, stick charts were found that indicated the relative position of the islands within the known environment of the native population. These charts served as maps of the region with which the people were familiar. The inhabitants of the Pacific islands obviously had a complete knowledge of the distribution of islands within their immediate environment, and they had an oral tradition, often mythical, that explained how their ancestors had arrived from distant points of origin. This type of knowledge was typical of that existing among inhabitants of the entire world prior to voyages of discovery initiated near the end of the 15th century.

Humankind probably first viewed the ocean as a source of food. At some later stage in the development of civilization, vessels were built to move upon the ocean's surface, thereby making it a wide avenue over which distant societies could begin to interact.

The first westerners that developed the art of navigation were the Phoenicians, who as long ago as 2000 B.C. were investigating the Mediterranean Sea, the Red Sea, and the Indian Ocean. The Phoenicians established trade with the eastern cultures of Southeast Asia and discovered the Canary Islands. The first recorded circumnavigation of Africa in 590 B.C. was made by the Phoenicians, who had also sailed as far north along the European coast as Great Britain.

Contributions of the Greeks

The world as it was viewed by the Greeks is presented for us on a map constructed in 450 B.C. by the geographer Herodotus in which he depicts the Greek civilization centered around the Mediterranean Sea (figure 1–1). To the north, east, and south lie the three continents—Europe, Asia, and Libya—bordered by three major seas—Mare Atlanticum to the west, Mare Australis

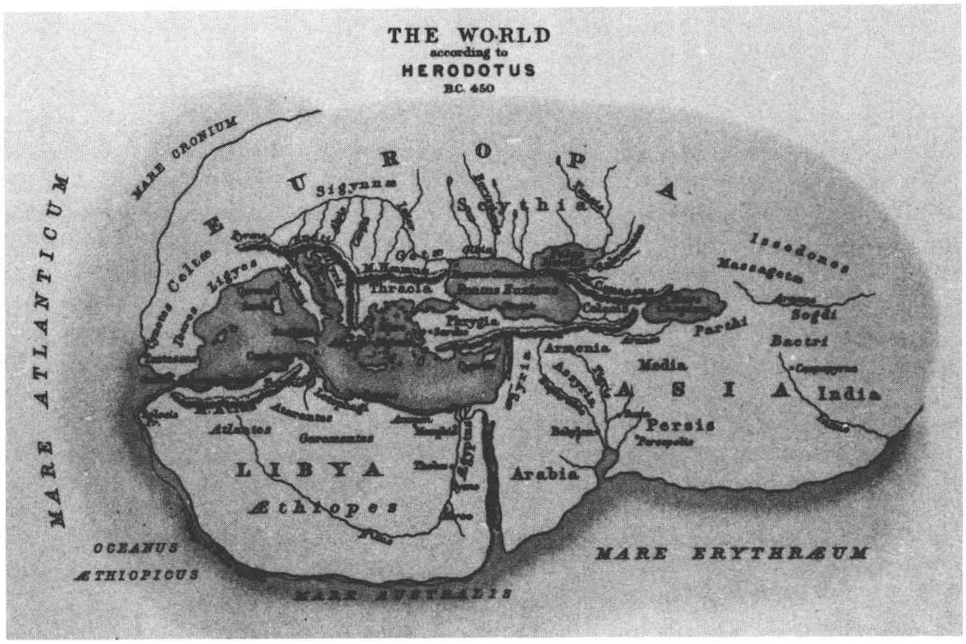


FIGURE 1–1 **The World of Herodotus.**
The world according to Herodotus, 450 B.C. (from *Challenger* report, Great Britain, 1895).

to the south, and Mare Erythraeum to the southeast. The north and northeastern margins of the continents of Europe and Asia are indicated as unknown, but the Greeks believed that the oceans represented a margin of water that surrounded all three continents.

The Greek astronomer-geographer Pytheas sailed northward to Iceland in 325 B.C. and worked out a simple method for determining latitude which involved measuring the angle between the lines of sight from an observer to the North Star and the northern horizon. Using astronomical measurements, he also proposed that the tides were a product of lunar influence.

Eratosthenes (276–192 B.C.), a librarian at Alexandria, was the first known determiner of the world's circumference. He discovered that during the summer solstice, the time when the sun is directly overhead at the Tropic of Cancer, the sun was at zenith over Syene (now called Aswan). Eratosthenes observed that a vertical well in Syene was totally illuminated at noon on the day of the solstice and made the following assumptions (figure 1–2):

1. Due to the great distance existing between the earth and the sun, the sun's rays falling on both Syene and Alexandria to the north could be considered as parallel.
2. The distance between Alexandria and Syene was 5000 stadia, 1 stadium equalling approximately 0.16 km (0.1 mi).
3. Alexandria and Syene lay on a north-south line, a *meridian,* perpendicular to the equator.

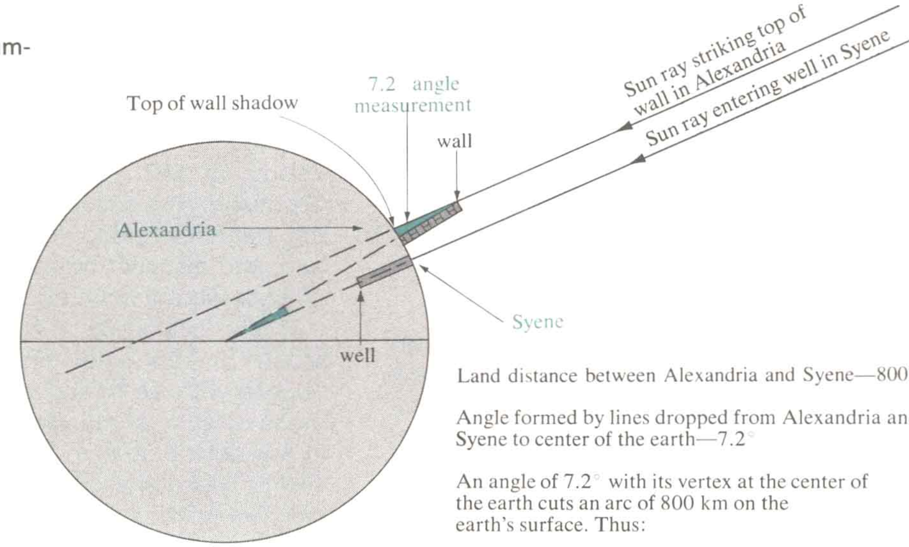
With these three assumptions and the knowledge that a straight line intersecting two parallel lines creates corresponding angles that are equal, Eratosthenes was prepared to measure the circumference of the planet on which he lived.

By observing the shadow of a vertical wall in Alexandria at noon on the day of the summer solstice, Eratosthenes could measure the angle defined by a line connecting the top of the wall and the top of the wall's shadow on the earth's surface. This angle was measured as 7.2°. The meridian on which he had assumed Syene and Alexandria lay could, of course, be continued in a full circle around the surface of the earth. The circle would contain a total of 360°. The corresponding angle to the one that Eratosthenes measured is the angle defined at the center of the earth by extending a line along the wall's surface to that point where it intersected the sun's ray that passed through Syene. Since 7.2° represents one-fiftieth of the number of degrees that are contained within a full circle, the distance defined along the circumference of the circle by an angle of 7.2° must be one-fiftieth of the total circumference of the earth. Therefore, if 5000 stadia represent 800 km (500 mi), the circumference of the earth is 40,000 km (24,840 mi). This figure compares very well with the 40,032 km (24,875 mi) meridional circumference determined by the more precise methods in use today.

Contributions of the Romans

Two Roman contemporaries of Jesus Christ, one a geographer named Strabo (63 B.C.–A.D. 24) and the

FIGURE 1–2 Eratosthenes' Determination of the Circumference of the Earth.



Land distance between Alexandria and Syene—800 km (500 mi)

Angle formed by lines dropped from Alexandria and Syene to center of the earth—7.2°

An angle of 7.2° with its vertex at the center of the earth cuts an arc of 800 km on the earth's surface. Thus:

$$\frac{7.2^\circ}{800 \text{ km } (500 \text{ mi})} = \frac{360^\circ}{\text{Circumference of the earth}}$$

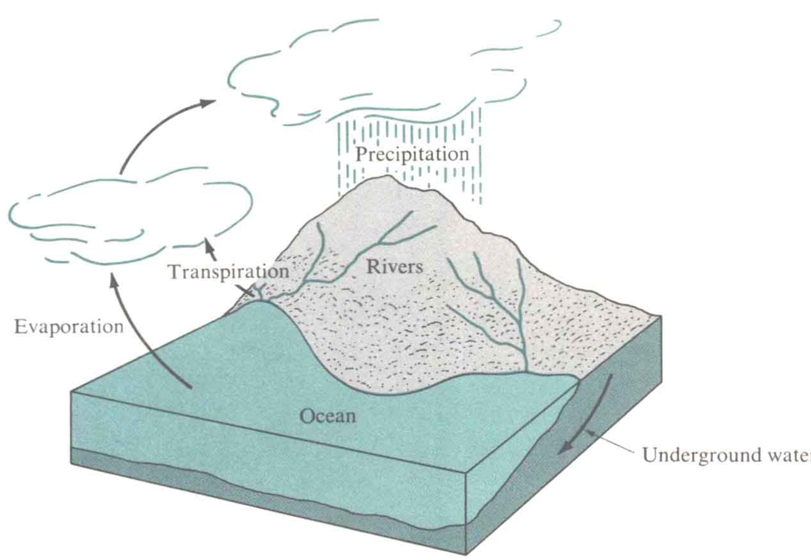
Circumference of the earth = 40,000 km (24,840 mi)

other a rhetorician named Seneca (54 B.C.–A.D. 30), added greatly to our understanding of the world upon which we live. Strabo had observed the volcanic activity that is characteristic of the Mediterranean area and concluded that, as a result of this activity, the land periodically sank and rose, causing the sea to invade and then recede from the continents. He further observed that the rivers flowing across the continent erode material from the surface and transport it to the oceans.

Seneca introduced the concept of the *hydrologic cycle* (figure 1–3), part of which is the flow of the rivers into the oceans. He explained that the level of the oceans did not rise as a result of the continual inflow provided by the rivers because of the process of evaporation of water as water vapor into the atmosphere. Some of this vapor is transported over the continents, where it condenses and is released as precipitation onto the continents from where it returns as runoff to the oceans.

In approximately A.D. 150, Ptolemy produced a map of the world that represented the Roman knowledge at that time. He introduced lines of longitude and latitude on his map. Mariners could determine the latitude of any point on the surface of the earth using the method

FIGURE 1–3 The Hydrologic Cycle.
Evaporation and plant transpiration send water vapor into the atmosphere. The vapor condenses and returns to the earth's surface as precipitation. That which falls onto the land is evaporated, runs to the oceans through river systems, or soaks into the ground to become underground water.



introduced by Pytheas, but it was impossible for them to accurately determine longitude. Ptolemy's map indicated, as did the earlier Greek maps, the continents of Europe, Asia, and Africa, and showed the Indian Ocean to be surrounded by a partly unknown landmass. All oceanic bodies were generally considered to be seas similar to the Mediterranean, having boundaries defined by unknown landmasses.

The Middle Ages

After the fall of the Roman Empire the Mediterranean area was dominated by Arab influence, and the writings of the Greeks and Romans passed into the hands of the Arabs to be forgotten by the Christians in Europe. Subsequently, the Western concept of geography degenerated considerably, and one notion envisioned the world as a disc with Jerusalem at the center.

The post–Roman Empire concept of geography, as held by much of the Western world, is represented by the map of the 6th century navigator Cosmas (figure 1–4). His map depicts the earth as a rectangle measuring 20,000 km (12,420 mi) by 10,000 km (6,210 mi).

The Arabs, meanwhile, were trading extensively with east Africa, Southeast Asia, and India and had learned the secret of the monsoons. They took advantage of these winds, making their trade voyages easier. During the summer seasons when the monsoon winds blew from the southwest, ships laden with goods for trade would leave the Arabian ports and sail eastward across the Indian Ocean. The return voyage would be timed to take advantage of the northeasterly trade winds that occurred during the winter season, making the transit relatively simple for their sailing vessels.

In Europe, the nautical inactivity of the southern Europeans was offset by the vigorous exploration of the Vikings of Scandinavia. Late in the 9th century, unshackled by considerations of Christian theology and aided by a period of climatic warming, the Vikings conquered Iceland. In 982 Eric the Red sailed westward from Greenland and discovered Baffin Island. In 995 Eric's son, Leif Ericson, discovered what was then called Vineland, and he spent the winter in that portion of North America we call Newfoundland.

By the beginning of the 13th century, the climate began to cool and the northern Atlantic became clogged with ice throughout most of the year, leading to the isolation of the Viking colonies in Greenland. Due to this deterioration in climate, the explorations of the Vikings were curtailed, and they were unable to exploit their newly discovered territories.

Age of Discovery

During the thirty-year period from 1492 to 1522, known as the Age of Discovery, the Western world came to a full realization of the vastness of the earth's water-covered surface. The continents of North and South America were "discovered." The globe was circumnavigated, and it was learned that human populations existed elsewhere in the world. Human cultures were found throughout the newly discovered continents and islands, although they were vastly different from those with which the voyagers were familiar.

Precipitating these voyages was the capture of Constantinople, the capital of eastern Christendom, in 1453 by Sultan Mohammed II. This event isolated the Mediterranean ports from the riches of the East Indies and

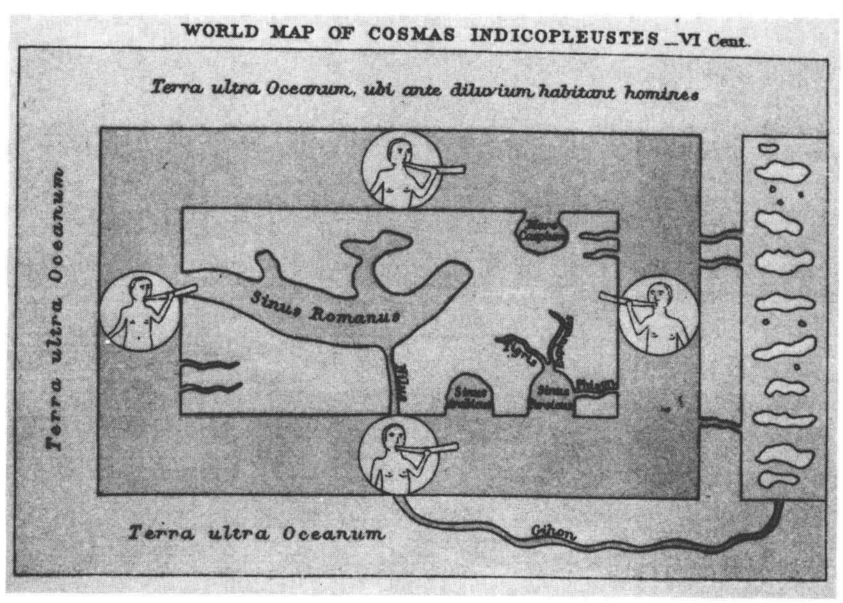


FIGURE 1–4 **The World of Cosmas.**
The map of Cosmas Indicopleustes shows how the southern European concept of the world had deteriorated by the sixth century (from *Challenger* report, Great Britain, 1895).

caused the Western world to search for a new trading route to this area. As a result of the Arab occupation of Constantinople, the ancient knowledge of the Greeks and Romans was carried out of that city and became available to the powers of southern Europe who were interested in reestablishing trade connections with the East Indies.

Prince Henry, "the Navigator" of Portugal, had established a marine observatory to improve the Portuguese sailing skills, but its attempts to reestablish trade by ocean routes met with failure for years.

One of the greatest obstacles to an alternate trade route was the need to travel around the tip of Africa. Cape Agulhas was finally rounded by Bartholomeu Diaz in 1486. He was followed in 1498 by Vasco da Gama, who continued his trip around the tip of Africa to India.

The idea for a voyage such as the one Columbus undertook was initiated by the Florentine astronomer Toscanelli. He wrote to the king of Portugal, suggesting that a course be charted to the west in an attempt to reach the East Indies by crossing the Atlantic Ocean. Columbus later contacted Toscanelli and was given a copy of the information indicating that India could be reached at a distance that would have carried him just west of the continent of North America.

After his well-known difficulties in originating the voyage, Columbus set sail with 88 men and three ships August 3, 1492, from the Canary Islands. During the morning of October 12, 1492, the first land was sighted, which is generally believed to have been Watling Island. Because Columbus had greatly underestimated the distance to the East Indies via the Atlantic Ocean, he was convinced that he had arrived at these islands. Upon his return to Spain and the announcement of his discovery, additional voyages were planned, and the Spanish and Portuguese continued to explore the coasts of North and South America.

The Atlantic Ocean became familiar to the European explorers, but the Pacific Ocean was not seen by them until 1513 when Vasco Nunez de Balboa attempted a land crossing of the Isthmus of Panama and sighted the Pacific Ocean from atop a mountain.

The culmination of this period of discovery is marked by the circumnavigation of the globe by Ferdinand Magellan (figure 1–5). In September of 1519, Magellan left

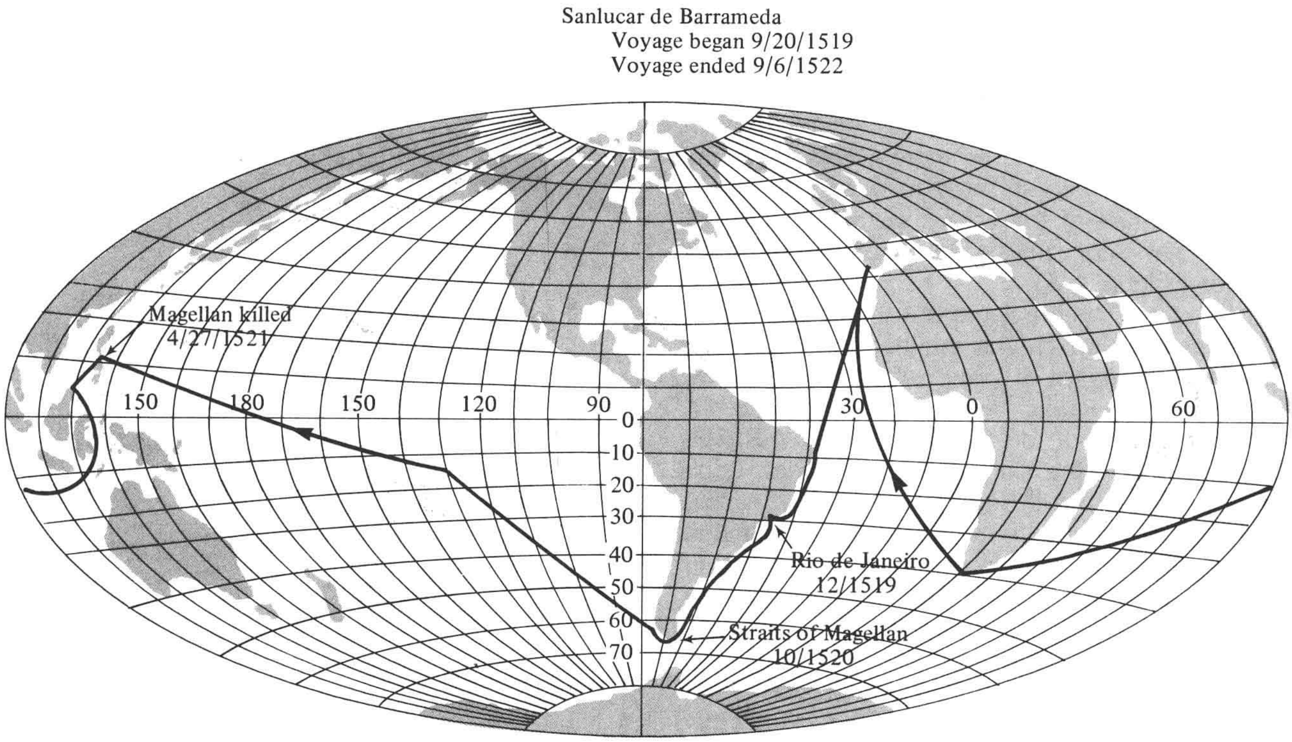


FIGURE 1–5 Voyage of Magellan.
Searching for a western route to the East Indies, Magellan culminated the Age of Discovery by beginning a voyage that ended for him with death in the Philippines. San Juan Sebastian del Caño returned to Spain in the *Victoria,* one of five ships that began the voyage, to complete the first circumnavigation of the earth. (Base map courtesy of National Ocean Survey.)

Sanlucar de Barrameda, Spain, and traveled through a passage to the Pacific at 52° S latitude, now named the Straits of Magellan. After discovering the Philippines on March 15, 1521, Magellan was killed in a fight with the inhabitants of these islands. Sebastian del Caño completed the circumnavigation by taking one of the ships, *Victoria*, across the Indian Ocean and back to Spain in 1522. On this trip Magellan had attempted to measure the depth of the Pacific Ocean by a weighted line, but he was unable to reach bottom.

Subsequent to these voyages, the Spanish initiated many others for the purpose of removing the gold that had been found in the possession of the Aztec and Inca cultures in Mexico and South America. While the Spanish concentrated on plundering the Aztecs and Incas, the English and Dutch plundered the Spanish. Eventually, the profit that could be expected from these voyages dissipated to the degree that the ocean ceased to be used principally as an avenue to newly discovered treasures.

THE SEARCH TO INCREASE SCIENTIFIC KNOWLEDGE OF THE OCEANS

Captain James Cook

The next major interest in the oceans was more scientific, as the English determined that increasing their knowledge of the oceans would help them maintain their maritime superiority. The more successful of the early voyages that were initiated to learn more about the physical nature of the oceans were conducted by the English navigator James Cook (1728–79), son of a farm laborer (figure 1–6).

In 1768, Cook, then a lieutenant, had command of H.M.S. *Endeavour*, which was assigned to conduct observations of the transit of Venus. After completing his tasks in the South Pacific, the ship sailed south to 40° latitude in search of a continent, Terra Australis, thought to exist in the high southern latitudes. Cook did not observe any land, so he sailed to what is now New Zealand and charted those islands. He also charted the eastern coast of Australia, nearly losing his ship in crossing the Great Barrier Reef, before returning home from his first major voyage into the Pacific.

Cook's second voyage, commissioned to continue the search for a continent in the southern ocean, left England on July 13, 1772. The expedition included two ships, the *Resolution* and the *Adventure*. With this voyage, Cook established that if any continent existed in the southern oceans it must be beyond the ice fields and possibly covered by them. Before completing the voyage, Captain Cook discovered and charted South Georgia and the South Sandwich Islands in the South Atlantic. He returned home July 30, 1775.

Following this, his greatest voyage, Cook was honored for preserving the health of his seamen by requiring them to eat sauerkraut and other foods regularly, thus preventing the dread disease scurvy that plagued sailors who spent long periods of time at sea. This diet prevented the vitamin C deficiency that was the cause of this disease.

Cook volunteered to take command of a third voyage to examine the northern Pacific coast of America in search of a northwest passage. He visited New Zealand, Tonga, and the Society Islands before sailing north on December 8, 1777, and discovered the Hawaiian group on January 18, 1778. After reaching the coast of North America, he sailed along it and through the Bering Strait as far as 70° 44′ N latitude before being stopped by pack ice. Returning to Hawaii for the winter, Cook anchored in Kealakekua Bay from January 17 to February 4, 1779. Shortly after leaving port, the ships had to put back in to repair a top mast, and on February 14, Cook was killed in a skirmish with the natives ashore.

Cook's expeditions added greatly to the scientific knowledge of the oceans. He determined the outline of the world's largest ocean and was the first person known to cross the Antarctic Circle. Cook also led the way in sampling subsurface temperatures, measuring winds and currents, sounding, and in collecting important data on coral reefs. By proving the value of John Harrison's chronometer as a means of determining longitude, Cook made possible the first accurate maps of the earth's surface.

FIGURE 1–6 **Captain James Cook, RN.**
(From U.S. Navy photograph.)