Oceanography An Invitation to Marine Science 9th Edition Garrison Solutions Manual

CHAPTER 2
A HISTORY OF MARINE SCIENCE

SIX MAIN CONCEPTS

- ☐ The ocean did not prevent the spread of humanity. By the time European explorers set out to "discover" the world, native peoples met them at nearly every landfall.
- ☐ Any coastal culture skilled at raft building or small-boat navigation had economic and nutritional advantages over less skilled competitors.
- ☐ The first global exploratory expeditions were undertaken by Chinese admiral Zheng He beginning in 1405.
- ☐ The three expeditions of Captain James Cook, British Royal Navy, were perhaps the first to apply the principles of scientific investigation to the ocean.
- ☐ The voyage of H.M.S. *Challenger* (1872 – 1876) was the first extensive expedition dedicated exclusively to research.
- ☐ Modern oceanography is guided by consortia of institutions and governments.

MAIN HEADINGS

2.1 UNDERSTANDING THE OCEAN BEGAN WITH VOYAGING FOR TRADE AND EXPLORATION
Early Peoples Traveled the Ocean for Economic Reasons
Systematic Study of the Ocean Began at the Library of Alexandria
Eratosthenes Accurately Calculated the Size and Shape of Earth
Seafaring Expanded Human Horizons
Viking Raiders Discovered North America
The Chinese Undertook Organized Voyages of Discovery
2.2 THE AGE OF EUROPEAN DISCOVERY
Prince Henry Launched the European Age of Discovery
2.3 VOYAGING COMBINED WITH SCIENCE TO ADVANCE OCEAN STUDIES
Captain James Cook: First Marine Scientist
Accurate Determination of Longitude Was the Key to Oceanic Exploration and Mapping
2.4 THE FIRST Scientific Expeditions WERE UNDERTAKEN BY GOVERNMENTS
The United States Exploring Expedition Helped Establish Natural Science in America

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Matthew Maury Discovered Worldwide Patterns of Winds and Ocean Currents
The Challenger Expedition Was Organized from the First as a Scientific Expedition
Ocean Studies have Military Applications
2.5 CONTEMPORARY OCEANOGRAPHY MAKES USE OF MODERN TECHNOLOGY
Polar Exploration Advanced Ocean Studies
New Ships for New Tasks
Oceanographic Institutions Arose to Oversee Complex Research Projects
Robot Devices are becoming more capable
Satellites Have Become Important Tools in Ocean Exploration

CHAPTER IN PERSPECTIVE

In this chapter your students learned that science and exploration have gone hand-in-hand. Voyaging for necessity evolved into voyaging for scientific and geographical discovery. The transition to scientific oceanography was complete when the *Challenger Report* was published in 1895. The rise of the great oceanographic institutions quickly followed, and those institutions and their funding agencies today mark our path into the future.

HOW HAS THIS CHAPTER CHANGED FOR THE NINTH EDITION?

No dramatic changes, but many small text additions and alterations. Most of the new material is in the form of changed illustrations to avoid – as much as possible – using images whose expense would increase the price of the text (Herb Kane has, sadly, been cut back to one, and a new portrait of Mahan has been obtained). Fewer illustrations overall. New chapter opener has been added. The Harrison chronometer material has been slightly rewritten to make clearer the association between Harrison and the Board of Longitude's prize. Boxes changed to "How Do We Know" features. New Nat Geo explorer (Mark Polzer replaces Kathy Bell). "Thinking Beyond the Figure" features added to more captions.

SUGGESTIONS FOR PRESENTING THE MATERIAL

This brief history is presented in a straight line from people being "a restless and inquisitive lot" to the advent of the great oceanographic institutions and the rise of satellite oceanography. The immense importance of the Library at Alexandria -- not just because of Eratosthenes' work there on the size of the Earth -- can be discussed in relation to the critical importance of knowing one's location on the trackless sea. What good is an oceanic discovery unless you can find your way back to it for further study?

Where to begin? Here's an interesting way to start a lecture on the history of marine science:

An expedition led by Ferdinand Magellan was the first to circumnavigate Earth. Of

270 sailors who set out from Seville on five ships, only 18 managed to return after three years on a worm-eaten and barely-floating vessel laden with valuable spices. Magellan was not among the returning voyagers -- he had been killed in a battle with the natives on Mactan Island in the Philippines.

Of all the oddities they encountered, few seemed as intractable as the last -- the mystery of the extra day. After 1,084 agonizing days at sea, the sailors appeared to have gained a full day on the rest of the world. For them it was *Wednesday*, but for those ashore it was *Thursday*. A young Italian nobleman whose diary serves as our most important source of information about the voyage wrote that this extra day "…was a great cause of wondering to us... we could not persuade ourselves that we were mistaken; and I was more surprised than the others, since having always been been in good health, I had every day, without intermission, written down the day that was current."

After much thought, the answer to the mystery became clear: "There was no error on our part, since we had always sailed toward the west, following the course of the sun, and had returned to the same place, we must have gained 24 hours, as is clear to anyone who reflects upon it."

A later English circumnavigator, William Dampier, made a related discovery. In 1687, when he reached Mindanao in the Philippines, he noted that on some Pacific islands the natives and settlers were keeping the same day as his crew, while on others they were using a date one day earlier. He suddenly realized that the discrepancy depended on where the settlers of a particular island had come from. If the settlers were French, Dutch, or British, and had arrived by way of Asia, their calendars were a day behind his. But if the island was settled by Spaniards who, like himself, had come recently from America, the calendars concurred.

It was not until 1884 that the jumble of dates and times was finally cleaned up. In that year the International Meridian Conference was held in Washington, D.C. Delegates from all over the world agreed that the zero longitude line would pass through the transit circle at Greenwich, England; and that the International Date Line would be established directly opposite at 180° longitude.

From this point of departure one could launch a discussion of the importance of knowing where you are (and when you're there). What good is an oceanic discovery unless you can find your way back to it for further study? So, how did oceanic navigation begin, and where? The immense importance of the Library at Alexandria -- not just because of Eratosthenes' work there on the size of Earth -- can be discussed here.
The Polynesian theme in this chapter is an important opportunity to discuss the use of the ocean for social, economic, and spiritual purposes. Why were the greatest voyages of colonization undertaken? How successful were they?

I have become particularly interested in the voyages of Chinese Admiral Zheng He, and you and your students might find his case as fascinating as I have. Gavin Menzies' popular 2002 book *"1421: The Year China Discovered America,"* has caused an intensive re-examination of the voyages of Zheng He and his subordinates. Menzies makes a compelling (though *far* from bulletproof) case that part of the Ming fleet continued westward around the tip of Africa and into the Atlantic. Menzies bases his argument on cartographic evidence, artifacts, and inferences in the logs of European explorers that they were following paths blazed by someone who had gone before. The equipment was up to the task, but the jury is out on whether these discoveries were made as Menzies claims. Still, the size and sophistication of these ships is astonishing – they even had the capacity to make fresh water on board (via distillation). And, by the way, the Emperor in charge at the time was the same fellow who moved the capital to Peking (Beijing) and built the Forbidden City.

Of particular interest (to me, anyway) is why the Chinese suddenly abandoned this exploration. Again, the jury is out, but less than a century after this maritime high-water mark, it was a crime even to go to sea from China in a multi-masted ship!

The Chapter differentiates between the early experiences of voyagers who used their knowledge of the ocean for getting around, and the later expeditions whose purpose was partially or wholly scientific. Remember the difference between *marine science for voyaging* and *voyaging for marine science*. Captain James Cook's first expedition is the turning point.

When marine science got too big for the exploits of individual (Maury, Forbes, etc.), the great institutions began their ascent. Big Marine Science still depends on them, and their nationally funded counterparts. Satellite investigations are playing ever-larger roles.

ANSWERS TO CONCEPT CHECKS

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- Any coastal culture skilled at raft building or small boat navigation would have economic and nutritional advantages over less skilled competitors. From the earliest period of human history, understanding and appreciating the ocean and its life-forms benefited coastal civilizations.
- The Alexandrian Library and the adjacent museum could be considered the first university in the world. Earth's size was calculated from observations of the geometry of the sun's shadows at different latitudes, and the distances between the observations. Earth's shape was deduced from observations of Earth's shadow on the moon during lunar eclipses.
- Overpopulation and depletion of resources became a problem on the home islands. Politics, intertribal tensions, and religious strife shook society. Groups of people scattered in all directions from some of the "cradle" islands during a period of explosive dispersion. Great dual-hulled sailing ships, some capable of transporting up to 100 people, were designed and built. New navigation techniques were perfected that depended on the positions of stars barely visible to the north. New ways of storing food, water, and seeds were devised.
- Norwegian Vikings began to explore westward as European defenses against raiding became more effective. Though North American was colonized by A.D. 1000, the colony had to be abandoned in 1020. The Norwegians lacked the numbers, the weapons, and the trading goods to make the colony a success.
- In addition to the compass, the Chinese invented the central rudder, watertight compartments, fresh water distillation for shipboard use, and sophisticated sails on multiple masts, all of which were critically important for the successful operation of

large sailing vessels. The Chinese intentionally abandoned oceanic exploration in 1433. The political winds had changed, and the cost of the "reverse tribute" system was judged too great.

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- Although Prince Henry was not well traveled, captains under his patronage explored from 1451 to 1470, compiling detailed charts wherever they went. Henry's explorers pushed south into the unknown and opened the west coast of Africa to commerce.
- European voyages during the Age of Discovery were not undertaken for their own sake. Each voyage had to have a material goal. Trade between east and west had long been dependent on arduous and insecure desert caravan routes through the central Asian and Arabian deserts. This commerce was cut off in 1453 when the Turks captured Constantinople, and an alternate ocean route was sought. Navigators like Columbus exploited this need, and others followed.

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- Cook deserves to be considered a scientist as well as an explorer because of the accuracy, thoroughness, and completeness in his descriptions. He drew accurate conclusions, did not exaggerate his findings, and successfully interpreted events in natural history, anthropology, and oceanography.
- Longitude is east-west position. Longitude is more difficult to determine than latitude (north-south position). One can use the North Star as a reference point for latitude, but the turning of Earth prevents a single star from being used as an east-west reference. The problem was eventually solved by a combination of careful observations of the positions of at least three stars, a precise knowledge of time, and a set of mathematical tables to calculate position.

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- The goals of the United States Exploring Expedition included showing the flag, whale scouting, mineral gathering, charting, observing, and pure exploration. The expedition returned with many scientific specimens and artifacts, which formed the nucleus of the collection of the newly established Smithsonian Institution in Washington, D.C.
- Maury assembled information from ship's logs into coherent wind and current charts. Maury himself was a compiler, not a scientist, and he was vitally interested in the promotion of maritime commerce. Maury's understanding of currents built on the work of Benjamin Franklin, who had discovered the Gulf Stream, a fast current off America's east coast.
- The first sailing expedition devoted completely to marine science was that of HMS *Challenger*, a 2,306-ton steam corvette that set sail on 21 December 1872 on a four-year voyage around the world, covering 127,600 kilometers. *Challenger* scientists made major advances in marine biology, deep-ocean structure, sedimentology, water chemistry, and weather analysis.
- Sir John Murray's major contribution was The *Challenger Report*, the record of the expedition, published between 1880 and 1895. It was the 50 volume *Report*, rather than the cruise itself, that provided the foundation for the new science of oceanography.

- Mahan stressed the interdependence of military and commercial control of seaborne commerce, and the ability of safe lines of transportation and communication to influence the outcomes of conflicts. The arms races, naval hardware, and strategy and tactics of the last century’s greatest wars – along with their outcomes – was influenced by his clear analysis.

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- Scientific curiosity, national pride, new ideas in shipbuilding, questions about the extent and history of the southern polar continent, and the quest to understand weather and climate – not to mention great personal courage -- led in the early years of the last century to the golden age of polar exploration.
- The 1925 *Meteor* expedition was first to use an echo sounder in a systematic probe of the seabed. An echo sounder is faster and more accurate than a weighted line in determining depth. Accurate use of an echo sounder depends on knowing the speed of sound in water, which can vary with temperature and salinity.
- The demands of scientific oceanography have become greater than the capability of any single voyage. Oceanographic institutions, agencies, and consortia evolved in part to ensure continuity of effort.
- Satellites beam radar signals off the sea surface to determine wave height, variations in sea-surface contour and temperature, and other information of interest to marine scientists. Photographs taken from space can assist in determining ocean productivity, current and circulation patterns, weather prediction, and many other factors.
- Marine science is by necessity a field science: Ships and distant research stations are essential to its progress. The business of operating the ships and staffing the research stations is costly and sometimes dangerous, yet “ground truth” – verification of readings taken remotely – is an essential part of the scientific process.

ANSWERS TO “THINKING BEYOND THE FIGURE” QUESTIONS

Figure 2.3: Eratosthenes’ estimate was based on the idea that the sun is infinitely distant. It isn’t, of course, but within the limits of his ability to measure, its true distance made little difference in the final experimental outcome. But imagine if the sun were really close. Lines of sunlight approaching Syene and Alexandria would no longer be parallel (or almost so). His estimate would have been skewed, perhaps placing Syene in the southern Hemisphere!

Figure 2.6: Lots of Polynesian exploration was literally hit or miss. It is not difficult to imagine some accidental (or even intentional) contact with South America. Researchers investigating the genetic make-up of some populations of native South Americans have detected evidence of Asian/Polynesian genes. And then there’s the potato. Sweet potatoes arrived in South America from Polynesian about 400 years before Columbus’ voyages. Even the language suggests contact: the Polynesian word for sweet potato — "kuumala" — resembles "kumara," the word for the vegetable in Quechua, a language spoken by Andean natives.

Figure 2.10: Unlike most Western cultures at the time, the Chinese were not hindered by a pervasive religious tradition insisting that Earth was very young. Until Lyell's pivotal discoveries (and the writings of some of his contemporaries), most European felt compelled to reconcile observation with religious teachings.

Figure 2.11: The new Ming emperor, grandson of Zhu Di (under whose reign Zheng He began his explorations) considered the cost of the expeditions to be too great and against the "ancestral injunctions of the august Ming." Despite the many benefits attained (suppression of pirates, new trade routes, Imperial expansion, etc.), the fleet was ordered destroyed along with plans for vessel construction, drydock facilities, and other assets.

Figure 2.14: The next was Sir Francis Drake (1577-1580). Sailing for England, he was the first to complete a circumnavigation as captain and leader throughout the entire expedition.

Figure 2.16: The problem arose, in part, because Harrison (understandably) would not turn over his clock for inspection by experts appointed by the Board. He knew that a competent watchmaker would discover secrets that he had spent decades perfecting. But the Board was concerned that Harrison's chronometer would be too complex or expensive to produce in quantity, and insisted on professional inspection. The standoff persisted for years.

Figure 2.17: No, nothing special. The zero latitude is a natural place (the equator, equidistant between the poles). The zero longitude could be anywhere, and for any maritime country usually ran through a government's capital city (Paris, Washington, D.C., etc.). By 1884, over two-thirds of all ships and tonnage used England's reference meridian (running through the Royal Observatory at Greenwich, now a suburb of London) as the reference meridian on their maps. In October of that year, 41 delegates from 25 nations met in Washington, D.C. for the International Meridian Conference. This group selected the Greenwich meridian as the official Prime meridian due to its popularity. However, France abstained from the vote and French maps continued to use the Paris meridian for several more decades.

Figure 2.22: They did not get along well. The crew was not used to the ways of science **–** as far as they were concerned, a muddy mess of sediments and animals on a previously clean deck was a huge waste of time and effort. Labs stunk, preservatives were unstable, and the long times spent in bottom sampling was boring and dangerous at the same time. Also, the Captain was not always pleased with the navigational demands placed upon him and his officers -- having civilians in charge of where and when the ship would go was simply *not* the way things were done in the Royal Navy. Things were so bad for the crew that a quarter of the 269 sailors eventually deserted!

Figure 2.23: Mahan's influence was tremendous. For a *really* good read, settle down with Robert K. Massie's two epic books outlining the naval history of World War I. The first, "Dreadnaught **–** Britain, Germany, and the Coming of the Great War," will introduce you to Admiral Jackie Fisher, one of the most interesting characters in recent British history. The second, "Castles of Steel," describes the fleet actions based on Mahan's insistence that sea

lanes must be controlled by a country wishing to dominate commerce and political influence. Both books were published by Random House.

Figure 2.25: Echosounders measure distance by noting the time a sound pulse takes to make the round trip between transmitter, seabed, and receiver. Anything influencing the speed of sound in water will affect the results. As you'll read in Chapter 6, water temperature, salinity, elasticity, and viscosity all influence the speed of sound in water.

ANSWERS TO END-OF-CHAPTER QUESTIONS

1. How could you convince a 10-year-old that Earth is round? What evidence would a child offer that it's flat? How can you counter those objections?

You and your son/grandson/neighbor kid are standing at the end of a pier looking out to sea on a very clear day. You say, "Did you know Earth is round?" He finds this preposterous, of course, and points to the flat horizon. You respond that Earth is so big that from down here it appears to be flat, but really is spherical. He is still unconvinced. You remind him that nearby bodies look spherical – moon and sun. You draw a diagram of a lunar eclipse in the sand and note that the shadow of Earth on the moon is circular. You might even show him some Apollo photos of Earth when you return home. He responds (as did our kids) with the ultimate objection: a spherical Earth is clearly ridiculous because people on the other side would fall off.

I recommend trying again when the kid is 18.

2. How did the Library of Alexandria contribute to the development of marine science? What happened to most of the information accumulated there? Why do you suppose the residents of Alexandria became hostile to the librarians and the many achievements of the library?

The great Library at Alexandria constituted history's greatest accumulation of ancient writings. As we have seen, the characteristics of nations, trade, natural wonders, artistic achievements, tourist sights, investment opportunities, and other items of interest to seafarers were catalogued and filed in its stacks. Manuscripts describing the Mediterranean coast were of great interest.

Traders quickly realized the competitive benefit of this information. Knowledge of where a cargo of olive oil could be sold at the greatest profit, or where the market for finished cloth was most lucrative, or where raw materials for metalworking could be obtained at low cost, was of enormous competitive value. Here perhaps was the first instance of cooperation between a university and the commercial community, a partnership that has paid dividends for science and business ever since.

After their market research was completed, it is not difficult to imagine seafarers lingering at the Library to satisfy their curiosity about non-commercial topics. And there would have been much to learn! In addition to Eratosthenes' discovery of the size of the Earth (about which you read in the chapter), Euclid systematized geometry; the astronomer

Aristarchus of Samos argued that Earth is one of the planets and that all planets orbit the sun; Dionysius of Thrace defined and codified the parts of speech (noun, verb, etc.) common to all languages; Herophilus, a physiologist, established the brain was the seat of intelligence; Heron built the first steam engines and gear trains; Archimedes discovered (among many other things) the principles of buoyancy on which successful shipbuilding is based.

The last Librarian was Hypatia, the first notable woman mathematician, philosopher, and scientist. In Alexandria she was a symbol of science and knowledge, concepts the early Christians identified with pagan practices. After years of rising tensions, in 415 A.D. a mob brutally murdered her and burned the Library with all its contents. Most of the community of scholars dispersed and Alexandria ceased to be a center of learning in the ancient world.

The academic loss was incalculable, and trade suffered because ship owners no longer had a clearing house for updating the nautical charts and information upon which they had come to depend. All that remains of the Library today is a remnant of an underground storage room. We shall never know the true extent and influence of its collection of over 700,000 irreplaceable scrolls.

Historians are divided on the reasons for the fall of the Library. But we know there is no record that any of the Library's scientists ever challenged the political, economic, religious, or social assumptions of their society. Researchers did not attempt to explain or popularize the results of their research, so residents of the city had no understanding of the momentous discoveries being made at the Library at the top of the hill. With very few exceptions, the scientists did not apply their discoveries to the benefit of mankind, and many of the intellectual discoveries had little practical application. The citizens saw no practical value to such an expensive enterprise. Religious strife added elements of hostility and instability. As Carl Sagan pointed out, "When, at long last, the mob came to burn the Library down, there was nobody to stop them."[1]

As for speculations on historical impact had the Library survived, some specialists have suggested that much of the intellectual vacuum of the European Middle Ages might have been "sidestepped," in a sense, if the information processing and dissemination processes centered at the Library had continued. Instead of the subsequent fragmentation and retraction, one wonders if continued academic stimulation might have reinvigorated the West? Also, had the Library lasted longer, one wonders if researchers there might have discovered the intellectual achievements of China, a civilization much advanced at the time.

3. How did Eratosthenes calculate the approximate size of Earth? Which of his assumptions was the "shakiest"?

The geometry is straightforward. The shadow angle would be easy to measure, especially if the pole were quite long. The most difficult parameter to measure, and the factor subject to the largest error, would be the overland distance from Alexandria to Syene. Indeed, given that difficulty it is impressive that Eratosthenses' original estimate was as close as it was.

[1] Sagan, C. 1980. Cosmos. New York: Random House.

4. If Columbus didn't discover North America, then who did?

Columbus never saw North America. North America was "discovered" by people following migrating game across the Bering Straits land bridge about 20,000 years ago, during the last ice age.

5. What were the contributions of Captain James Cook. Does he deserve to be remembered more as an explorer or as a marine scientist?

Captain James Cook's contributions to marine science are justifiably famous. Cook was a critical link between the vague scientific speculations of the first half of the eighteenth century and the industrial revolution to come. He pioneered the use of new navigational techniques, measured and charted countless coasts, produced maps of such accuracy that some of their information is still in use, and revolutionized the seaman's diet to eliminate scurvy. His shiphandling in difficult circumstances was legendary, and his ability to lead his crew with humanity and justice remains an inspiration to naval officers to this day.

While Captain Cook received no formal scientific training, he did learn methods of scientific observation and analysis from Joseph Banks and other researchers embarked on HMS *Endeavour*. Because his observations are clear and well recorded, and because his speculations on natural phenomena are invariably based on scientific analysis (rather than being glossed over or ascribed to supernatural forces), some consider him the first marine scientist.[2] But, to be rigorously fair, perhaps his explorational and scientific skills should be given equal weighting.

6. What was the first purely scientific oceanographic expedition and what were some of its accomplishments?

The expeditions of Cook, Wilkes, the Rosses, de Bougainville, Wallis, and virtually all other runners-up to HMS *Challenger* were multi-purpose undertakings: military scouting, flag-waving, provision hunting, and trade analysis were coupled with exploration and scientific research.

The first sailing expedition devoted *completely* to marine science was conceived Charles Wyville Thomson, a professor of natural history at Scotland's University of Edinburgh, and his Canadian-born student of natural history, John Murray. They convinced the Royal Society and the British Government to provide a Royal Navy ship and trained crew for a "prolonged and arduous voyage of exploration across the oceans of the world." Thomson and Murray even coined a word for their enterprise: Oceanography.

HMS *Challenger*, the 2,306 ton steam corvette chosen for the expedition, set sail on 7 December 1872 on a four-year voyage that took them around the world and covered 127,600 kilometers (79,300 nautical miles). Although the Captain was a Royal Naval officer, the six-man scientific staff directed the course of the voyage.

The scientists also took salinity, temperature, and water density measurements during

[2] For more information on Cook as scientist, see Richard Hough's biography: Hough, R. 1994. *Captain James Cook.* New York: W. W. Norton.

these soundings. Each reading contributed to a growing picture of the physical structure of the deep ocean. They completed at least 151 open water trawls, and stored 77 samples of seawater for detailed analysis ashore. The expedition collected new information on ocean currents, meteorology, and the distribution of sediments; the locations and profiles of coral reefs were charted. Thousands of pounds of specimens were brought to British museums for study. Manganese nodules, brown lumps of mineral-rich sediments, were discovered on the seabed, sparking interest in deep sea mining.

This first pure oceanographic investigation was an unqualified success. The discovery of life in the depths of the oceans stimulated the new science of marine biology. The scope, accuracy, thoroughness, and attractive presentation of the researchers' written reports made this expedition a high point in scientific publication. The *Challenger Report*, the record of the expedition, was published between 1880 and 1895 by Sir John Murray in a well-written and magnificently illustrated 50-volume set; it is still used today. The *Challenger* expedition remains history's longest continuous scientific oceanographic expedition.

7. Who was probably the first person to undertake the systematic study of the ocean as a full-time occupation? Are his contributions considered important today?

Matthew Maury is a likely candidate. A Virginian and officer (at different times) in both the United States and Confederate States Navy, Maury who was the first person to sense the worldwide pattern of surface winds and currents. Based on an analysis undertaken while working full-time for the Bureau of Charts and Instruments, he produced a set of directions for sailing great distances more efficiently. Maury's sailing directions quickly attracted worldwide notice: He had shortened the passage for vessels traveling from the American east coast to Rio de Janeiro by 10 days, and to Australia by 20. His work became famous in 1849 during the California gold rush -- his directions made it possible to save 30 days around Cape Horn to California. Applicable U.S. charts still carry the inscription, "Founded on the researches of M.F.M. while serving as a lieutenant in the U. S. Navy." His crowning achievement, *The Physical Geography of the Seas*, a book explaining his discoveries, was published in 1855.

Maury, considered by many to be the father of physical oceanography, was perhaps the first man to undertake the systematic study of the ocean as a full-time occupation.

8. What famous American is also famous for publishing the first image of an ocean current? What was his motivation for studying currents?

While serving as Postmaster General of the northern colonies, Benjamin Franklin noticed the peculiar fact that the fastest ships were not always the fastest ships -- that is, hull speed did not always correlate with out-and-return time on the run to England. Naturally he wanted the most efficient transport of mail and freight, and the differences in ship speeds concerned him. Franklin's cousin, a Nantucket merchant named Tim Folger, noted Franklin's puzzlement and provided him with a rough chart of the "Gulph Stream" that he (Folger) had worked out. By staying within the stream on the outbound leg and adding its speed to their own, and by avoiding it on their return, captains could traverse the Atlantic much more quickly. It was Franklin who published, in 1769, the first chart of any current.

9. What is an echosounder? Can you think of some ways error could be introduced in an echosounder's readings?

Echo sounders sense the contour of the seafloor by beaming sound waves to the bottom and measuring the time required for the sound waves to bounce back to the ship. Because the speed of sound depends on water temperature, density, salinity, and pressure, knowledge of these variables is essential to accurate measurements. Still, echo sounders are more accurate than a weighted line that waves in the currents as it descends.

10. Sketch briefly the major developments in marine science since 1900. Do individuals, separate voyages, or institutions figure most prominently in this history?

Individuals and voyages are most prominent in the first half of this century. Captain Robert Falcon Scott's British Antarctic expedition in HMS *Discovery* (1901-1904) set the stage for the golden age of Antarctic exploration. Roald Amundsen's brilliant assault on the south pole (1911) demonstrated that superb planning and preparation paid great dividends when operating in remote and hazardous locales. The German *Meteor* expedition, the first "high tech" oceanographic expedition, showed how electronic devices and sophisticated sampling techniques could be adapted to the marine environment. And certainly the individual contributions of people like Jacques Cousteau and Emile Gagnan (inventors in 1943 of the "aqualung," the first scuba device) and Don Walsh and Jacques Piccard (pilots of *Trieste* to the ocean's deepest point in 1960) are important.

But the undeniable success story of late twentieth century oceanography is the successful rise of the great research institutions with broad state and national funding. Without the cooperation of research universities and the federal government (through agencies like the National Science Foundation, the National Oceanic and Atmospheric Administration, and others), the great strides that were made in the fields of plate tectonics, atmosphere-ocean interaction, biological productivity, and ecological awareness would have been much slower in coming. Along with the Sea Grant Universities (and their equivalents in other countries), establishments like the Scripps Institution of Oceanography, the Lamont-Doherty Earth Observatory, and the Woods Hole Oceanographic Institution, with their powerful array of researchers and research tools, will define the future of oceanography.

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