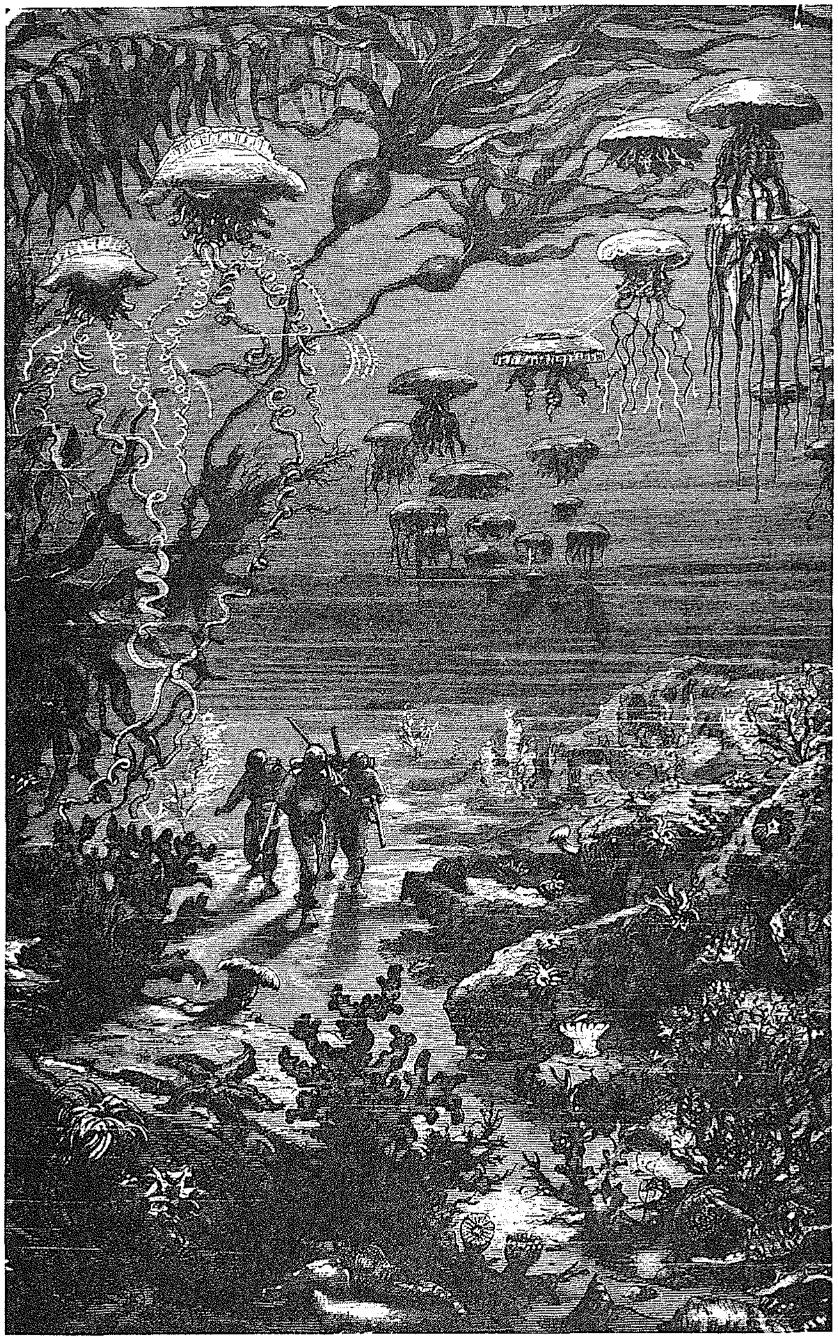

Captain Nemo and companions in the forest of Crespo, from Jules Verne's Twenty Thousand Leagues under the Sea *(1870). "It was then ten in the morning," the narrator recalls, "the rays of the sun struck the surface of the waves at rather an oblique angle, and at the touch of their light, . . . flowers, rocks, plants, shells and polypi were shaded at the edges by the seven solar colors."*

The Oceans

"Man marks the earth with ruin—his control / Stops with the shore." So it was when the poet Lord Byron wrote those words in 1812. In the century and a half since then, man's understanding of the marine environment has rapidly advanced. Man has also come to rely heavily on the oceans for food and fuel. One day, he may tap the sea-bed as an important new source of key minerals. Men and governments have yet to mark the seas with ruin, but preventing ruin, given man's proclivities, has not been easy. Here, marking the Year of the Oceans, historian Susan Schlee chronicles the evolution of marine science; political scientist Ann Hollick considers the use and misuse of the oceans and the United Nations' decade-long attempt to fashion a workable Law of the Sea amid conflicting interests and ideologies.

SCIENCE AND THE SEA

by Susan Schlee

From outer space, Earth resembles a ball of azure liquid. With nearly 71 percent of its surface covered with water, the planet has been aptly called the "blue drifter." Even the white whorls of clouds that embroider the planet's atmosphere are vaporous extensions of the oceans below.

The seas have long piqued man's curiosity, and he has imbued them with his fondest hopes and his most poignant fears. In the Babylonian epic of Gilgamesh, based on tales told nearly 5,000 years ago, the hero poles his way across a Sea of Death in search of a plant, flowering on a river bottom, that promises eternal life. Many centuries later, the power of the "wine-dark sea" to help, and of the "solid deep-sea swell" to harm, was evoked by Homer in *The Odyssey*. During the Dark Ages, the poets who composed the Icelandic sagas sang of "ocean-striding ships" moving across broad expanses of the Atlantic. Upon their death, Norse kings were "launched alone across the ocean" in flaming funeral barks.

The oceans seem to have had a stimulating effect on the peoples who have known them best. Sailors learned early how to predict the tides, navigate by the stars, and use the trade winds. At least until the Middle Ages, the art of fishing was far more advanced than that of farming, and until the evolution of the railroad, travel by sea was faster and easier than travel by land. The ocean-going vessel was a marvel of continually improving technology; by contrast, the horse-drawn carriage changed little in millennia. The first great empires were maritime empires, not land empires, and historically it has been the restless, voyaging, maritime peoples, not their landlocked neighbors, who have put the greatest distance between themselves and barbarism.

Fringe Benefits

Curiosity, new technology, the prospect of political or economic gain—these three factors, not always acting in concert, impelled man to extend his domination over the seas. Scientific inquiry on a significant scale, though a product of more recent times, has been shaped by those same conflicting motivations. Oceanography, as a result, has developed, during its short life, in a haphazard and sometimes lopsided way.*

Although we can reach back into antiquity and find men theorizing about the origin, character, and extent of the sea, the observations made from the sixth century B.C. through the 17th century A.D. were isolated ones that, even when correct, did not prompt any profound appreciation by man of the interaction of ocean phenomena.

As late as the 17th and early 18th centuries, most marine studies were conducted on land and focused on a single aspect of ocean dynamics in isolation from others. Examples include

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*In French, the word "*océanographie*" was used during the late 1500s, but did not survive. It reappeared in 1878 (in the *Grand Dictionnaire Universal*) and was defined as "*la description de l'océan*." During the early 1880s, the German chemist William Dittmar was among the first to use the word "oceanography" in English, and by the close of the century, it was in common use.

Susan Schlee, 44, is a writer who specializes in oceanography. Born in New York City, she received a B.A. from Vassar in 1961 and subsequently studied oceanography at Duke University. A resident of Woods Hole, Massachusetts, she is the author of On the Edge of an Unfamiliar World *(1973) and* On Almost Any Wind: The Saga of the R/V *Atlantis (1978).*

THE LURE OF THE SEA

Herman Melville used the opening pages of his novel, Moby Dick *(1851), to reflect on the peculiar visual attraction of water. "Were Niagara but a cataract of sand," he asked, "would you travel your thousand miles to see it?" An excerpt:*

Whenever I find myself growing grim about the mouth; whenever it is a damp, drizzly November in my soul; whenever I find myself involuntarily pausing before coffin warehouses, and bringing up the rear of every funeral I meet; and especially whenever my hypos get such an upper hand of me, that it requires a strong moral principle to prevent me from deliberately stepping into the street, and methodically knocking people's hats off—then, I account it high time to get to sea as soon as I can. This is my substitute for pistol and ball. With a philosophical flourish Cato throws himself upon his sword; I quietly take to the ship. There is nothing surprising in this. If they but knew it, almost all men in their degree, some time or other, cherish very nearly the same feelings towards the ocean with me.

There now is your insular city of the Manhattoes, belted round by wharves as Indian isles by coral reefs—commerce surrounds it with her surf. Right and left, the streets take you waterward. Its extreme down-town is the battery, where that noble mole is washed by waves, and cooled by breezes, which a few hours previous were out of sight of land. Look at the crowds of water-gazers there.

Circumambulate the city of a dreamy Sabbath afternoon. Go from Corlears Hook to Coenties Slip, and from thence, by Whitehall, northward. What do you see?—Posted like silent sentinels all around the town, stand thousands upon thousands of mortal men fixed in ocean reveries. Some leaning against the spiles; some seated upon the pier-heads; some looking over the bulwarks of ships from China; some high aloft in the rigging, as if striving to get a still better seaward peep. . . .

Why is almost every robust healthy boy with a robust healthy soul in him, at some time or other crazy to go to sea? 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 own brother of Jove. Surely all this is not without meaning. And still deeper the meaning of that story of Narcissus, who because he could not grasp the tormenting, mild image he saw in the fountain, plunged into it and was drowned. But that same image, we ourselves see in all rivers and oceans. It is the image of the ungraspable phantom of life; and this is the key to it all.

Robert Boyle's "Observations and Experiments on the Saltness of the Sea" (1674) and Sir Isaac Newton's explanation of the tides (1684).

The situation began to change after 1750, the impetus being partly economic. As European seafarers ranged across the oceans seeking new sources of gold, spices, and, later, raw materials, as well as new markets for finished goods, many governments created special bureaus to produce nautical charts and other aids to navigation. Some scientific work was accomplished as a fringe benefit.

In Britain, for example, the Admiralty during the 18th century made a practice of sending scientists along on government-sponsored surveying expeditions, such as those conducted by Captain James Cook between 1768 and 1779. At first, these specialists were interested primarily in gathering data on the stars and tides, but eventually naturalists were taken aboard to collect plants and animals from both land and sea. That is how Charles Darwin secured a berth on HMS *Beagle* sailing from Plymouth in 1831.

Lifting the Veil

Meanwhile, European scientists working without government help began studying the gulfs, shoals, and bays closer to home. Scholars interested in what would today be called marine biology spent their vacations exploring shallow coastal waters. The Danish biologist Otto Müller spent four summers during the 1770s off the southern coast of Norway, trying to dredge up sediment from the sea bottom at a depth of 180 feet. Müller concluded that research at sea "abounds with expense and many forms of danger." In spite of the difficulties, amateur and professional scientists were increasingly drawn to the sea, and summer collecting trips enjoyed tremendous popularity.

More taxing intellectually were chemical and physical studies of the sea. In France, chemist Antoine Lavoisier published an (imperfect) analysis of seawater in 1776. In Britain, Charles Blagden, in 1788, related the variable freezing point of water to the concentration of dissolved substances it contained. And by 1820, the retired French physician, Alexander Marcet, had shown that seawater from different parts of the ocean contains the same ingredients, and in approximately the same proportions.

In physics, the French mathematician Marquis Pierre Simon de Laplace, in 1773, elaborated on the Newtonian explanation of the tides; Austria's Franz Joseph von Gerstner, in 1802, published the first theory of surface waves in deep water; and

Gaspard Gustave de Coriolis, in 1835, described the force named after him—the Coriolis Force—which deflects winds to the right in the Northern Hemisphere, to the left in the Southern Hemisphere. The Coriolis Force became an important element in the calculation of ocean currents.

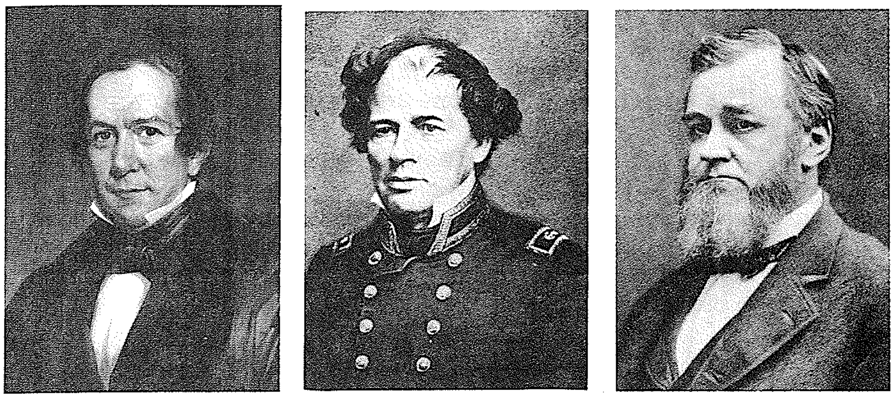
In the United States, oceanographic studies became a kind of seaward extension of the new republic's rapid territorial gains. Early research was supported by three important government agencies, created by Congress to help extend the life expectancy of sailors, minimize the loss of cargo, and maximize the catch of fish and whales.

The Ocean's River

The first of these agencies was the U.S. Coast Survey (now the National Ocean Survey), established in 1807 to chart the nation's coastal waters. Between 1843 and the Civil War, the Coast Survey was headed by Alexander Dallas Bache, great-grandson of Benjamin Franklin. Under his guidance, the survey undertook the first sustained study of the Gulf Stream, whose "qualities as hindrances and aids to navigation," Bache told Congress, "require that the navigator should be well informed in regard to it." Coast Survey scientists made 14 "transects" across the Gulf Stream between Florida and New Jersey, taking soundings, sampling temperatures, and collecting sediments.

Later, during the 1880s, the Coast Survey's John Elliot Pillsbury, a Navy lieutenant, measured the currents and countercurrents within the Gulf Stream from an anchored ship. "In a vessel floating [i.e., adrift] on the Gulf Stream," Lieutenant Pillsbury wrote, "one sees nothing of the current and knows nothing but what experience tells him; but to be anchored in its depths far out of the sight of land, and to see the mighty torrent rushing past at a speed of miles per hour, . . . one begins to think that all the wonders of the earth combined can not equal this one river in the ocean."

The Gulf Stream, we now know, carries roughly 1,000 times the volume of the Mississippi River: It pours some 70 million tons of water per second through the Straits of Florida. Evidence supplied by drift buoys suggests that by the time it reaches the Grand Banks off Newfoundland its internal structure consists of baroque spirals of eddies and countercurrents. Joined here by the Labrador Current, what is left of the Gulf Stream becomes the eastward-flowing North Atlantic Current, which eventually makes its way south as the Canary Current, then turns west and becomes the North Equatorial Current. The Gulf Stream is thus



American pioneers on a new frontier: the Coast Survey's Alexander Dallas Bache (left); Matthew Fontaine Maury of the Depot of Charts and Instruments (center); and the Fish Commission's Spencer Fullerton Baird (right).

but one portion of an enormous, clockwise gyre.

While Alexander Dallas Bache and his successors at the Coast Survey studied coastal waters, a second government agency, the Navy's Depot of Charts and Instruments (now the Naval Oceanographic Office), was turning its attention to conditions on the high seas. Founded in 1830 as a storage facility, the depot quickly evolved into a clearing-house for information on marine meteorology and physical oceanography. Directed between 1842 and 1861 by a strong-willed, self-taught polymath, Lt. Matthew Fontaine Maury, U.S. Navy, the depot was soon publishing wind and current charts for all of the most frequently traveled sea routes in the world. Maury gathered the necessary information by distributing thousands of "short-form" logs to merchant captains and requesting that they fill out the logs as they traveled. From these, Maury constructed monthly wind and current averages for each five-degree section of the ocean that lay across commercial shipping routes. Sea captains soon discovered that it was well worth their while to sail one of Maury's recommended routes which, though usually longer in miles, were graced by favorable winds and currents.

Encouraged by his success and rewarded by Congress with a growing budget, Maury turned to more ambitious explorations. Beginning in 1851, he sent a makeshift research vessel, the *Dolphin*, on three Atlantic cruises. Her crew used the Brooke Patent Sounding Lead, a device that measured the depths of the ocean quite reliably and, as a bonus, brought up samples of sea-floor oozes in its small sounding cup.

Maury used the 200 deep soundings made by his ships to compile the first bathymetrical map of the North Atlantic basin in 1854. From the small number of soundings at his disposal, it was as accurate as could be expected. While the original edition of the map included an imaginary depression (seven to eight miles deep) off the Grand Banks, it also showed a broad rise in the middle of the Atlantic—what Maury called the "Dolphin Rise"—which was the first indication of the extensive Mid-Atlantic Ridge. This ridge, oceanographers later learned, is part of a massive, continuous chain of undersea mountains that winds for 34,000 miles underneath the Atlantic, Pacific, Indian, and Arctic oceans.

In 1855, just a year after his contour map appeared, Maury published an immensely popular book, *The Physical Geography of the Sea*. Readers across Europe and America were captivated by Maury's rolling style and his startling facts and speculations. Jules Verne, author of *Twenty Thousand Leagues under the Sea* (1873), was so impressed that he mentioned the lieutenant by name in the novel and borrowed heavily from *Physical Geography* for his information about the sea. Scientists were not quite as enthusiastic. Much of Maury's information, they knew, was wrong, or correct but poorly explained. Nevertheless, the book brought marine science for the first time to the attention of a wide audience.

'This Thing Called Science'

The third federal agency to take up marine exploration was the United States Fish Commission (now the Bureau of Fisheries). The commission was organized, in 1871, by Spencer Fullerton Baird, the assistant secretary of the Smithsonian Institution. While assuring Congress that a fish commission would help the country's fishing industry, Baird was in fact more interested in launching a sustained ecological study of North American waters. Within a decade of his appointment, Baird had convinced Congress to pay for the country's first specially-built oceanographic research vessel (the 234-foot steamer *Albatross*) and to build a laboratory at Woods Hole, Massachusetts, on Cape Cod. Every summer, scientists and graduate students came from universities throughout the East to collect shallow-water animals and study the life cycles of fish or the diseases and parasites that affected them. Friends and colleagues of Baird soon set up a second research institution at Woods Hole, the privately operated Marine Biological Laboratory (MBL).

Unfortunately, the Fish Commission's productive period was cut short by Baird's death in 1887. Moreover, as shipping and maritime interests in the United States declined relative to inland industrial development, Washington grew increasingly ambivalent toward what one Congressman called "this thing called Science here." The directorship not only of the Fish Commission but also of the Coast Survey and the Depot of Charts and Instruments became a political appointment; all three agencies were forced to confine their endeavors to more immediately utilitarian pursuits. "The Fish Commission is hardly in condition to do more than attend to the problems they have in hand," lamented biologist Alexander Agassiz in 1902. In short, by the turn of the century, oceanographers in America were becalmed.

Across the Atlantic, meanwhile, marine science was developing along vastly different lines. To British, French, German, and Scandinavian naturalists, who had started collecting and cataloguing local shallow-water animals almost 100 years before the Americans did, the most exciting prospect during the

THE OCEANS: SOME FACTS AND FIGURES

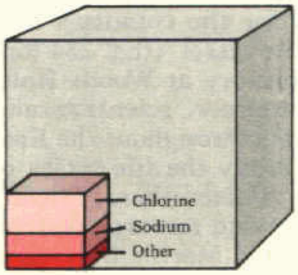
Area: 139.5 million square miles, covering 70.8 percent of the Earth's surface (including almost all of the Southern Hemisphere).

Volume: 318 million cubic miles.

Mean depth: 12,216 feet, or 2.3 miles. The Pacific is, on average, deeper than any other ocean; the Arctic, on average, shallower. Deepest recorded point (38,635 feet) is in the Pacific basin's Marianas Trench.

Mean Temperature: 39 degrees Fahrenheit.

Pressure: One atmosphere (i.e., one kilogram per square centimeter, or 14.7 pounds per square inch) at sea level, increasing by one atmosphere with each 10 meters (32.8 feet) of depth.



Composition: Seawater contains about 35,000 parts per million (ppm) of dissolved solids, mostly chlorine and sodium but also including significant amounts of magnesium (1,350 ppm), sulfur (885 ppm), calcium (400 ppm), and potassium (380 ppm). Though not commercially exploitable, traces of almost all known elements can be found in the oceans. Some 45 pounds of gold is dispersed in each cubic mile of seawater.

mid–19th century was that of studying the creatures of the deep, or *abyssal*, sea. That seemingly impractical fascination led the Europeans to organize the first purely oceanographic expeditions. This they could do because, unlike Americans, educated Europeans were accustomed to supporting the esoteric projects of scientific societies such as the British Association for the Advancement of Science or the *Institut de France.*

The Big Picture

European scientists had long held the sensible belief that the cold and black abyss, which stretched for unmeasured miles below the reach of fishermen's nets, could not possibly harbor any living things. The eminent Manx naturalist, Edward Forbes, contended during the 1840s that below 300 fathoms there was "a probable zero of life." That view changed dramatically during the middle of the 19th century, when bottom surveys by cable companies and the dredging done on polar expeditions inadvertently turned up a menagerie of starfish, tube worms, and other exotic creatures living in the depths.* As a result, wrote the Scottish botanist, C. Wyville Thomson, "the land of promise for the naturalist . . . [became] the bottom of the deep sea."

Thomson was director of Britain's *Challenger* expedition, the most important oceanographic effort of the 19th century. Between December 1872 and May 1876, the Royal Navy's 226-foot corvette *Challenger* circumnavigated the globe at a brisk "walking" pace, covering 68,930 miles and along the way collecting more than 13,000 new varieties of animals and plants, nearly 1,500 water samples, and hundreds of bottom deposits (including the first manganese nodules, which today lure those who would attempt to "mine" the ocean floor). The real work began when the ship returned to England. Over the course of the next two decades, subsidized by the Treasury, 76 scientists contributed to the 50-volume *Report on the Scientific Results of the Voyage of HMS* Challenger.

Here the grand outlines of oceanography were first drawn. By 1895, when the last of the *Report*'s volumes appeared, the bare bones that the *Challenger* staff had to some extent discovered, and to a greater degree arranged, had been fashioned into a skeleton that would support the further discoveries of oceanographers for many years, with remarkably few alterations. Es-

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*The first transatlantic cable was laid by the Atlantic Telegraph Company in 1858. It failed after transmitting 723 messages, and a permanent connection was not established until 1866. Then as now, the needs of commerce encouraged some basic oceanographic inquiry: What is the texture of the sea floor? How corrosive is seawater? What are the teething habits of large fish that might chew on cables?

pecially in the fields of zoology and geology, later exploration filled in the blanks—discovered deeper trenches, a few more animals—but left the picture of the oceans much as it had been drawn in the *Challenger* report.

Sampling the Bottom

The expedition's profound impact on marine geology illustrates the point. When the *Challenger* put to sea in 1872, the sea floor lying off the immediate coastlines of busy maritime nations had already been mapped; scattered observations of depths and sediments (like the few made by Maury) had been made in the deep sea. But no one knew much about either the configuration of the ocean basins or their coatings of sediments.

Using dredges and trawls to gather sediments and various sounding devices to measure depth, the men aboard the *Challenger* found that coastal zones are filled with a jumble of rock and gravel that has been washed off the continents, primarily by rivers. At intermediate depths, the ocean floor is covered mostly by organic oozes. These are largely composed of planktonic shells and skeletons that, as Sir John Murray, second in command of the expedition's scientists, rightly concluded, are the remains of surface plankton that have "rained" on the bottom.* Below 2,500 fathoms, the nature of sea-floor sediment changes again—to a reddish brown clay. The reason: Pressures at these depths are so great (up to several tons per square inch) that the lime-like planktonic debris is dissolved before it reaches the bottom.

The slowly accumulating red clay, which Murray remembered as "soft, plastic, and greasy," also elicited considerable interest aboard the *Challenger*. Some of the clay consisted of volcanic material and minerals obviously blown from land. But Murray discovered that, if he dissolved bottom clay in a basin of water and stirred the mixture with a magnet wrapped in ironpaper, he could collect scores of metallic particles of a type not found in terrestrial rocks. These, he surmised, were thrown off by meteorites passing through the Earth's atmosphere. It is estimated today that from 35,000 to one million tons of cosmic matter plummet into the oceans every year.

In the very deepest portions of the oceans—five miles

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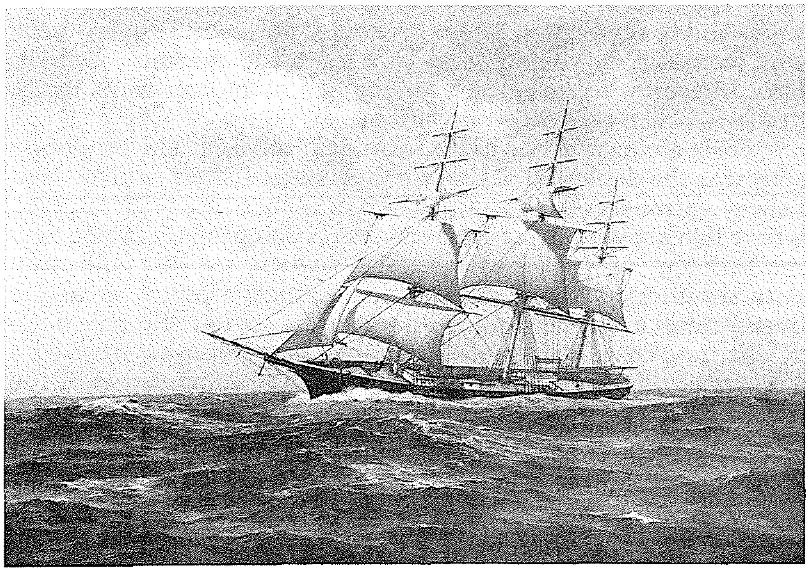
*The term "plankton" was not actually coined until 1887, when biologist Victor Hensen used it to describe all the plants and animals in the sea that drift passively. A feathery mat of sargasso weed is plankton, as are fish eggs and larvae, but most members of Hensen's community are microscopic and many are transparent. Gradually the idea developed that plant plankton (phytoplankton) formed the same basis for life in the sea that land plants formed for animal life on Earth.



Thanks to Matthew Fontaine Maury's wind and current charts, clipper ships could save as much as a month on the 15,000-mile passage from New York around Cape Horn to San Francisco. The Flying Cloud *(above) made the trip in 89 days—a record—on her maiden voyage in 1851.*

down and more—still another kind of sediment was encountered, "radiolarian ooze." The *Challenger* first came across it in the eastern Pacific near the island of Guam. By chance, the ship hove to over what is now called the Marianas Trench, and a sounding was made in 4,475 fathoms of water. The sounding tube returned with a sample of straw-colored clay. When examined under a microscope, the clay was found to be composed of the glassy skeletons of small planktonic animals called radiolarians. These delicate creatures, shaped like stars with a hundred arms or like clusters of minute glass bubbles, live near the ocean surface like other kinds of plankton. But because their skeletons are made of silica, their remains do not dissolve as they lazily trickle down through five miles of water. Some 3,500 new species of radiolarians were discovered on the *Challenger* expedition.

Oceanography's status during the early 20th century was both potentially promising and curiously directionless. Practitioners of the young science had a vast new field to explore and new technologies at their disposal. But there were problems. In Europe, governments quickly grew weary of financing expensive expeditions that merely corroborated the *Challenger*'s results. And in the United States, as noted, the federal government was increasingly reluctant to pay for basic marine research. New interests, techniques, and sources of money were badly needed to keep oceanography afloat.

For a time, all three came from Scandinavia. The economic spur was the depletion of the North Atlantic fisheries. (The term fishery variously refers to the catch of a particular fish, a place where fish are caught, or the business of catching fish.) The new methodology was "synoptic studies," which involves collecting data simultaneously at several closely spaced points arranged over a small area of the sea. And the organization that posed the scientific questions and coordinated the necessary research fleets was the International Council for the Exploration of the Sea (ICES), established in 1902.

Counting the Rings

Four times a year, each of the eight nations originally comprising the ICES—Norway, Sweden, Denmark, Finland, Germany, the Netherlands, Russia, and Britain—sent a research vessel into the Baltic or North seas, or the eastern North Atlantic on a specified date. The ships carried standardized thermometers, nets, water bottles, and other apparatus; each vessel serviced a tight grid of stations or data-collecting points. Once analyzed, the data from these cruises were sent to the council's headquarters in Copenhagen, where the thousands of physical measurements and plankton counts were synthesized into "snapshots" of the sea at given moments. The council's ultimate aim, in the words of one member, was to "tell the commercial [fishing] world how far greed might safely go."

The ICES brought European fishery scientists into contact with meteorologists and chemists. New projects were begun almost annually. Once biologists learned how to tell the age of fish—by counting the growth rings on their scales—the important concept of "year classes" was formulated, helping to explain why fish populations fluctuated so widely over time.*

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*The Norwegian zoologist Johan Hjort discovered before World War I that the population dynamics of fish were very different from those of other animals, and that major fluctuations in fish populations were caused by the variable size of each age cohort or "year class." Hjort found that, every so often, when environmental conditions were just right, a particular species in a particular area would spawn an unusually large generation that would dominate the population for years to come. (Hjort showed, for example, that spring herring born in 1904 accounted for 43 percent of the herring catch in 1909, 77 percent in 1910, and more than 70 percent in 1911.) When conditions were poor, a "year class" might be abnormally small.

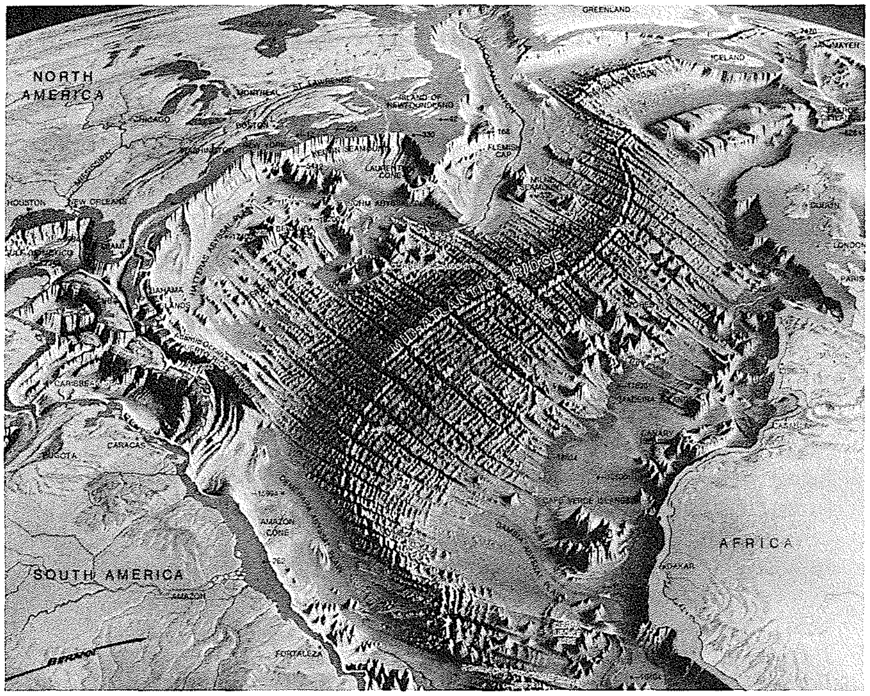
Biologists sampled the seas to measure the availability of plankton and thereby estimate potential fish concentrations from place to place. Meteorologists studied the geostrophic, or "turning," tendencies of ocean currents and developed the so-called dynamic method of current calculation, which Admiral Edward ("Iceberg") Smith adopted during the 1920s to aid the International Ice Patrol in tracking icebergs.

Summer School

The influence of the ICES was felt by scientists worldwide, and oceanographers soon ranked the importance of the council's work with that of the *Challenger* expedition. As the eminent American biologist Henry Bigelow remarked, for almost four decades the council "controlled the lines along which oceanography . . . advanced" in northern Europe. In the United States, however, modern ocean science remained in its infancy, confined to a handful of private laboratories on the Atlantic and Pacific coasts. There, part-time investigators struggled to use the new ICES methods without sufficient ship time or money.

In California, the Scripps Institution for Biological Research (now the Scripps Institution of Oceanography, at La Jolla) was begun, in 1892, as a portable laboratory-in-a-tent. Founded by biologist William Ritter, the informal collecting station took up a new location each summer, until Ritter had the good fortune to meet the wealthy newspaper baron, E. W. Scripps, and his sister, Ellen. They agreed to support his work. By 1906, Ritter had acquired a research ship and land on which to build a permanent laboratory. Unfortunately, for several decades, despite the Scripps family's generosity, a severe financial pinch limited the range of work done at Scripps. Not until the early 1940s, with the failure of the sardine fishery and the onset of World War II, did state or federal governments find compelling reasons to pour money into oceanography.

On the East Coast, the Woods Hole Oceanographic Institution (WHOI—"Whooey," as it is sometimes called) was organized in 1930. The laboratory built on the traditions and facilities of older institutions already established in Woods Hole, notably the Marine Biological Laboratory. Indeed, it was MBL director Frank Lillie who, in 1925, had urged the Rockefeller Foundation to make money available for a new oceanographic institution. The foundation eventually came through with $3 million. Within a year of its creation, WHOI had a three-story laboratory building, a new steel-hulled ketch (the *Atlantis*), and a distinguished director (Henry Bigelow).



A portion of the midocean ridge snakes beneath the Atlantic Ocean. Thanks to European and American interest, the North Atlantic has been the most thoroughly explored of any body of water. By contrast, much of the sea-bed terrain in the Southern Hemisphere has never been accurately mapped.

For a decade, WHOI was a summertime laboratory with a staff made up of a dozen university professors and their graduate students. The *Atlantis* made weekly cruises; regardless of the delicacy of digestive systems, all were expected to go to sea.* Much of the work done from the rolling decks of the *Atlantis* during the 1930s was biological. The ketch crisscrossed the Gulf Stream and Georges Bank, trailing plankton nets. Scientists measured the intensity of light at different depths to ascertain the limit of plant growth by photosynthesis. Summer workers produced studies on everything from "The Role of Bacteria in

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*Except women, who were routinely excluded from oceanographic cruises until the late 1950s. The reason usually given involved the ships' primitive plumbing, but one female stowaway on a WHOI vessel during the 1950s discovered that a far more important reason was the sailors' and scientists' firm belief that a research ship, like Huck Finn's raft, was a floating male refuge, where all hands were free to sweat, swear, play poker, and generally ignore the polite conventions. Today, less than 12 percent of the nation's 1,357 oceanographers are women.

the Cycle of Life in the Sea" to "Marine Erosion of Glacial Deposits in Massachusetts Bay." After Labor Day, most of the staff and all of the students returned to their universities. Often, the remaining scientists then sailed south on the *Atlantis* to work the Caribbean or Gulf of Mexico.

Helping the Navy

Some of the *Atlantis*'s winter duties during the late 1930s involved military problems. Oceanographers had worked intimately with the Navy during World War I to perfect the echo-sounder as a submarine detection device. (Sonic depth finders were later used to make profiles of the topography of the ocean floor.) While collaboration was infrequent during the years between the wars, Henry Bigelow did agree, in 1937, to send the *Atlantis* to the U.S. naval base at Cuba's Guantánamo Bay to help explain why the Navy's new directional sonar system refused to work on sunny afternoons.

The destroyer *Semmes* had been equipped with a sonar system that swept a beam of sound through the water like the beam of light from a flashlight. With this beam, the destroyer's crew attempted to locate a companion submarine, which cruised beneath the bay. Men with earphones sat deep in the ship, listening for the echoes that should bounce off the submarine when it came within sonar range. The sonar operators found that they could track the submarine every morning; but during the afternoons, something frequently went wrong, especially on windless days when the hot sun glared off the deep blue waters of the bay.

That is when WHOI was called in. After two weeks of shadowing the *Semmes*, the scientists aboard the *Atlantis* came up with an explanation. They discovered that in the mornings, the surface water of Guantánamo Bay was fairly well mixed; although the temperature of the water dropped with depth (and temperature was known to affect the speed of sound), the gentle gradient did not greatly distort the sonar's beam. On hot afternoons, however, a thin layer of very warm water formed over the cooler, deeper water, and the abrupt gradient, or "thermocline," bent the sonar's beam so badly that the submarine could come right up to the destroyer without being detected.

Obviously, a thorough understanding of how the temperature of the sea affected sound transmission was essential for effective submarine and antisubmarine warfare. While few men in or out of the Navy realized it at the time, the two weeks of research done on the *Atlantis* helped open the door to an enormous expansion in ocean science.

World War II lifted American oceanography out of the doldrums. It contributed to the ascendancy of physical and geophysical studies over marine biology. And it abruptly pushed the United States into the lead within the international oceanographic community, a position that it has retained.

A New Earth

Spurred by urgent needs for everything from accurate wind and wave predictions, which would aid amphibious landings, to an understanding of the sea-floor distribution of different ocean sediments (which distorted sonar pulses in distinctive ways), wartime Washington poured so much money into Scripps, Woods Hole, and other research laboratories that the budgets of these institutions had to be kept secret. The size of their staffs increased as much as 10-fold, and operations shifted from seasonal to year-round. Scientists could be found hanging hundreds of painted metal squares beneath local fishing wharves to see which compounds best resisted fouling. Others developed instruments such as the bathythermograph, which depicted temperature variations by depth and helped U.S. submarine crews "hide" acoustically from Japanese sonar. The contribution of oceanography to the war effort was significant. But it was dwarfed by the contribution of the war effort to oceanography.

Immediately after the war there was, to be sure, some question as to what role, if any, the federal government would play in ocean science. But before long, as the Cold War got under way, the Navy, the Atomic Energy Commission, the new National Science Foundation (1950), and other government agencies adopted a policy of long-term financing.* The postwar period became the time of real gain for oceanographers. Although the necessities of war had increased their numbers and the variety of their equipment, it was only in the years that followed that these strengths could be used for a basic investigation of the sea.

One of the most dramatic examples of postwar progress was provided by geologists and geophysicists, who developed an entirely new concept of the nature of the Earth's surface. Instead of

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*In 1982 alone, the federal government spent some $1.2 billion on marine science, including $375 million for Pentagon-sponsored research, $321 million to support the ocean-related activities of the National Oceanic and Atmospheric Administration, and $105 million for ocean research funded by the National Science Foundation. In addition, many corporations now finance various types of marine research, usually associated with resource extraction. No precise figures are available.

SEA-FLOOR SPREADING

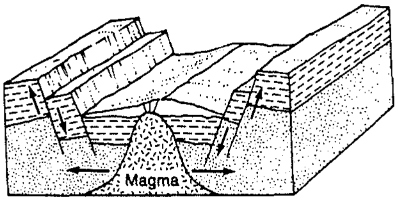
In The Origin of Continents and Oceans *(1915), geophysicist Alfred Wegener, noting the "fit" of the coastlines on either side of the Atlantic, advanced the theory of continental drift. He suggested that 100–200 million years ago there existed a single large continent, Pangaea, that was subsequently fractured into the seven major land masses that we have today. However, Wegener was unable to explain "what forces have caused these displacements." The answer was found not on land but under the sea, as investigations of the ocean floor yielded the theory of plate tectonics. Physicist Jean Francheteau explains:*

From the point of view of the earth scientist, our planet probably should be called Ocean rather than Earth, not only because 70 percent of it is covered by water but also because 60 percent of its solid surface is covered by the thin crust that is manufactured in a unique geologic mill at midocean.

In plate-tectonic theory the crust and the upper mantle of the earth are divided into the lithosphere, or strong layer, and the asthenosphere, or weak layer. The lithosphere includes the crust and part of the upper mantle. [It] is broken up into a set of fairly rigid plates that are much like rafts floating on the less rigid material of the asthenosphere.

The plates move at a rate of a few centimeters per year with respect to each other, and the boundary between two plates can be described according to the relative plate motion. At divergent boundaries the plates separate. At convergent boundaries the plates move toward each other, and one plate generally plunges under the other and into the asthenosphere in the process called subduction. At transform boundaries the plates slide past each other. The spreading center of the midocean ridge, where molten rock from the mantle is injected into the crust, is a divergent plate boundary.

The injection of magma, or molten silicate liquid, plugs the gap left by the moving apart of the plates [see diagram below]. The plates continue to diverge, however, and the plug is ultimately rifted open. A new cycle . . . begins. Meanwhile the crust formed in the previous round of upwelling is moving outward from the spreading center.



From "The Oceanic Crust" by Jean Francheteau, *Scientific American* (September, 1983). © 1983 by Scientific American, Inc. All rights reserved.

THE OCEANS AND CLIMATE

Weather (which exists in the short-term and changes quickly) and climate (which exists in the long-term and changes slowly) are determined by the interactions among water, air, land, and ice. The oceans, vast reservoirs of solar energy, play a generally stabilizing role. Slow to gain or lose heat, they warm the atmosphere during winter and cool it during summer, moderating extremes of temperature.

"In a sense," writes oceanographer Alastair Couper, "the atmosphere and the oceans constitute a single system of two fluids interacting with each other." The complicated feedback loops between these fluids—the chemical transactions, the interplay of winds and currents—are still not well understood. One question mark involves the impact of the sea on the level of carbon dioxide in the atmosphere, which is known to be increasing at a historically unprecedented rate (thanks largely to the burning of fossil fuels). There is 60 times more carbon dissolved in the ocean than exists in all the gaseous carbon dioxide of the atmosphere. To what extent does the sea regulate the global carbon-dioxide "budget"?

The capabilities of geodetic satellites have not only forged new links between oceanography and meteorology but have also prompted scientific interest in the possibility of long-range weather forecasting. Attention has been focused in particular on local variations in sea-surface temperature (SST) as predictors of weather patterns many months ahead.

SST fluctuations in the Pacific Ocean led meteorologists to suspect as early as May 1982 that *El Niño*—an anomalous warming of surface waters off the coast of South America—was on the way. Normally, the equatorial "easterlies" push seawater westward, building up a thick layer of warm surface water in the western Pacific. Only a thin layer of such water remains off the coasts of Ecuador and Peru, allowing nutrient-rich colder waters to well up from below and sustain an immense population of fish. Winds always blow from high-pressure to low-pressure areas. But every few years, the difference in atmospheric pressure between the eastern and western Pacific narrows; indeed, the pressure slope is sometimes reversed. This seesaw phenomenon—called the Southern Oscillation—causes the winds to collapse, even change direction. A mass of warm water moves back across the ocean, disrupting weather patterns throughout the Pacific basin and Western Hemisphere.

The most recent *El Niño*, which set in during July 1982, brought torrential rains to North and South America. It produced the snows that blanketed New England and the California storm that dogged Queen Elizabeth during February 1983. The shift of warm water also suppressed the upwelling of colder water off Peru and Ecuador, with disastrous results for the fish—and fishermen.

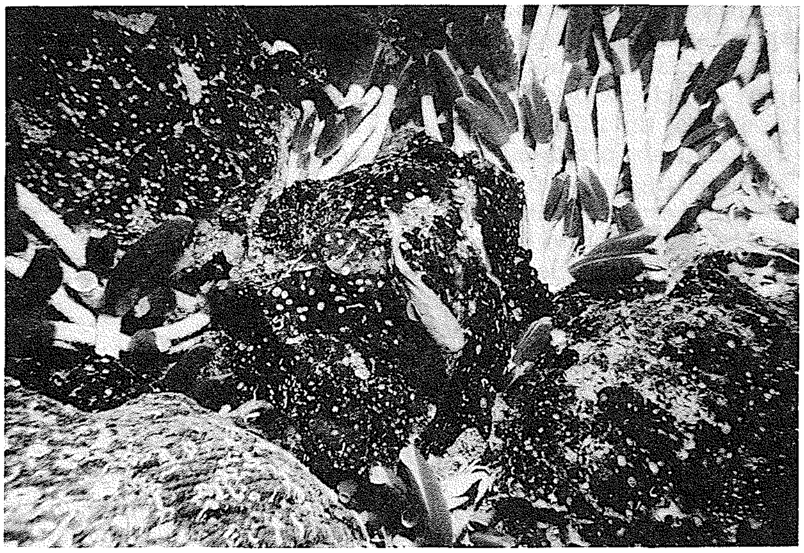
picturing the planet as permanently and statically divided into land masses and ocean basins, they postulated that the continents are situated on "plates" that are variously being pushed apart or driven together by a sea floor that is spreading along the axes of the midocean ridges. The theory of plate tectonics, first seriously proposed in 1960, seemed far-fetched to many. "What is the situation now with the new theory you are defending?" one Russian geologist wrote to a Canadian colleague, "There is simply no foundation to it." Bathymetric data, evidence from magnetic surveys, and the dating of undersea sediments eventually proved decisive. The validity of plate tectonics today is not seriously questioned (see box, p. 65).

Improved technology, including a new ability to drill deep holes in the sea floor and thereby probe once inaccessible layers of the Earth's crust, was crucial in advancing plate tectonics. Postwar oceanography has also made use of manned bathyscaphs (such as the French *Trieste*) and manned submersibles (such as the American *Alvin*), vessels capable of operating miles below the surface of the sea. Not only geology but also marine biology has benefited from development of new instruments such as remote-controlled, deep-sea cameras. One such camera, towed by the *Knorr* out of Woods Hole in 1977, brought back the first pictures of sea-floor vents and the remarkable assemblage of creatures that live around them.

Oases

Along the East Pacific Rise, the Galápagos Rift, and the Guaymas basin in the Gulf of California, at an average depth of 8,250 feet, chimney-like vents spew hot (up to 350 degrees Celsius), mineral-laden water into the perennial night of the abyss. These fissures, created by volcanic activity where the sea floor is spreading, are surrounded by communities of swaying tube worms three to six feet long, clams a foot wide, reefs of mussels, ambling crabs, a variety of darting fish, and clouds of bacteria. Everything about these oases is extraordinary.

For one thing, how can such a large population be supported miles from the ocean surface—miles, in other words, from the plankton that is the beginning of the food chain in the sea? As it happens, the tube worms and clams and other creatures can thrive because bacteria in these communities take the place of plants. The bacteria in turn derive their energy not from the sun via *photo*synthesis but from the vents via *chemo*synthesis; they live on hydrogen sulfide. The discovery of an ecosystem whose food chain is independent of the sun—the only one of its



Crabs, tube worms, and brotulid fish near a hot vent at the Galápagos Rift in the Pacific. One mystery: How do such "vent communities" re-establish themselves around new vents—perhaps 1,000 miles away—when old vents clog up? Most vents "die" within decades.

kind ever found—has far-reaching implications. As Roger Revelle, former director of the Scripps Institution, pointed out in a recent lecture, one of the perennial questions that man asks himself is: How (and where) did life begin? The undersea vent environment may help supply new answers.

Physical oceanography, meanwhile, is fast being transformed by the satellite and the computer. The measurements made from above of the variable temperature of the sea, of its roughness, color, topography, and so forth, will soon be so accurate, so closely spaced, and so frequently repeated, that oceanographers will attain a new level of understanding of the worldwide patterns of air and water circulation, and of the relationship between sea and atmosphere. Already, ocean-scanning satellites are capable of measuring the shape of the ocean surface with a radar altimeter that is accurate to within two inches.

When routinely employed, such measurements will give scientists their first accurate depiction of the low but massive mounds of wind-blown water from which some major ocean currents, including the Gulf Stream, arise. With virtually simultaneous observations of the whole ocean system, oceanographers expect that meteorologists will be better equipped to predict the onset and consequences of such phenomena as the Southern Oscillation, which, giving rise to *El Niño*, disrupted normal weather patterns throughout the world in 1982–83 (see box, p. 66). It is also critically important that scientists come to understand the role that the oceans play in accelerating or retarding the build-up of carbon dioxide in the atmosphere, which, thanks to the "greenhouse effect," could result in a gradual warming of the Earth's atmosphere and partial melting of the polar ice caps. "If a global warming of about three or four degrees Celsius were to occur over the next hundred years," a 1983 National Academy of Sciences report warned, "it is likely that there would be a global sea-level rise of about 70 centimeters (2.3 feet), in comparison with a rise of about 15 centimeters over the last century."

Oceanography has advanced rapidly in the 108 years since the *Challenger* circled the globe. During that time, the science has been both led and driven by a variety of motives. During the past two decades, many of the most exciting developments in oceanography have come in basic science, and the pursuit of basic science will continue to help shape oceanography's character. So will continued improvements in technology. But oceanographic research is expensive. The two-year Lewis and Clark expedition in 1804–06 cost the United States government less than $275,000 (in 1984 dollars), an amount that would cover the operations of a typical ocean research vessel for about a month. The projects that Washington most readily subsidizes are those that have obvious practical applications: nuclear waste disposal, weather forecasting, oil and gas exploration. One cannot really cry foul; it is, after all, the taxpayers' money.

But we should take care lest a consuming U.S. interest in defense and economic growth constrict the range of imaginative ocean studies. Here as elsewhere, the distinction between basic and applied research is in many respects artificial. The quest for answers to seemingly esoteric questions has already yielded insights into the origins and functioning of the natural world; such insights are essential if the planet's resources are to be exploited without doing harm. As Francis Bacon wrote in 1620, "Nature, to be commanded, must be obeyed."