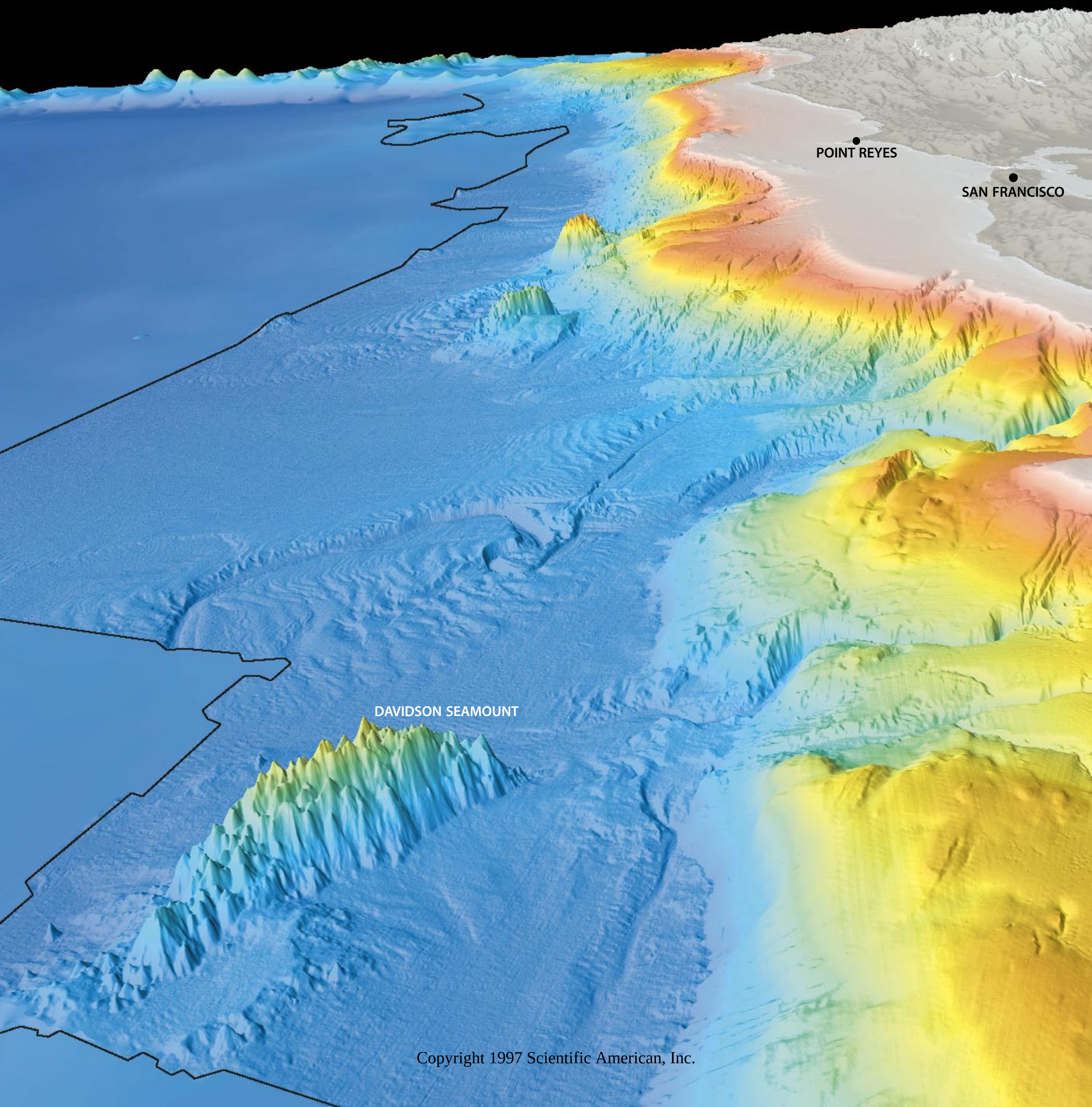
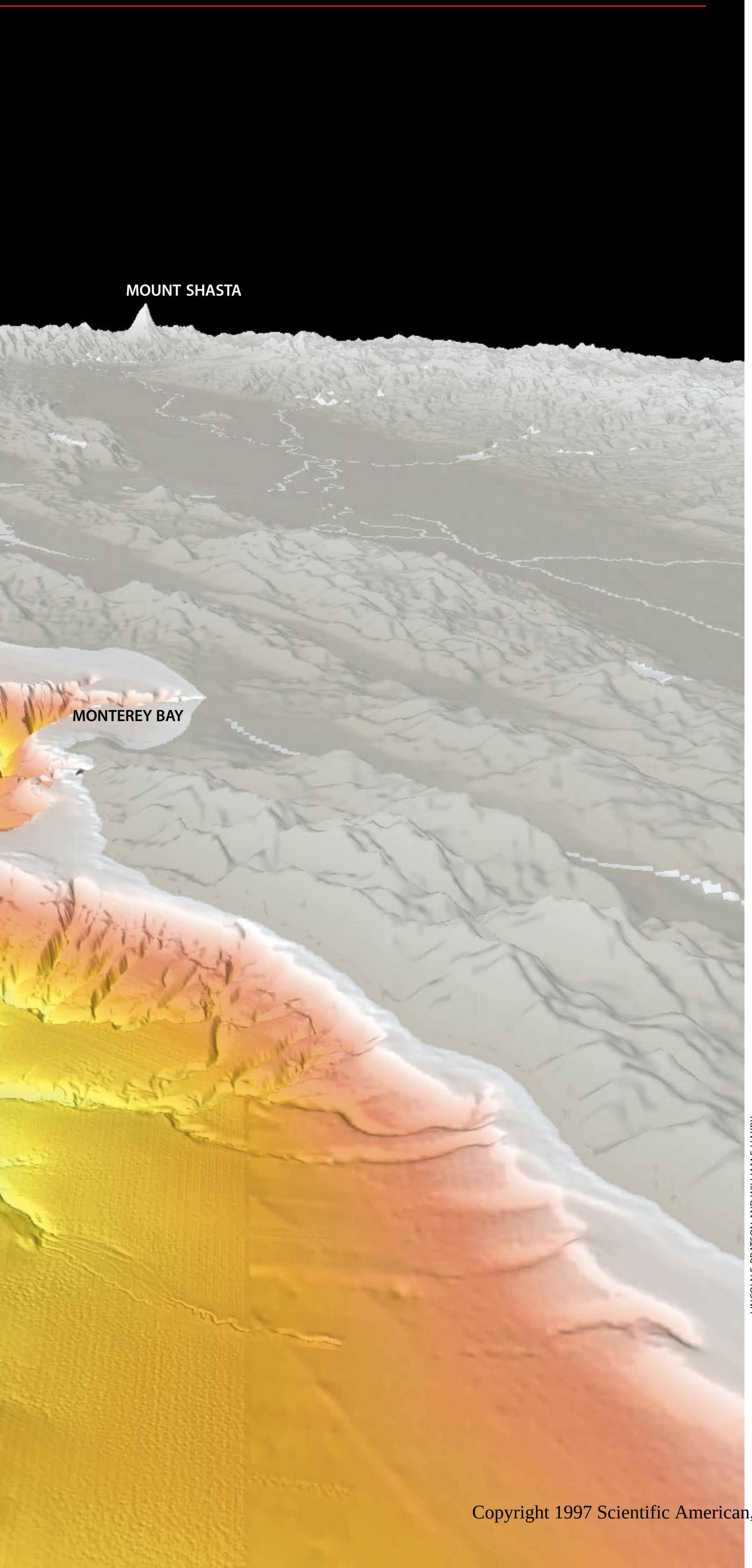
Panoramas of the Seafloor

Modern sonar techniques map the continental margins of the U.S. and reveal the richly varied scenery usually hidden underwater





LINCOLN F. PRATSON AND WILLIAM F. HAXBY

by Lincoln F. Pratson
and William F. Haxby

In 85 B.C. or thereabouts, a Greek named Posidonius set sail on a curious mission. He was not carrying freight or passengers, nor was he engaged in war. He simply wanted to answer an age-old question: How deep is the ocean? Halting his vessel in the middle of the Mediterranean Sea, Posidonius coaxed his ship's crew to let out nearly two kilometers of rope before a large stone attached to the end of the line finally hit bottom. He and his men must have been jubilant—at least until they realized that they then had to haul the great weight back on board.

For the next 2,000 years, naval surveyors and oceanographers continued to use exactly the same laborious line-and-sinker method to probe the ocean's depths. It is not surprising that they made scant progress. Then, during the 1920s, oceanographers developed the first echo sounders—instruments that could measure the water's depth by bouncing sound waves off the bottom. With the wealth of measurements these devices provided, scientists got their first glimmers of the true shape of the ocean basins.

In the past few decades engineers have constructed ever more sophisticated acoustic devices to speed the mapping of this hitherto hidden part of the earth. The major impetus for these developments initially came from concerns about national defense, but more recently economic considerations have taken precedence.

Beginning with the U.S. in 1981, the world's maritime nations declared the waters and seafloor within 200 miles of their shores to be "Exclusive Economic Zones." To help assess the value of the vast undersea expanse claimed by the U.S., the National Oceanic and Atmospheric Administration began surveying parts of the newly annexed area in 1983. That effort (which continued until 1993) mapped more than 200,000 square kilometers of the seafloor off the coasts of the Atlantic and Pacific oceans and the Gulf of Mexico.

Over this same period, the National Science Foundation funded two smaller sur-

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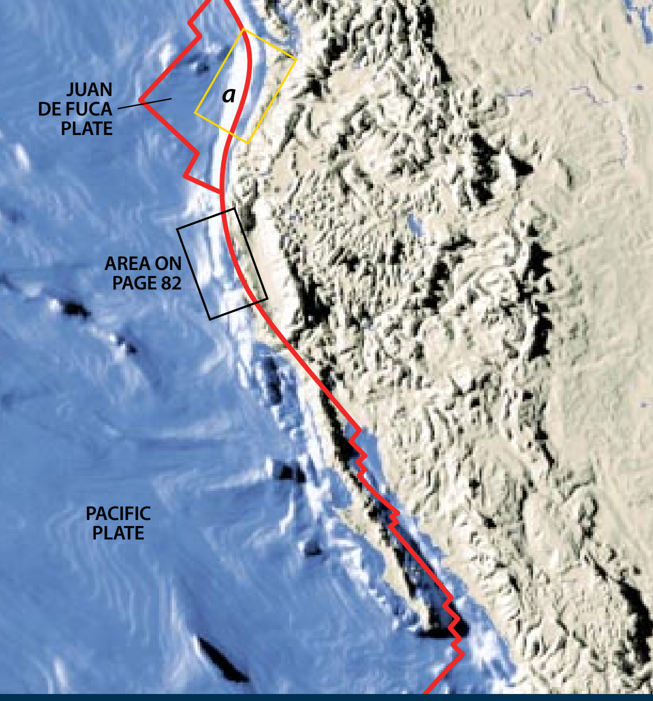
COMPUTER-GENERATED IMAGES of the seafloor surrounding the U.S. show geologic features in great detail in regions where specialized sonar mapping has been done (*right of black line*).

SEAFLOOR FAILURE carved a pocket in the continental slope offshore from central Oregon. The trail of debris extending outward from the crescent-shaped embayment in the continental slope marks the path the material traveled. The excavated pocket is six kilometers wide—about the width of the island of Manhattan. Some of the dislodged blocks that now rest on the continental rise are as tall as a modern skyscraper. The collapse that sent these huge chunks tumbling down the slope was most likely triggered by an earthquake. Such dramatic failures of the continental slope can generate violent tsunamis that may inundate the coast nearby or travel across the Pacific and create havoc on distant shores.



EDWARD BELL

THREE TYPES OF MARGINS exist along the borders of North America. The sides facing the Atlantic Ocean and the Gulf of Mexico are termed passive margins, because they are embedded within the North American Plate and simply ride along with this great slab as it moves. The western margin of the U.S., on the other hand, lies along the leading edge of the North American Plate, where it bumps and grinds its way past oceanic crust underlying

ILLUSTRATIONS BY LINCOLN F. PRATSON AND WILLIAM F. HAXBY, EXCEPT AS NOTED

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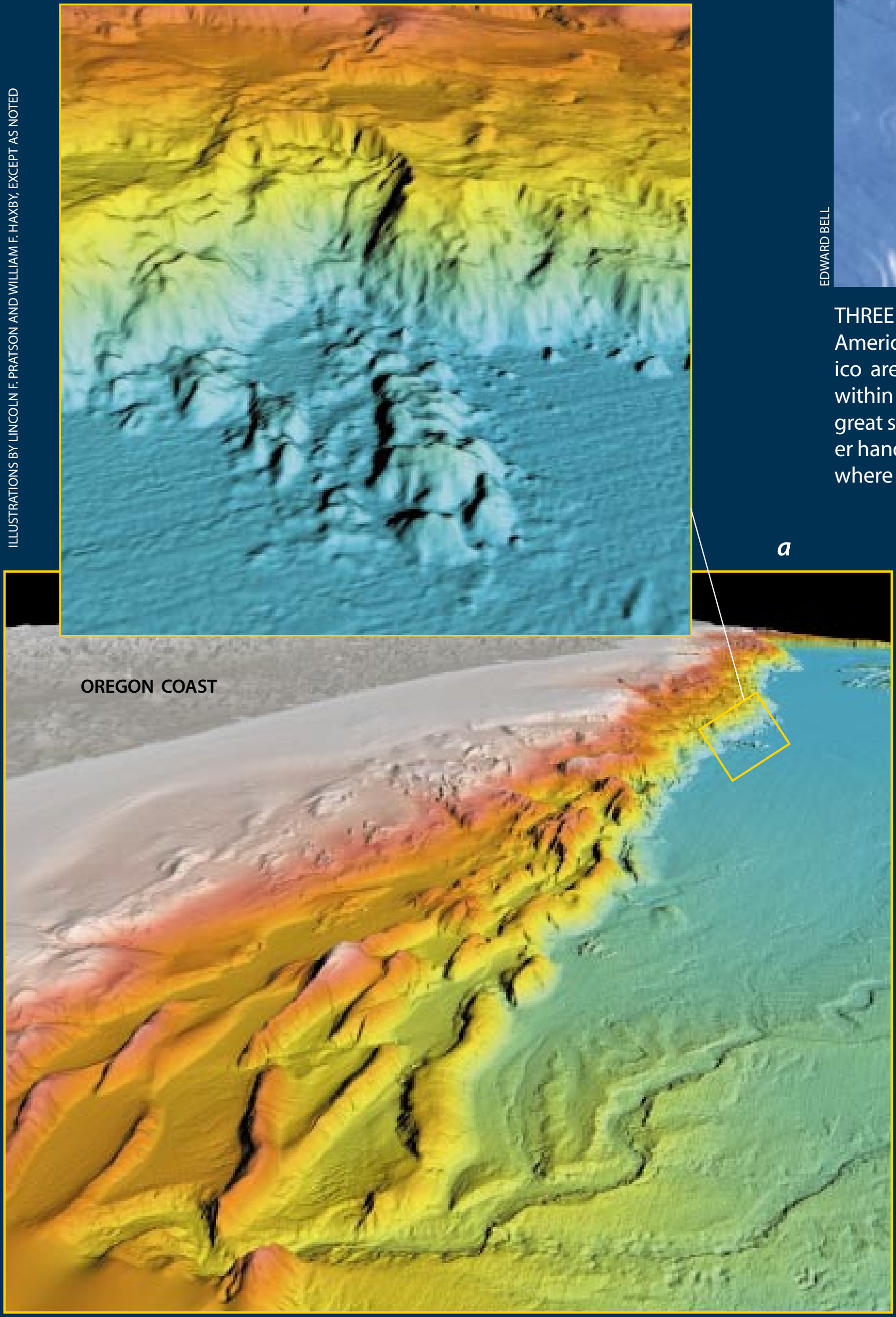
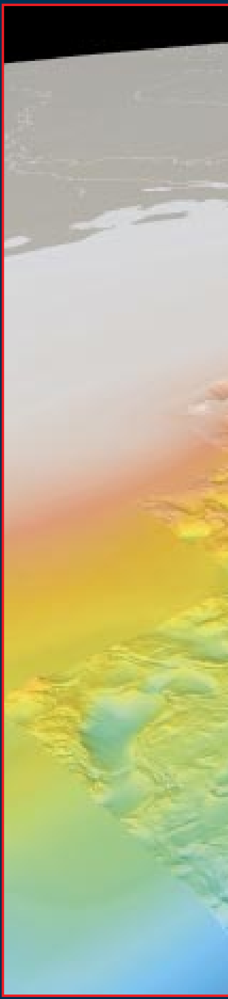
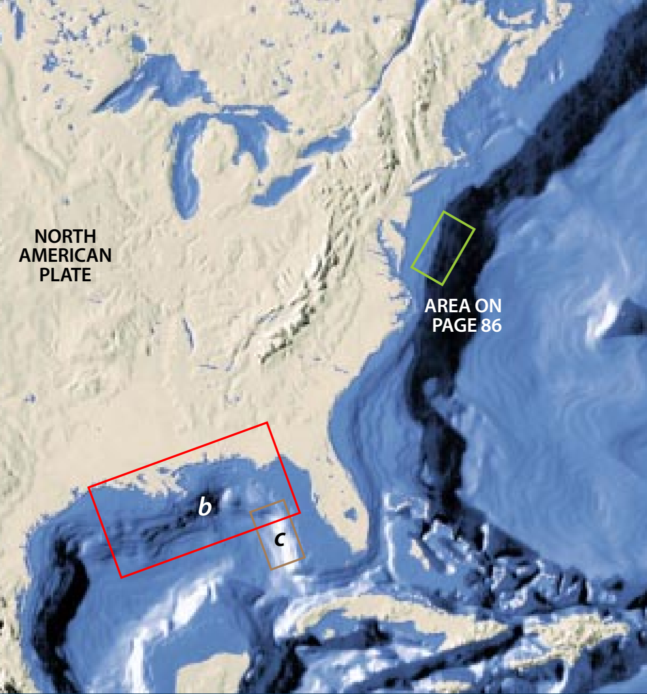


FOLDED CARPET of sediments covers the seafloor offshore of Oregon. The undulations result from the head-on collision between the North American and Juan de Fuca plates. Like a colossal bulldozer, the North American Plate scrapes sediments off the down-going Juan de Fuca Plate and piles them into folds. To the north (*lower left*), the folds of sediment form distinct ridges. To the south (*upper right*), where part of the Juan de Fuca Plate breaks through its sedimentary cover, the folds are stacked so closely that they form terraces.

b

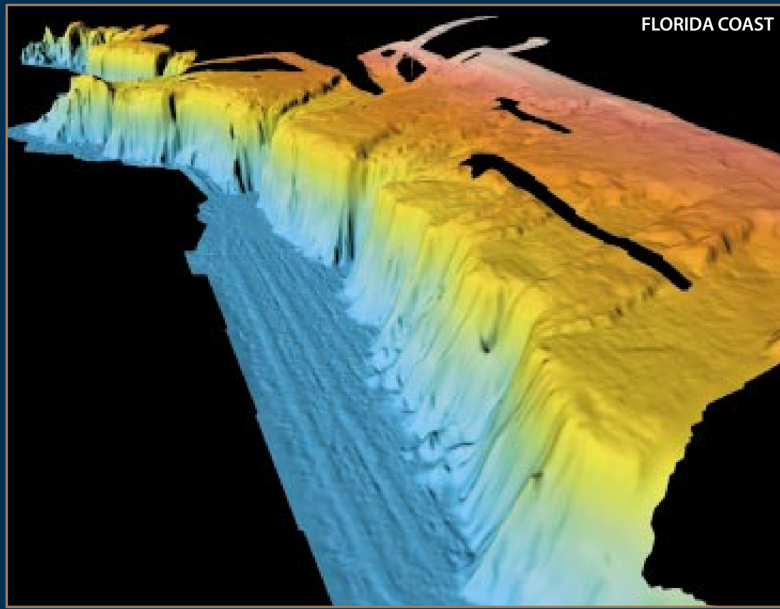


CRATERLIKE FEATURES pockmark the seafloor offshore from Mississippi to eastern Texas. These small basins are filled with thick accumulations of sediment—and, in some spots, billions of barrels of oil and gas. The ridges and domes between the basins hide shallowly buried salt bodies of various sizes and shapes. This salt formed initially by the evaporation of Gulf of Mexico waters (some 180 million years ago). The salt layer was then buried by a massive load of sediment eroded from the Rocky Mountains and carried into the gulf by the Mississippi River. Because salt resists compression, it will flow rather than compact. Hence, under the weight of the overlying sediment, giant blebs of the salt have bubbled upward and spread out toward the open sea.

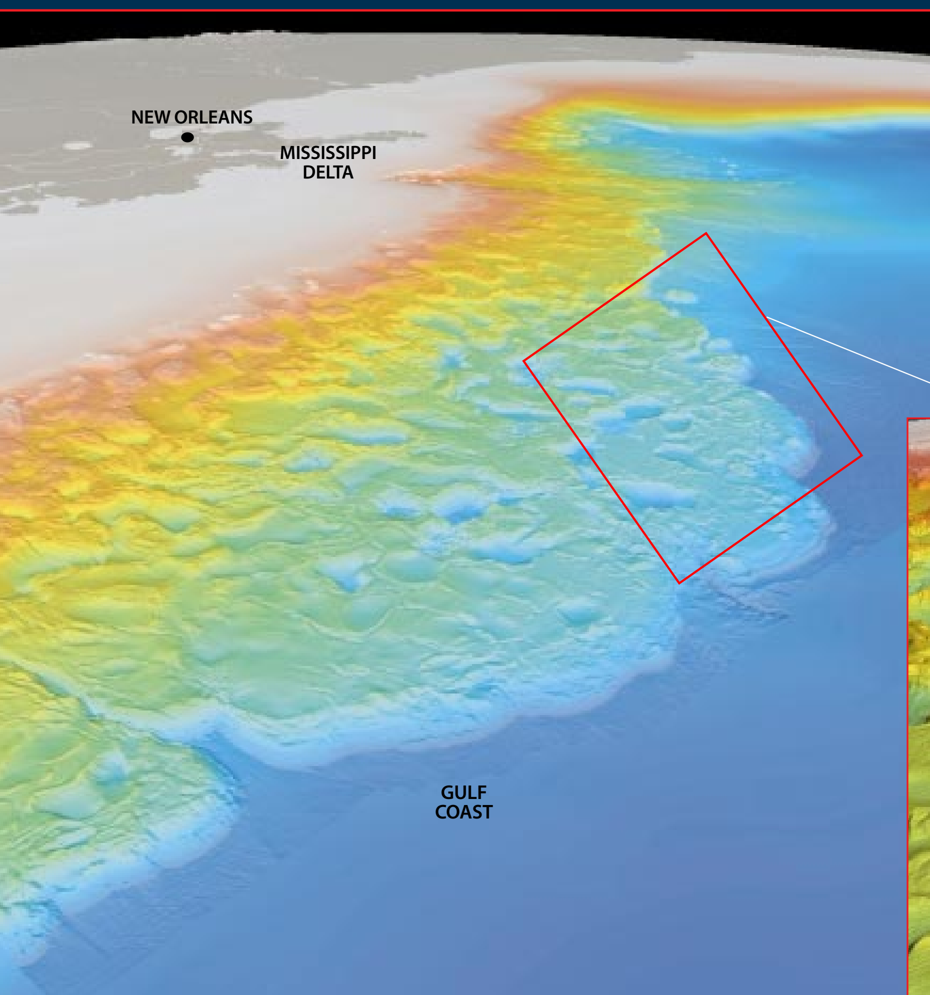


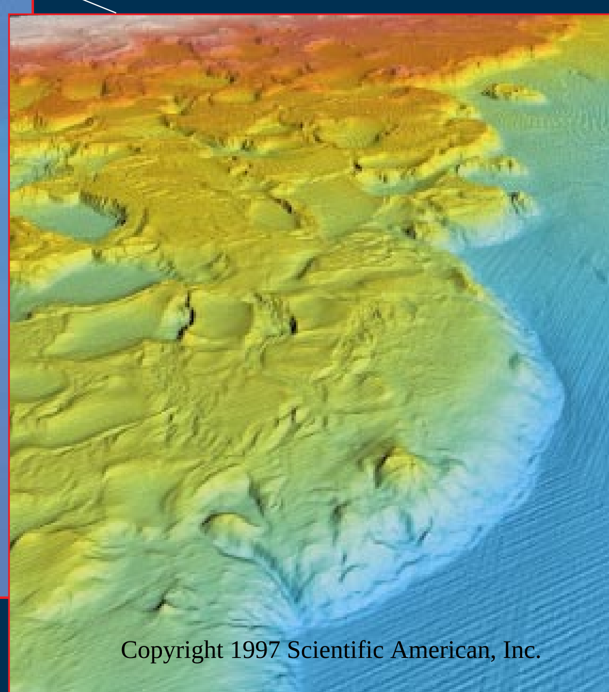
the Pacific Ocean. This collision takes two forms. Through most of the length of California (a strike-slip margin), the North American Plate slips sideways past the Pacific Plate along a system of near-vertical fractures in the earth collectively known as the San Andreas Fault. Farther up the coast (a convergent margin), the North American Plate is bulldozing its way over a sliver of oceanic crust named the Juan de Fuca Plate.

c



MILE-HIGH CLIFF marks the edge of the continental slope west of Florida. This undersea precipice, known as the Florida Escarpment, stands more than four times as high as the Empire State Building. Whereas the tilt of the continental slope elsewhere is typically just a few degrees, the face of the escarpment is, on average, slanted at 35 degrees. In many places the walls of the escarpment are near vertical. The seafloor here is made up of the countless skeletons of marine organisms that have cemented together. The gradual accumulation of this material once formed a gently dipping ramp. But some force, perhaps great sweeping currents, eroded the base of the slope. Today extremely salty groundwaters seep out of the face of the escarpment and dissolve the rock there. Weakened by this decay, the slope can collapse, taking a good deal of overlying material with it. Curiously, little if any vestige of the vast amount of material worn away can be found along the base of the cliff.





Seafloor Mapping Tools

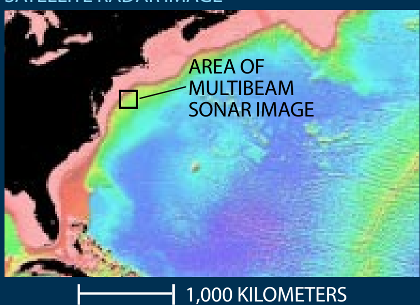
Our multibeam sonar images represent just one way scientists can visualize the seafloor. Other approaches are also used, and each has its peculiar advantages and shortcomings.

Satellites (*a*) cannot measure seafloor depth directly, but they can sense variations in the elevation of the water at the surface of the ocean. The U.S. Navy's Geosat satellite, for example, can measure the distance to the ocean surface to within five centimeters by bouncing radar pulses off the water below it. Because the precise position of the satellite is known, such determinations provide a measure of sea-surface height.

The ocean surface can vary in relief by as much as 200 meters. These undulations reflect minute differences in the earth's gravity from place to place that cause water to distribute itself unevenly. Most commonly, these gravitationally induced variations in the ocean surface are caused by rugged seafloor topography. For instance, a massive, submerged volcano that is 2,000 meters tall and 40 kilometers wide will pull water toward it, producing a bulge about two meters high in the ocean surface above it. But undersea features smaller than 10 kilometers across do not generally possess sufficient mass to affect the ocean surface and thus go undetected by satellite radars. What is more, gravity variations (particularly near continental margins) can reflect differences in the density of the underlying rock rather than topography. Still, satellites provide broad, if less than perfect, maps of regions not yet surveyed with ships.

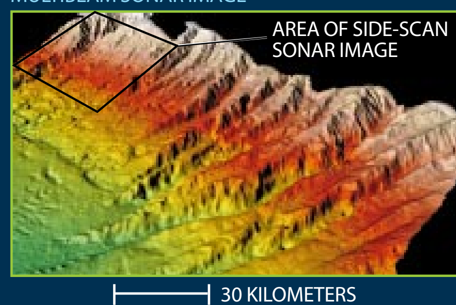
Multibeam sonar (*b*) bounces sound off the seafloor to gauge ocean depth. In contrast to simple echo sounders, this modern technique employs an array of sound sources and listening devices mounted on the hull of the survey vessel. Every few seconds the sources emit a burst that reaches only a slim strip of seafloor aligned perpendicularly to the direction the ship is moving. At the same time, the listening devices begin recording sounds reflected from the bottom. This equipment is arranged to detect sounds com-

SATELLITE RADAR IMAGE



WALTER H. F. SMITH *National Oceanic and Atmospheric Administration*

MULTIBEAM SONAR IMAGE



LINCOLN F. PRATSON AND WILLIAM F. HAXBY

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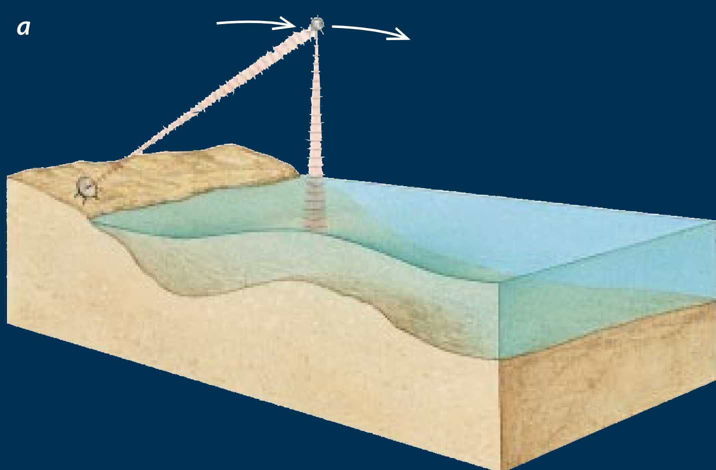

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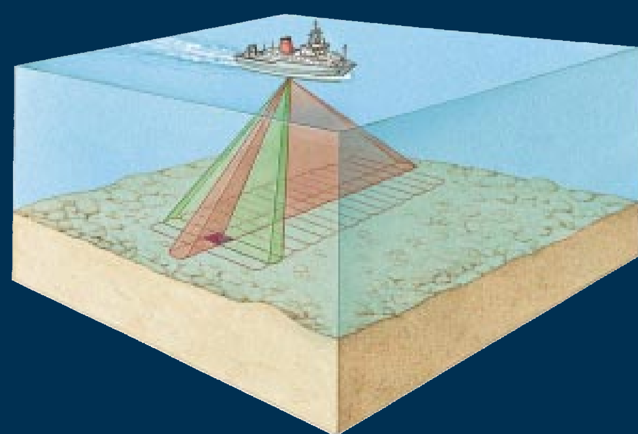

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veys to study parts of the seafloor near the coasts of New Jersey and western Florida. All the vessels involved used multibeam sonars, the most modern form of instrumentation available for measuring the topography of the ocean bottom.

These surveys provide unprecedented views of the country's continental slope. Although no sunlight actually penetrates to these great depths, computers can render images of seafloor vistas as they would appear with the oceans drained. Such a perspective is particularly valuable in planning industrial activities offshore. For example, submarine cables increasingly carry international communications, and petroleum producers are moving drilling platforms into ever greater depths of water. These enterprises require maps of where the seafloor appears to be stable—not prone to subsea avalanches or violent currents. Disposal of waste at sea also demands this information, because currents running along the bottom can disturb the sites where waste settles. Bottom surveys further help geologists to locate offshore fault systems and to assess their risk of triggering earthquakes.

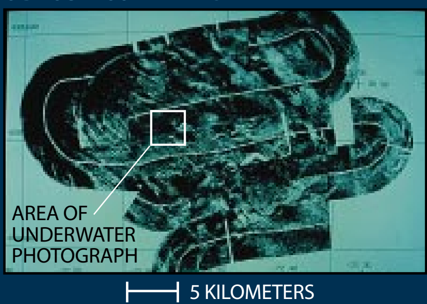
On a broader scientific level, undersea mapping is providing fundamental knowledge about the geologic forces that shape the ocean floor. Images such as those we have created offer scientists a way to take in vast stretches of undersea terrain in a glance—an ability they have long enjoyed while studying the surface of distant moons and planets. That perspective now offers some fascinating new insights into the marvelously complex evolution of the earth. SA ing only from within a series of narrow seafloor corridors that are aligned parallel to the ship's direction. Thus, the sound reflections received at the ship emanate from the regions where the slim strip of sound and the listening corridors intersect. The timing of these reflections provides a profile of seafloor depth. Such profiles are recorded every few seconds while the survey ship moves over the seafloor, and so successive observations build up a continuous swath of coverage along the ship's track. By running the ship in the same pattern one mows a lawn, scientists can produce a complete map of an area. With less than 200 vessels outfitted with the necessary equipment, however, charting the entire seafloor in this way would require hundreds of years.

Side-scan sonar (*c*) provides yet a different perspective on what the seafloor looks like. The equipment is usually attached to a "sled" that is towed behind a ship. Two sonar units, affixed to either side of the sled, act as both sound sources and listening devices. These units emit bursts of sound outward, to either side. If the seafloor is flat and smooth, none of the energy emitted will be reflected back (as with a beam of light directed obliquely onto a mirror). But if the seafloor is rough, the sound hitting the bottom will be scattered in all directions, and some will return to the sonar sled (just as a beam of light illuminating ground glass will reflect in all directions). By equating the amplitude of the recorded echoes to different shades of gray and displaying the results to show the distance from the sled, scientists can obtain an image of the texture of the seafloor that looks similar to a black-and-white photograph. But like a single aerial photograph, a side-scan sonar image does not indicate the heights of the surface below.

The most accurate and detailed view of the seafloor is provided by underwater photography (*d*), using either cameras towed along the bottom, piloted submersibles or remotely operated vehicles. Such camera-carrying equipment gives researchers the opportunity to explore the seafloor up close. Yet because even the most intense illumination does not penetrate seawater effectively, photographic views obtained in this way are limited to the short distances that artificial beams of light can penetrate.

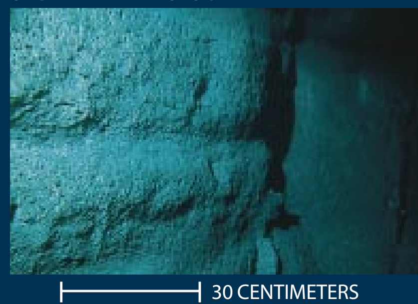
—*L.F.P. and W.F.H.*

SIDE-SCAN SONAR IMAGE



LINCOLN F. PRATSON AND WILLIAM B. F. RYAN

UNDERWATER PHOTOGRAPH



LINCOLN F. PRATSON

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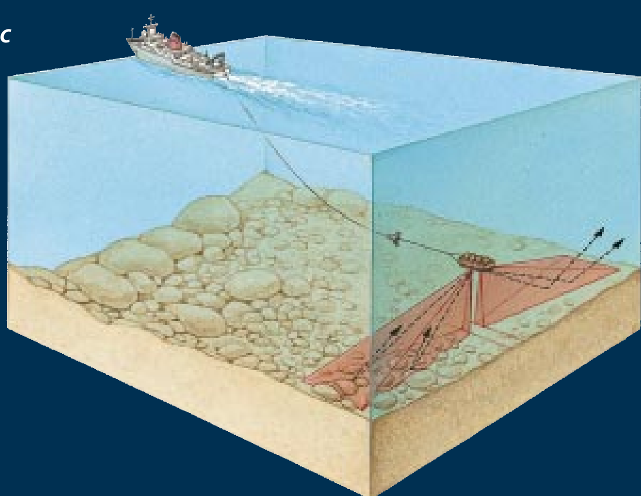

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ROBERTO OSTI

The Authors

LINCOLN F. PRATSON and WILLIAM F. HAXBY have worked together for two years probing the continental margins of the U.S. Pratson completed his Ph.D. in geological sciences at Columbia University in 1993. He then studied the topography of the seafloor for the Office of Naval Research at Columbia's Lamont-Doherty Earth Observatory. In 1996 he joined the Institute of Arctic and Alpine Research at the University of Colorado. Haxby earned his doctorate from Cornell University in 1978. Since then, he has conducted investigations of the ocean basins as a research scientist at Lamont-Doherty Earth Observatory.

Further Reading

SWATH BATHYMETRIC MAPPING. Special issue of *Journal of Geophysical Research*, Vol. 19, No. B3; March 10, 1986.

IMAGING THE OCEAN FLOOR: HISTORY AND STATE OF THE ART. Peter R. Vogt and Brian E. Tucholke in *Geology of North America*, Vol. M: *The Western North Atlantic Region*. Edited by P. R. Vogt and B. E. Tucholke. Geological Society of America, 1986.

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National Geophysical Data Center World Wide Web site available at http://www.ngdc.noaa.gov/mgg/mggd.html

