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U.S. Department of the Interior/Geological Survey

Marine Geology: Research Beneath the Sea



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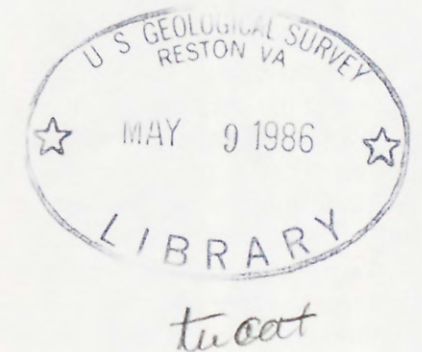


The USGS research vessel *Neecho* is used for studies of nearshore and inland water (USGS photo).

Offshore, deep-water research is conducted from the USGS' R/V *S. P. Lee* (front cover, photo by George W. Moore, USGS).

Marine Geology: Research Beneath the Sea

by Sarah B. Griscom



"There is, one knows not what sweet mystery about the sea, whose gentle awful stirrings seem to speak of some hidden soul beneath."

—Herman Melville



Imagine the ocean basins drained of all their water. What would the bottom topography look like? Were mountain ranges and carved canyons hidden beneath the dark waters? How old are the rocks and sediments on the ocean floors? Geologists in the early nineteenth century speculated that the ocean floors were dull expanses of mud—featureless and flat. For centuries, naturalists also thought that the oldest rocks on Earth were on the ocean floors. They believed that the present-day ocean basins formed at the very beginning of the Earth's history and throughout time they had slowly been filling by a constant rain of sediment from the lands. Data gathered since the 1930's have enabled scientists to view the seafloor as relatively youthful and geologically dynamic, with mountains, canyons, and other topographic forms similar to those found on land. The seafloor is no more than 200 million years old—a "young" part of the globe's crust compared to the continents which may contain rocks nearly 20 times that age.

Scope of Marine Geology

The Marine Geology program of the U.S. Geological Survey (USGS) strives to increase our understanding of the geology of the lands covered by water, just as the Survey's program on land has, since 1879, worked to understand the geology of U.S. lands ashore.

Marine geologists compile data about the topography or shape of the ocean floors, the distribution and type of bottom sediments, the composition and structure of the underlying rocks, and the geologic processes that have been at work throughout the seafloor's history. Using this information, marine geologists assess the mineral resources of the seafloor, predict the location of certain hazards, investigate marine geologic processes, and, in a more aesthetic sense, add to our overall scientific understanding of the Earth.

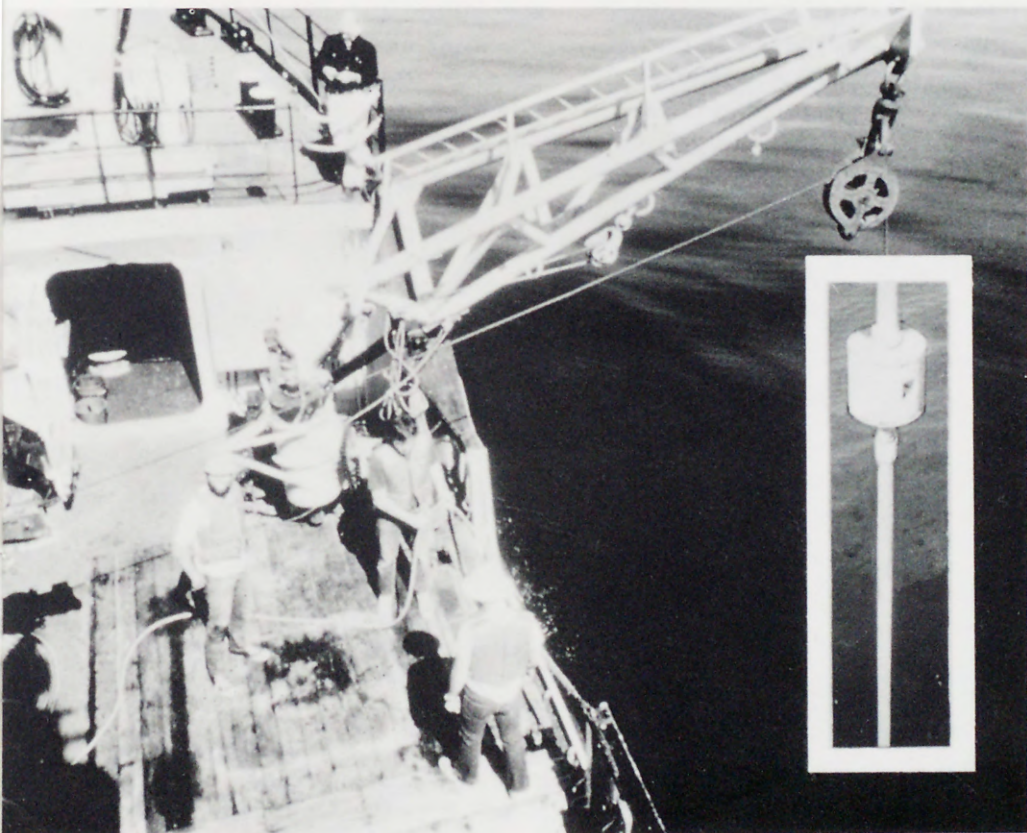
Methods and Equipment Used by Marine Geologists

Most of the tools and methods used to study the ocean floors have been invented and developed within the last half-century. Marine geology, in this regard, is still a relatively young science with many unexplored frontiers.

Because direct observation of the seafloor is difficult and time consuming, virtually all marine re-

search requires vessels and sophisticated oceanographic instrumentation. The USGS now uses from 12 to 15 ships of various sizes, and from these floating laboratories marine geologists deploy their instruments.

The quickest and easiest method of sampling the seafloor from a ship is by coring using a long metal pipe weighted at the top. The pipe is attached to a long multipurpose cable and is allowed to "free-fall" into unconsolidated sediments on

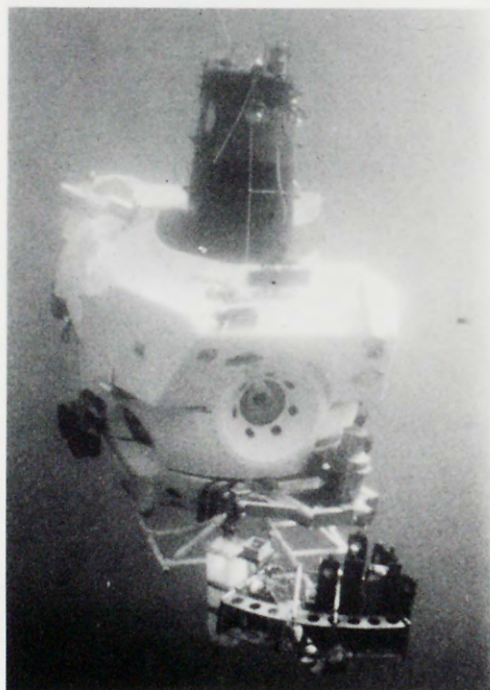


Gravity corers (inset) collect samples of seafloor sediments; the cores give valuable information on the Earth's recent climatic history (*photo by H. Gary Greene, USGS*).

the bottom. Data from core samples obtained by this method provide much information about the Earth's recent geologic history—for example, comparisons of the relative dates of volcanic eruptions and periods of glaciation. Highly disturbed or specially sorted layers can document catastrophic submarine landslides initiated by earthquakes. Hard bedrock is sampled by dragging dredges along the bottom, or up submarine cliffs or canyons to dislodge and recover pieces of rock.

Several new types of marine research vehicles have been developed that are proving to be valuable tools for marine geologic studies. They allow scientists to

descend beneath the water to observe and sample the seafloor. A small-sized deep submersible carries one navigator and one scientist, but some larger ones operate as much as 6,000 feet below the ocean's surface and carry a five-person crew. The deepest oceanic trenches at depths exceeding 7 miles have been visited by these vessels. Most submersibles are equipped with cameras, lights, mechanical arms for collecting samples, and can accommodate specialized instruments for measuring shear strength, inclination of the sediment surface, and temperature of sediments. These research vehicles are also used to investigate the nature of bottom



The deep submersible *Alvin* carries two scientists and one navigator to the seafloor. Mechanical arms dislodge samples of rock. Cameras, water samplers, and many other instruments collect an array of data (photo courtesy of Woods Hole Oceanographic Institution).

sediments, submarine canyons and seamounts, mineral deposits on the ocean floor, and submarine volcanoes.

In 1963, the National Science Foundation initiated a worldwide investigation of the seafloors called the Deep Sea Drilling Project (DSDP). Using technology developed by the petroleum industry, DSDP ships drilled and recovered extensive core sections, some over a mile long, from the ocean floor. In certain areas of the world, some of the oldest sedimentary rocks on the ocean floor record an uninterrupted rain of sediment for over 180

million years. These rocks are mostly the skeletons of countless microscopic plankton and clay-sized particles. If the history of the Earth is to be better known, it is essential to look to the sediments and sedimentary rocks in the oceans where the record is more complete. Information about the ancient climates of the Earth, oceanic current patterns, and variations in volcanic activity in the past can be found within these rocks.

Geophysical surveys provide a more sophisticated means of gathering data about the ocean floor.



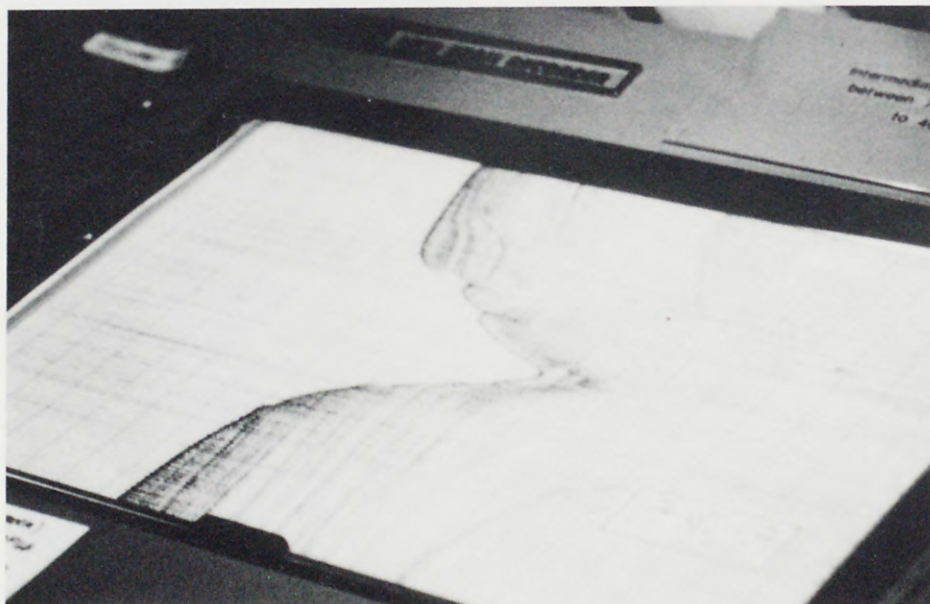
Long coring pipes of the Deep Sea Drilling Project could recover a complete column of sediment and rock over a mile long (*photo by H. Gary Greene, USGS*). The DSDP has been succeeded by the Ocean Drilling Program.

Information about the nature of sediment-covered bedrock can be obtained by shipboard gravimeters, which measure the rocks' density, and by magnetometers, which measure their magnetic properties. Seismic surveys, using reflected sound waves, give valuable information about submarine topography and the thickness and folding and faulting of rocks that are covered with sediment. Seismic surveys are particularly useful for locating oil and gas deposits commonly found trapped in deep accumulations of sedimentary rocks.

Seismic sound waves can be made by releasing compressed air, high voltage spark, mechanical clappers, or electronic pulse to

create a spectrum of sonar frequencies. The returning signals, or echoes, are printed on moving chart paper to create a graphic profile, or cross section, revealing the sediment/rock layers. The profiles are recorded with great clarity and in many cases show structures as deep as 6 miles beneath the seafloor.

Side-scan sonar, the latest acoustic system, sends out beams of sound waves sideways from the ship's course to map the seabed topography in broad swaths. Irregularities in the seafloor topography alter the energy in the signal bounced back to the receiver and these irregularities are used to

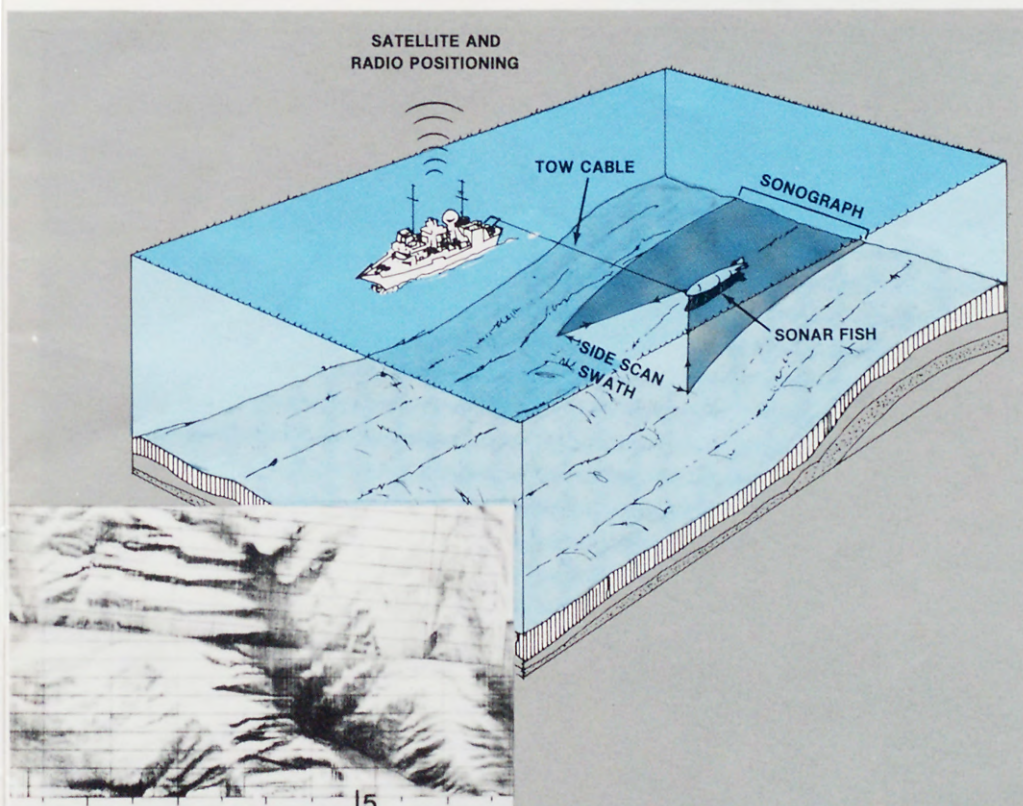


Seismic recorders are used to identify the depth to the ocean floor and the configuration of its sediment and rock layers. In this graphic record, the ship has just transected a submarine canyon (photo by Jeep Johnson, New York City).

produce an acoustic picture of the ocean floor. This system is especially useful for mapping large frontier regions, but it also can be used to map features as small as 20 feet across. Intricate patterns of meandering gullies and channels of oceanic canyon systems are transformed by side-scan sonar into a two-dimensional format much like an aerial photograph.

As in all scientific fields, computers are important tools for marine geologists. All large re-

search vessels carry banks of multipurpose computers. Magnetic and gravity data are recorded continuously on computer tape throughout the day and night. Another type of onboard computer system receives signals from navigation satellites and radio beacons and can locate a ship's position to within 300 feet on the often featureless expanse of open ocean. Onshore computers perform statistical analyses, plot maps, and transform seismic data into a clearer form.

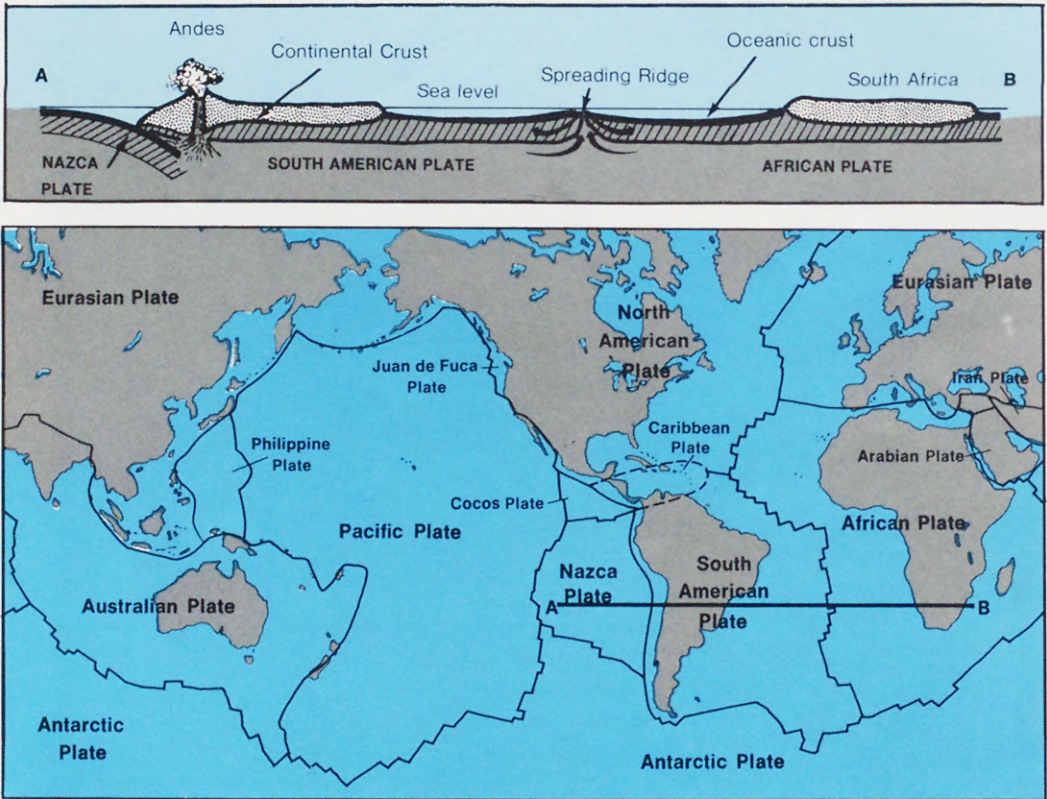


The side-scan sonar fish sends out acoustic signals in a broad swath. Inset is a sonograph of a submarine canyon system (photo courtesy of Bonnie A. McGregor, USGS).

Plate Tectonics

In the 1960's the unifying theory of plate tectonics was proposed to explain many regional and global geologic phenomena, including drifting continents, spreading sea-floors, and the worldwide distribution of mountains, earthquakes, and volcanoes. According to the plate tectonic model, the Earth's outer crust is a mosaic of gigantic continental and oceanic crustal plates, all of which are in motion

relative to each other. Over hundreds of millions of years, these plates have collided with each other to form deep trenches and they are periodically broken along the rift zones by processes acting deep within the Earth's mantle so that the huge fragments then spread away from each other. Marine geologists are making major contributions to this new explanation of the Earth's history by studying the trenches and spreading zones, most of which lie beneath the oceans.



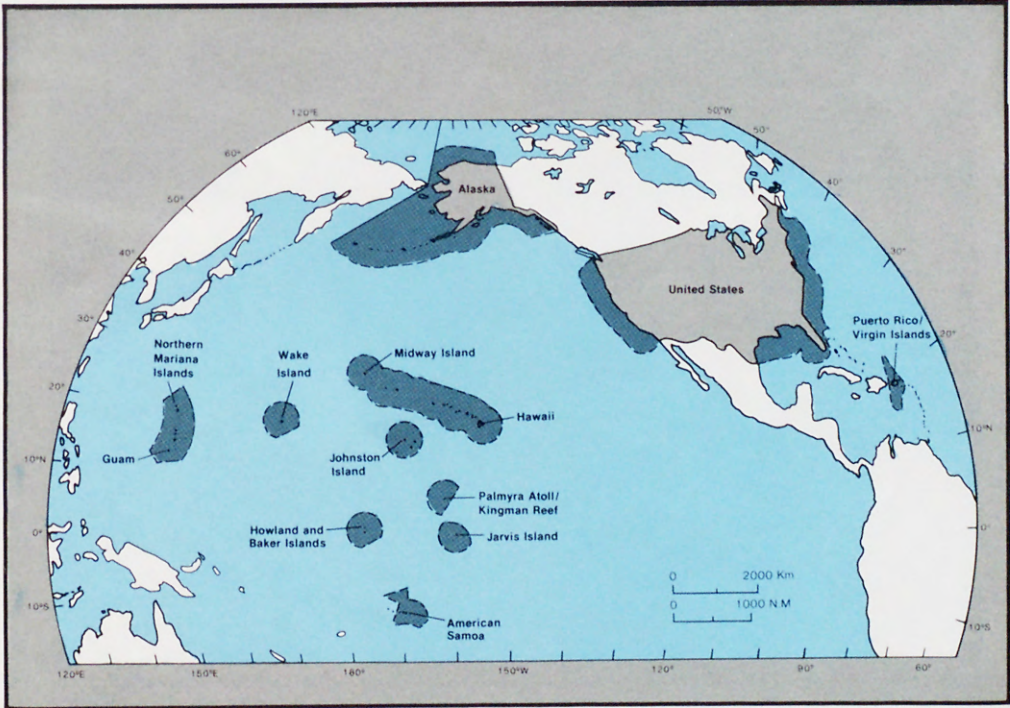
Tectonic plates of the Earth (below) and idealized cross section (AB) across the continents of South America and Africa (above).

Resources in the Marine Realm

Much of the research in marine geology relates directly or indirectly to assessing the seabed resource potential. With greater demands for certain mineral resources and depleting onland supply, the United States is looking toward the ocean as a new frontier and source of these vital resources.

In 1983, the United States extended its exclusive mineral rights outward to a 200 nautical mile

limit. The newly designated Exclusive Economic Zone (EEZ) extends from the shoreline and reaches across broad zones of flooded continental rocks known as the continental shelf, as well as deeper oceanic crust. Surprisingly, the area of the EEZ covers 3.9 billion acres, one-and-two-thirds times larger than the onshore area of the United States. In this vast domain lie resources of great importance to the Nation: an estimated 35 percent of the economically recoverable oil and gas yet to be found in the United States;



The United States Exclusive Economic Zone.

major resources of metals like cobalt, manganese, and nickel in seafloor crusts, pavements, and nodules; and major concentrations of heavy minerals such as gold and platinum in nearshore sand bodies.

Along continental margins around the world, USGS scientists are discovering areas which may contain large amounts of petroleum. Petroleum and natural gas are generally restricted to ancient basins within the continental crust

where thick piles of organic and terrigenous sediments have accumulated. Marine geologists have just learned, however, of the potential for natural gas in deeper water basins such as the Bering Sea in Alaska.

The new mineral deposits in the ocean are among the most exciting geologic discoveries of the past decade. Geologists now believe that most of the valuable mineral deposits mined on land originate at ocean-spreading ridges. Along



Scientists inspect a just-recovered dredge haul (below), which contains samples of volcanic basalt (above left) and a seafloor crust rich in manganese (above right) (photos courtesy of William R. Normark, USGS).

fractures and faults caused by crustal spreading, molten rock rises from beneath the Earth's surface, is injected in a linear zone along the axis of the ridge, and cools to create new seafloor. As the sea-floor spreading continues, the faults also provide conduits so that cold seawater can circulate downward into the hot crust. The water reacts with the hot rock, leaching from it elements such as manganese, zinc, iron, silver, copper, and cadmium in the form of metallic sulfides. When this hot mineral-laden water reaches the seafloor, it shoots upward in a plume of precipitating minerals and forms

spectacular, chimney-like columnal vents. These dynamic geysers or "smokers" were photographed from the submersible *Alvin* along the hydrothermally active Galapagos spreading ridge in 1979. Recently, USGS scientists have discovered these vents along other Pacific spreading ridges, including the Juan de Fuca Ridge off Oregon and Washington. Analyses of photographs, samples, and other data, some obtained by the *Alvin*, from these vents are giving onland geologists, who study ancient "fossilized" spreading zones, a greater ability to predict the location and extent of important mineral deposits.



Scattered along spreading ridges are submarine "hot springs" rich in metallic sulfides. The mineral-laden hot water shoots upward in a plume ("smoker") from vents on the seafloor (photo by William R. Normark, USGS).

Predicting Effects of Marine Processes

If people are to live and build along coastlines and out into the sea, they must understand and be able to predict the behavior of coastal geologic processes. Natural erosion along coasts is generally slow. Sea cliffs tend to retreat at moderate rates because they are protected against direct wave attack by natural bulwarks of beach

sand. But the construction of a jetty or breakwater interrupts the natural movement of sand along a shore. Sand will tend to pile up on one side of a structure but will be completely stripped away on the other side, exposing sea cliffs to the full vigor of the waves and producing a disastrous increase in the rate of erosion. These undesirable effects, however, can be minimized if the designs of such structures are guided by detailed studies of



Erosion often drastically increases along coastlines where jetties or breakwaters have been constructed (*photo by Gary B. Griggs, University of California, Santa Cruz*).

coastal erosion processes or if the structures are not built.

Major earthquakes, devastating as they may be in inland areas, are even more destructive along

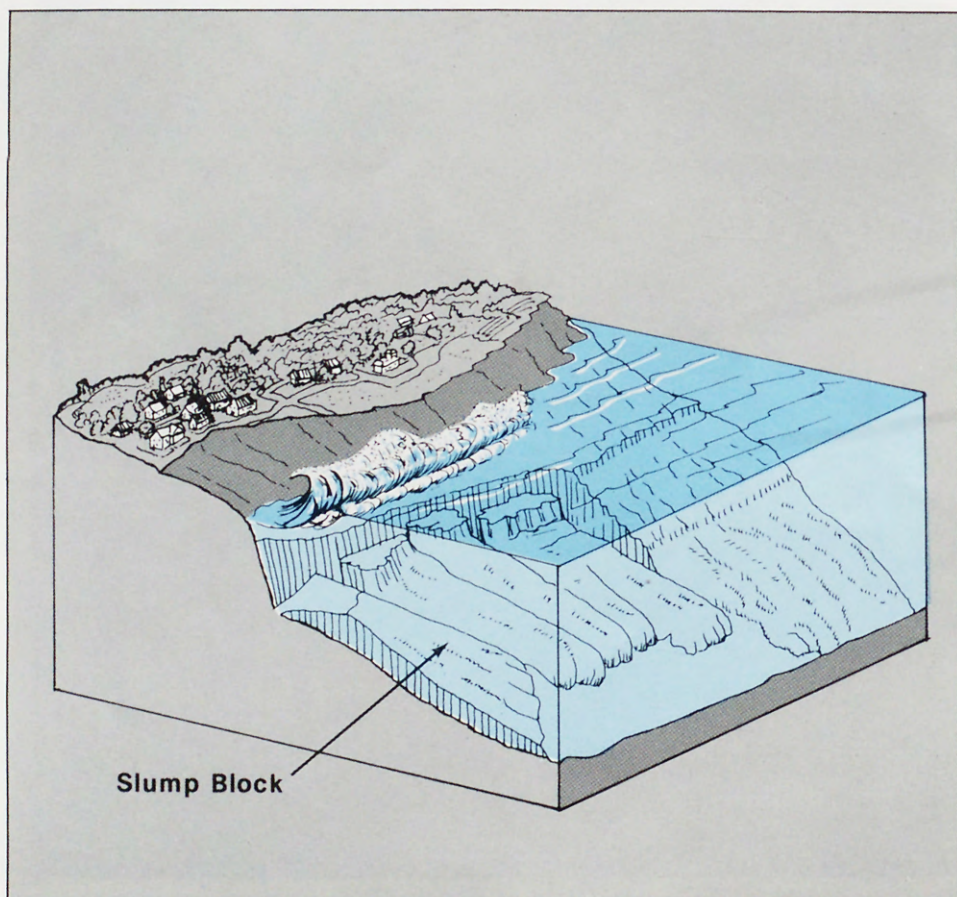
coasts. Buildings that would stand well on bedrock may be shaken to the ground if they are anchored in artificial fills or mud. Seismic sea-waves (tsunamis) set off by an



Effectively predicting the effects of storms along heavily populated shores is an important part of coastal planning (*photo by Asbury H. Sallenger, Jr., USGS*).

earthquake can sweep thousands of miles across the ocean to expend their destructive energies on distant shores. These tsunamis now can be forecasted in time for public warning, but local waves generated by submarine landslides are a more insidious hazard. When submarine landslides are set in motion by seismic vibrations, the water above them may be thrown into sudden violent waves capable

of sweeping onto the shore hundreds of feet above sea level. Surveys by marine geologists at the USGS show the location of faults near the coast and nearby unstable seafloors. Information of this kind may help identify, in advance, coastal regions where tsunamis are likely to originate and can aid coastal planners by discouraging development in areas with potential geologic hazards.



Nearshore submarine landslides pose a threat to coastal developers (from a drawing by Tau Rho Alpha, USGS).

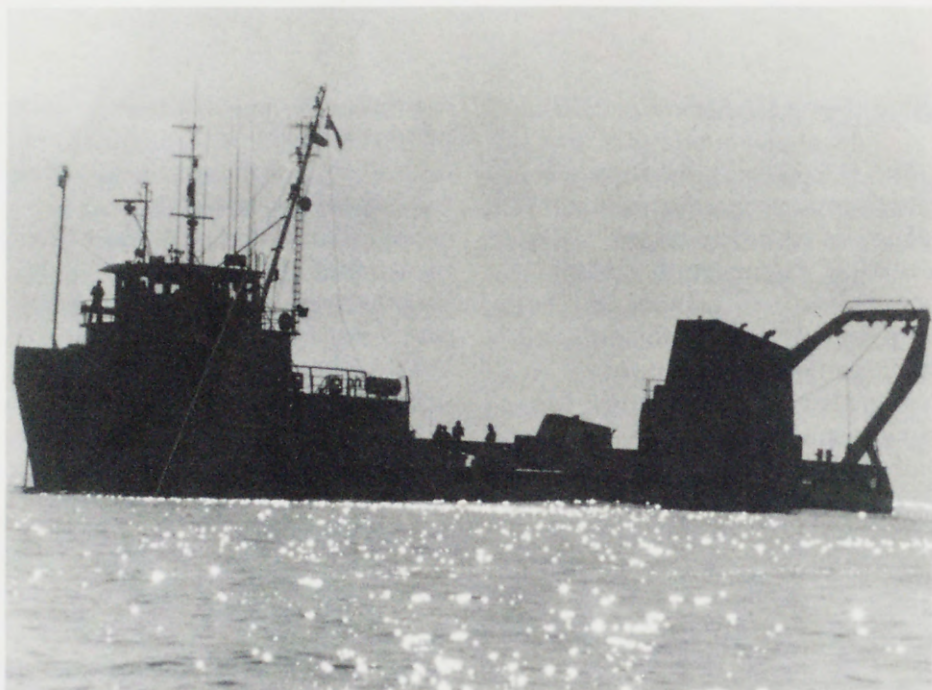
New Frontiers

The U.S. Geological Survey's marine program is global in its scope; its research began in the North Pacific and North Atlantic Oceans and now extends into both polar regions, the South and South-west Pacific Islands, off New Zealand, and the Caribbean. In many respects, the present state of knowledge of offshore regions is comparable to what was known of the Western States and territories immediately after the Civil War. At

that time, the need for regional and countrywide geologic studies led to the establishment of the U.S. Geological Survey. Today, with growing interest from other countries, cooperative marine geologic programs are being established with the United States. By combining the expertise of marine scientists around the world, we can expand our understanding of the oceans and ultimately appraise the extent of all the resources which lie beneath their surface.



The USGS research vessel *Karluk* carefully navigates around an iceberg in the Arctic Ocean. Harsh conditions permit less than 2 months of research in Arctic seas each year (photo by Peter W. Barnes, USGS).



The USGS research vessel *J. W. Powell* investigating the U.S. continental margin off Florida (photo by Andrew J. Stevenson, USGS).

Selected Readings

Edgar, T. N., 1983, The marine geology program of the U.S. Geological Survey: U.S. Geological Survey Circular 906, 23 p.

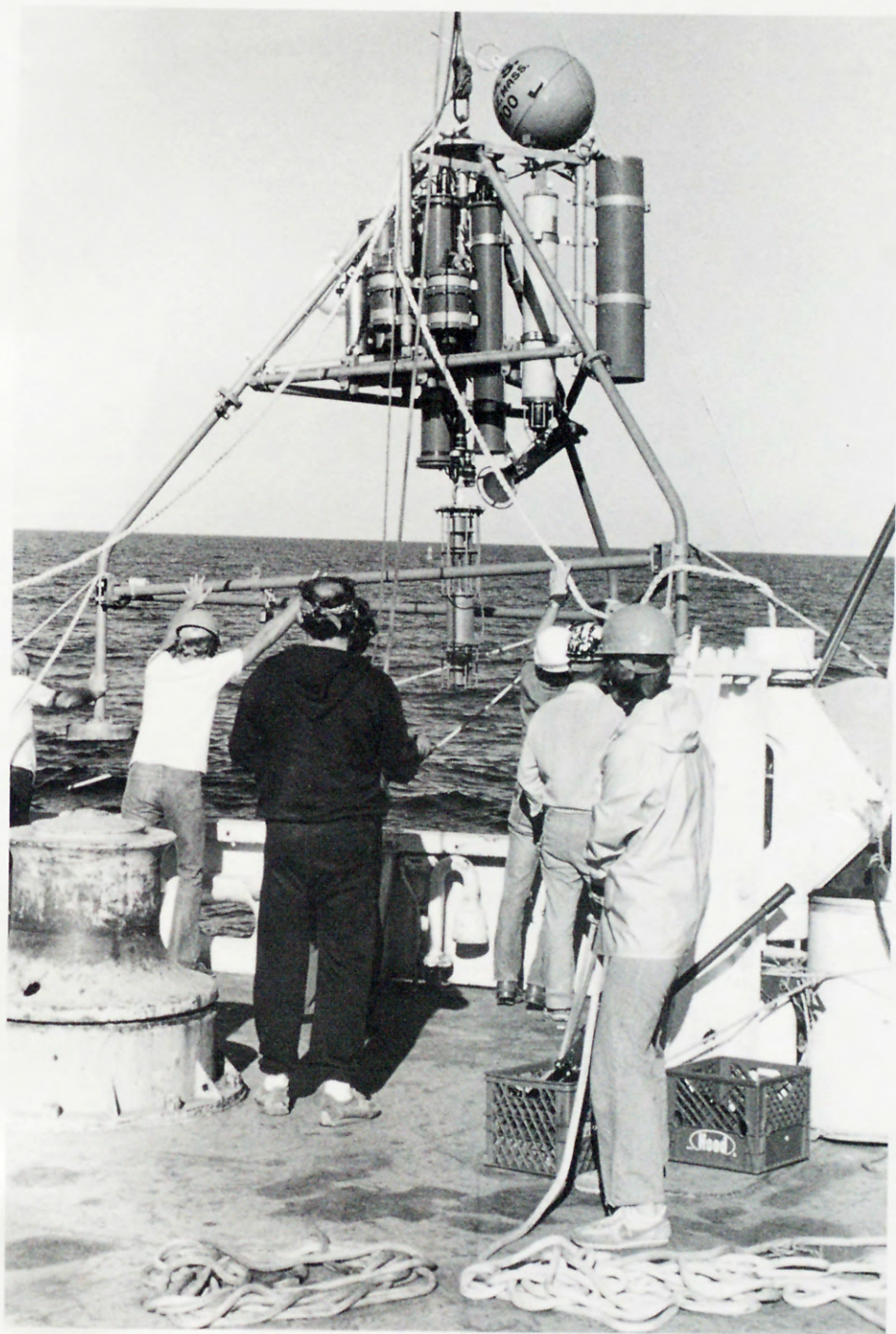
McGregor, B. A., and Offield, T. W., 1983, The Exclusive Economic Zone: An exciting new frontier: U.S. Geological Survey General Interest Publication, 24 p.

Rowland, R. W., Goud, M. R., and McGregor, B. A., 1983. The U.S. Exclusive Economic Zone—a summary of its geology, exploration, and resource potential: U.S. Geological Survey Circular 912, 29 p.

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Deploying a Sediment Transport System on the Outer Continental Shelf (USGS photo).



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