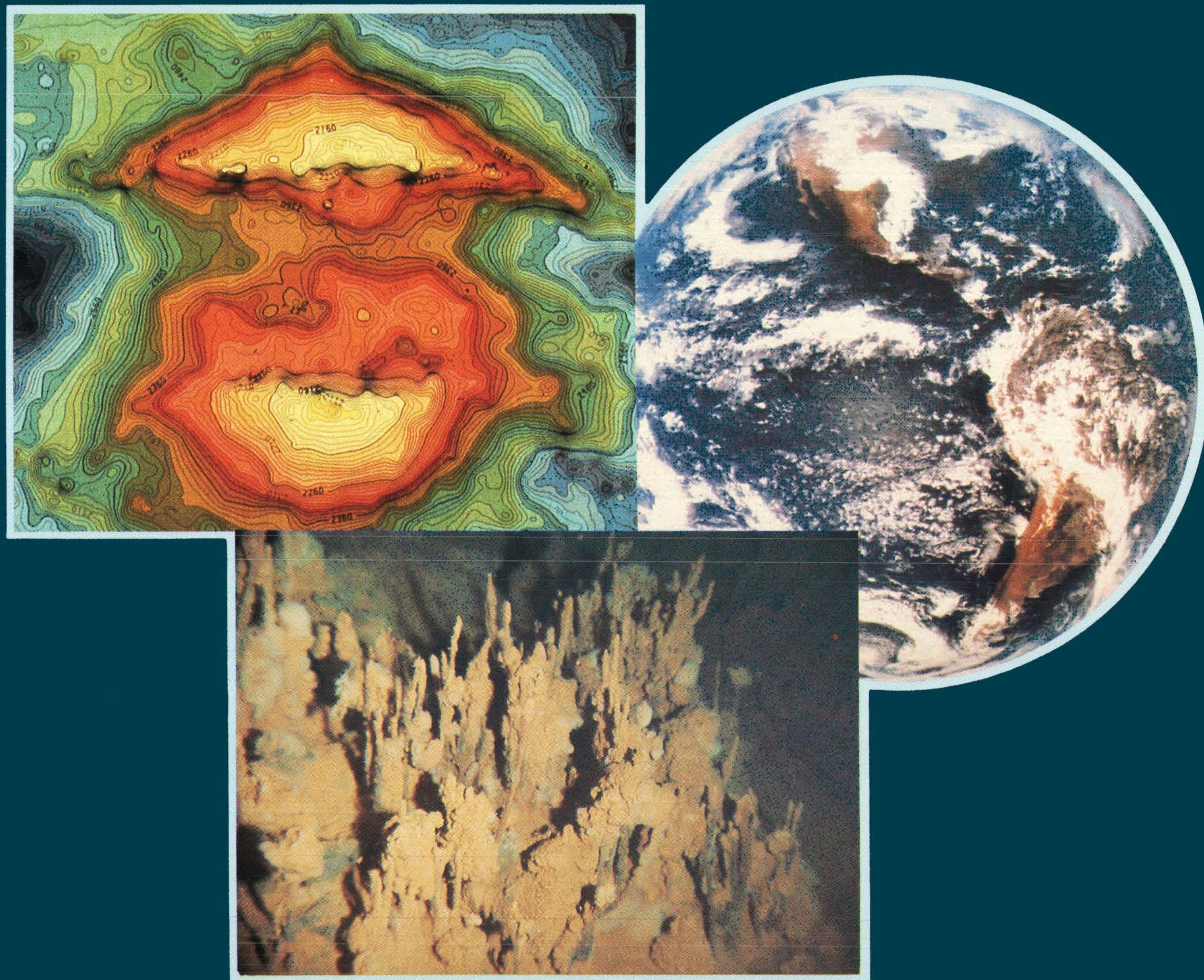
Department of the Interior
U.S. Geological Survey

Department of Commerce
National Oceanic and
Atmospheric Administration

Mapping and Research
in the Exclusive Economic Zone



Mapping and Research
in the Exclusive Economic Zone

by Bonnie A. McGregor, USGS
and Millington Lockwood, NOAA

Department of the Interior
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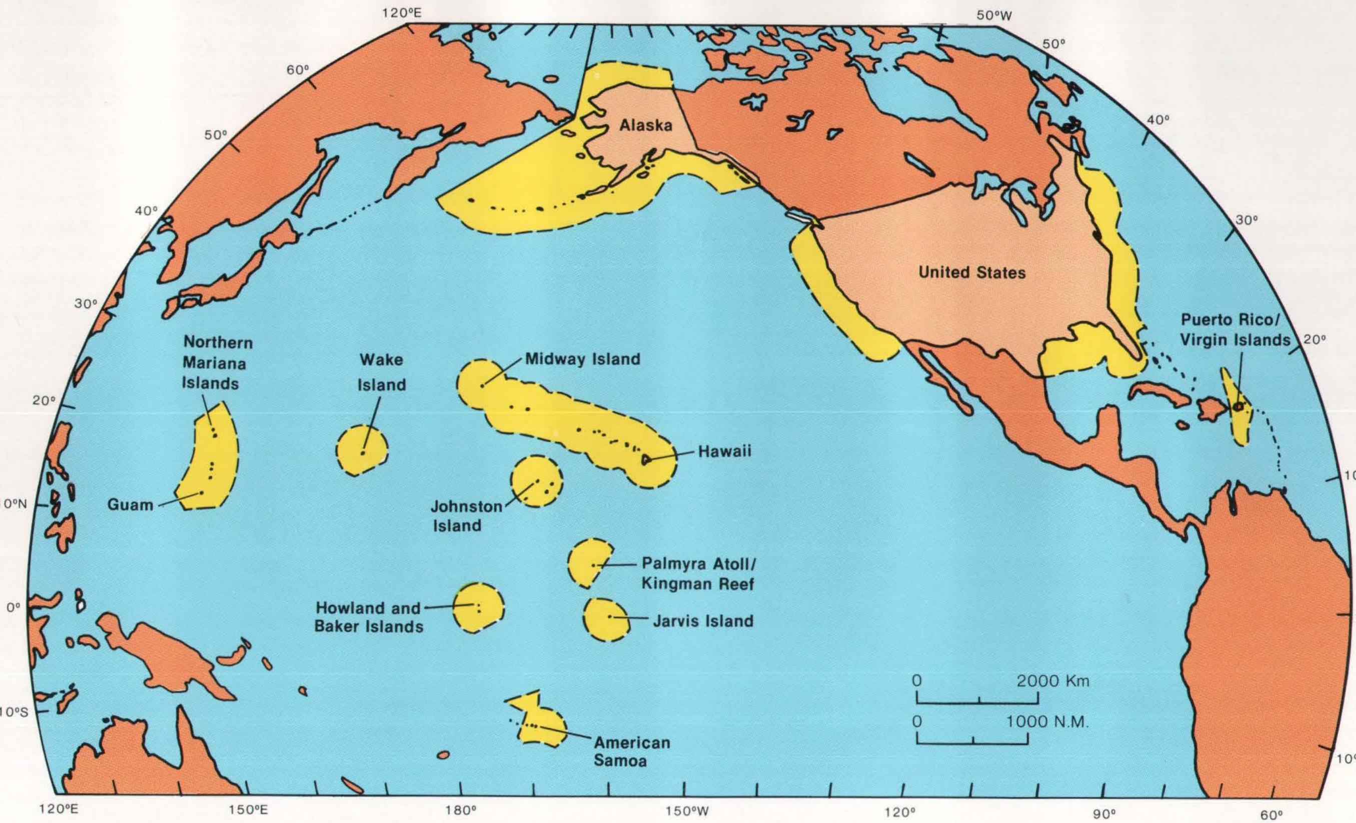
The Exclusive Economic Zone

What and Where Is It?

By proclamation of the President on March 10, 1983, the United States claimed sovereign rights and jurisdiction within an Exclusive Economic Zone (EEZ). The United States is responsible for wisely developing and managing the EEZ and its marine resources and for protecting its environment.

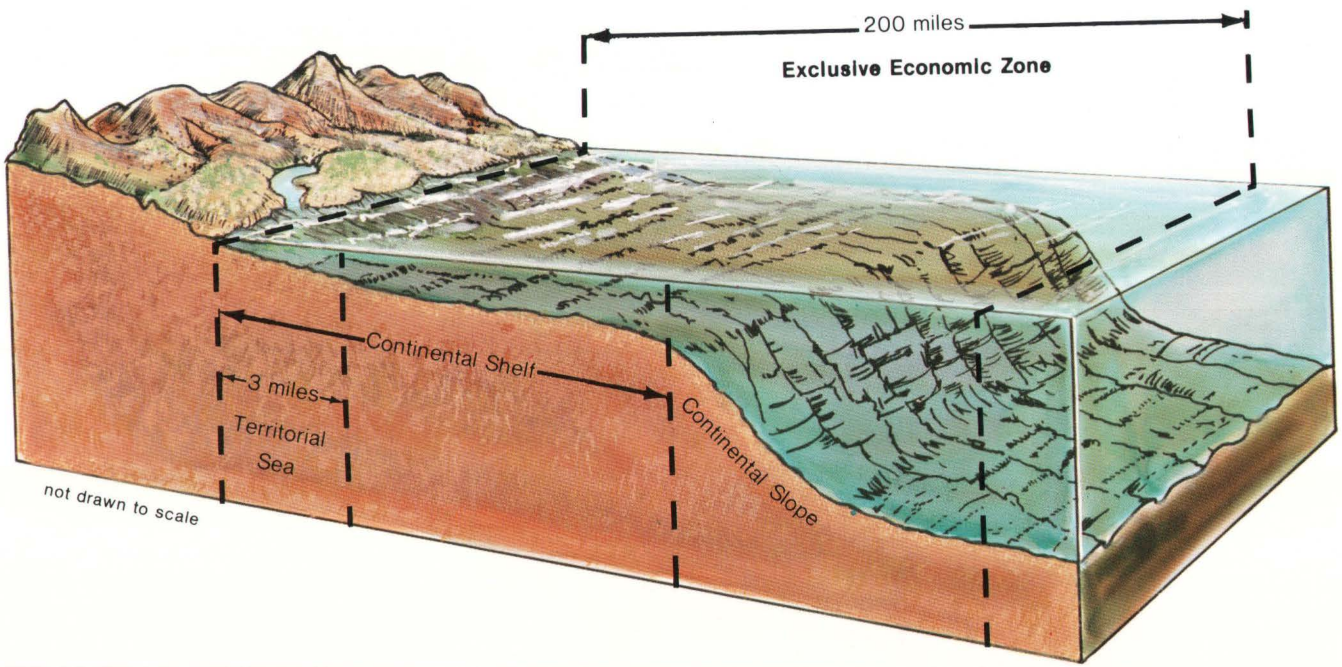
The U.S. Exclusive Economic Zone is a region that extends seaward 200 nautical miles from the coast and brings within the national domain over 3 million square nautical miles of submarine lands. The EEZ contains vital natural resources, both living and non-living, of the seabed, subsoil, and overlying water. Because most of the EEZ has not been explored, its resources and their potential remain undefined.



The Exclusive Economic Zone (EEZ), shown in yellow, covers a vast area of the U.S. continental margin and contains a potential wealth of resources.

Why Is It Important?

The rise of the United States to the status of a world power was made possible in part by the abundance of its natural resources, but the Nation was never fully self-sufficient in all the raw materials it required. The country's growth was accompanied by the often wasteful use of resources that many people believed unlimited in quantity. Continued use of on-land minerals and fuels also has depleted the reserves of these nonrenewable resources, although new sources or substitutes are always sought. Often shortages or the lack of some critically and strategically important minerals have forced the United States to rely increasingly on Third World countries for raw materials to ensure the Nation's economic stability and military security. The political stability or allegiance of these countries often places supplies in jeopardy. Also of concern is the imbalance of trade resulting from increased commerce in these vital minerals. The economic security of the Nation requires developing the full potential of the energy and critical- and strategic-mineral resources contained within the EEZ. A well-conceived and comprehensive resource plan is required for the efficient and wise development of these minerals while also protecting the marine environment. Because of the diversity of resources and uses of the marine realm, decisions on competing uses must be made. A vigorous program of marine exploration and research concerning the nonliving resources of the EEZ will provide a solid foundation of knowledge upon which to make informed decisions, to guide offshore activities, and to develop new interests beneficial to the United States.



The EEZ extends 200 nautical miles from the coasts and includes the edge of the continent that extends beneath the sea.

How Is It Explored and Assessed?

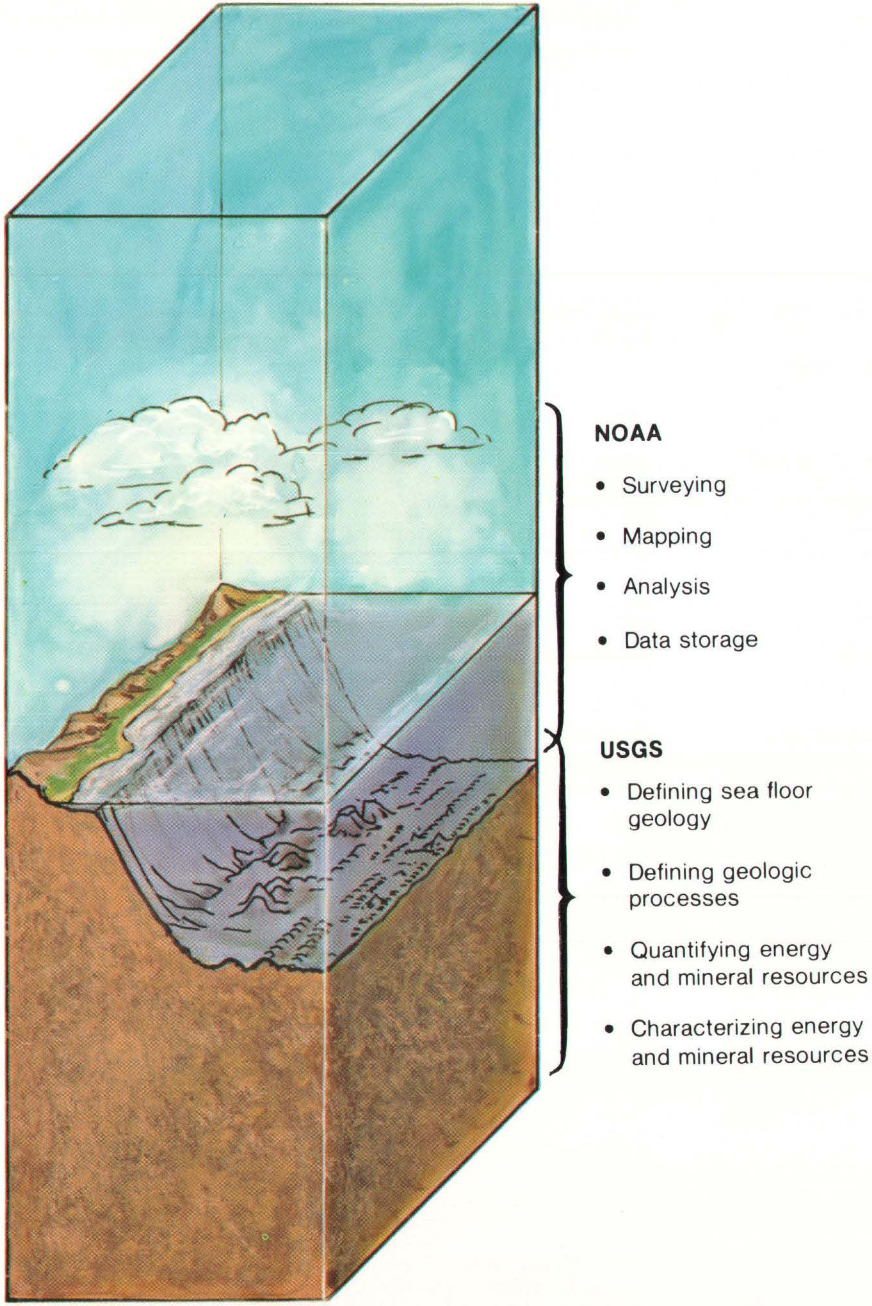
This vast underwater land and its potential resources were annexed at no cost. Oceanographic and marine research, however, require a sophisticated technology deployed from a suite of research platforms and vehicles. The portion of the Earth's surface that is covered by water and under U.S. jurisdiction is 30 percent larger than the land area of the United States. Surveying and developing this vast underwater frontier requires a cooperative effort and effective utilization of resources of both the public and private sectors. Two Federal organizations, the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA), provide a broad spectrum of expertise for investigations of the EEZ. NOAA's work focuses on ocean processes and environment; USGS studies center on geologic evolution and framework. Together, their work significantly can increase the information necessary for sound decisions on equitable development and use of the EEZ's nonliving resources.

This publication highlights the efforts and programs of NOAA and the USGS, as part of a national program, to assess the nonliving resources of the EEZ. These agencies are working together to provide a broad spectrum of knowledge and skills to understand the EEZ. Although other Federal and State agencies, industry, and academia ultimately will have roles in a national program, the USGS—on behalf of the Department of the Interior and acting on the President's mandate and assisted by NOAA—has assumed the lead role in focusing attention on the EEZ and the need to formulate a national effort to assess it.

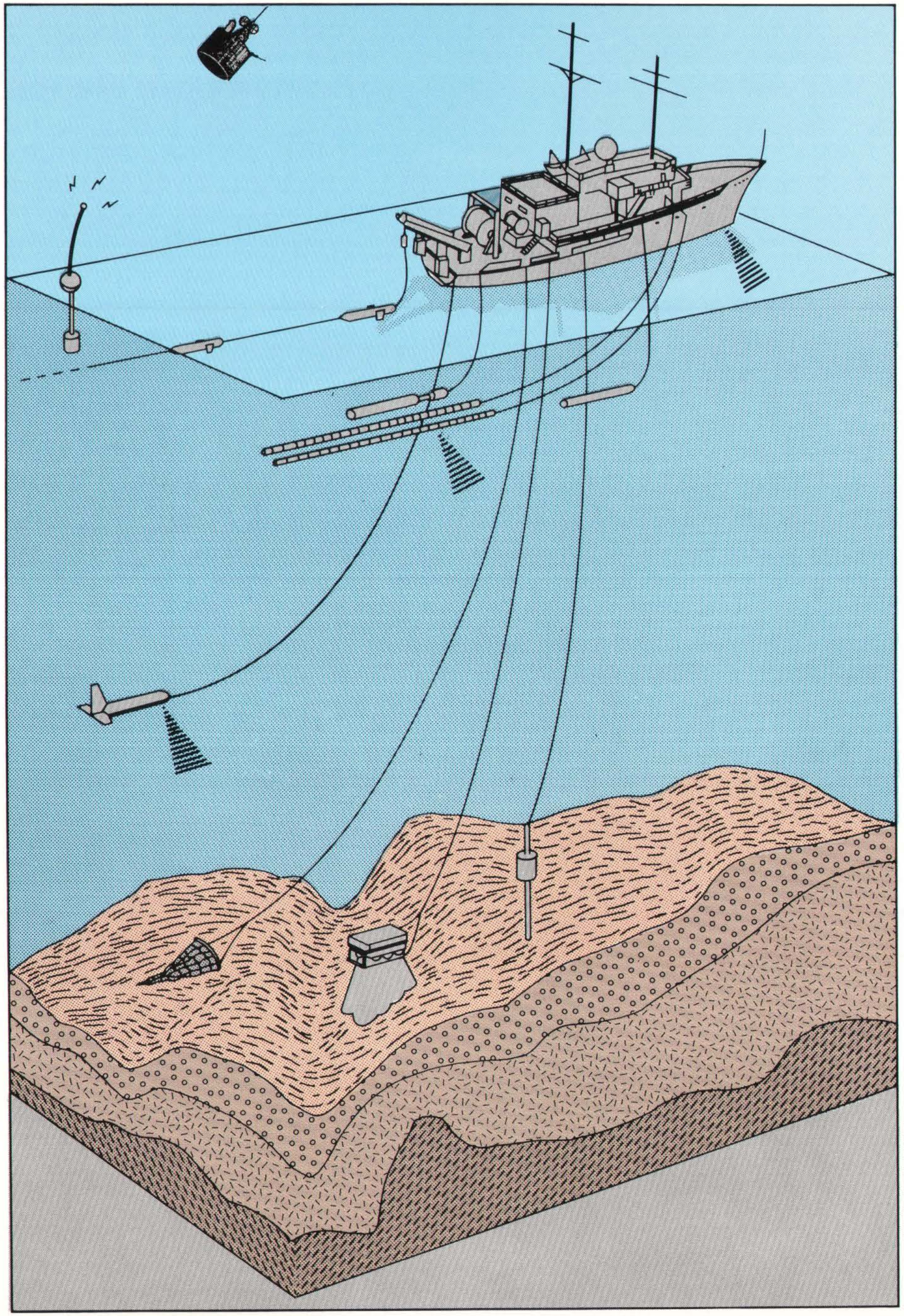
The Federal Government's exploration and evaluation of the EEZ will provide multidisciplinary information and regional evaluations as aids to resource evaluation. Basic scientific research is an important part of the assessment, development, and management of resources, as well as to determine the best use of the national domain. Intensive surveying and research in the EEZ is accumulating a storehouse of data unprecedented in volume and quality. Federal agencies ensure that these data are available to people in government, industry, and academic sectors concerned with exploration, resource evaluation, and environmental and managerial activities in the EEZ.

With regard to the EEZ's nonliving resources, NOAA's primary responsibilities include surveying, mapping, oceanographic analysis, and storage of data.

The primary responsibilities of the USGS in the Z include defining the sea-floor geology and geological processes, as well as characterizing and quantifying its energy and mineral resources. USGS and NOAA support each other's programs through a formal Memorandum of Understanding (MOU) and letters of agreement.



Primary responsibilities of NOAA and USGS in the EEZ.

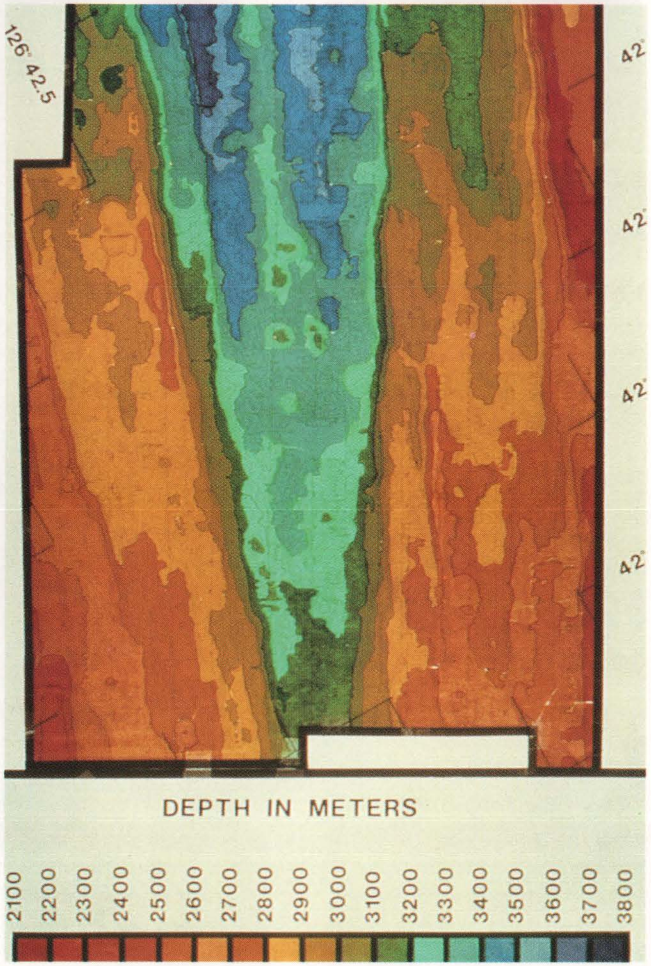


Understanding and assessing the EEZ's resources require a varied sophisticated technology.

The EEZ: Mapping

Bathymetric Mapping

Two of NOAA's ships are equipped with swath mapping systems, Sea Beam and Bathymetric Swath Survey System (BS^3). The BS^3 is used to map the continental shelves and upper continental slopes where the water depth is less than 650 meters. Sea Beam is used to map the continental slopes, rises, and the abyss where water depths are greater than 500 meters. Both these systems produce contour maps of the ocean bottom. For the shallow waters of continental shelves, nautical charts are produced that all ships need for navigation purposes. Bathymetric maps depict the relief and shape of features on the sea floor. Seamounts, canyons, and ridge crests at ocean spreading centers, often with thousands of meters of relief, are some of the spectacular features of the sea floor. The "absolute" depth of the sea floor and its regional slope are critical parameters for placing manmade objects on the ocean bottom as well as for interpreting the origin of the sea-floor topography.

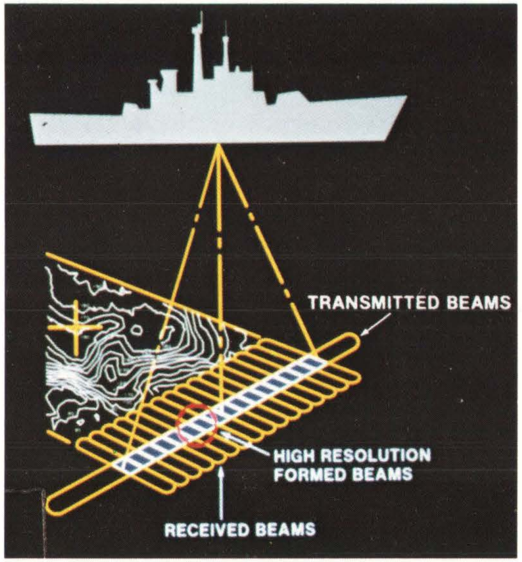


Bathymetry of the Gorda Ridge.

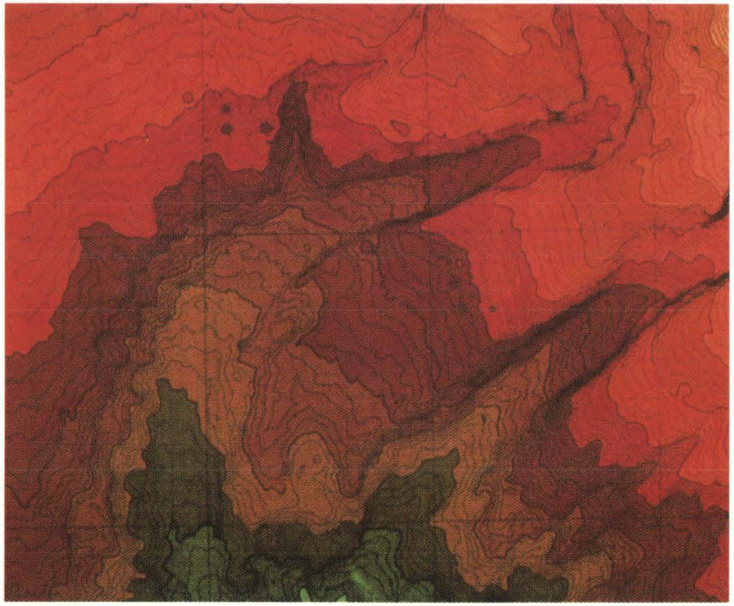
NOAA's ships *Davidson* and *Surveyor* use swath mapping systems to conduct bathymetric surveys in the EEZ.

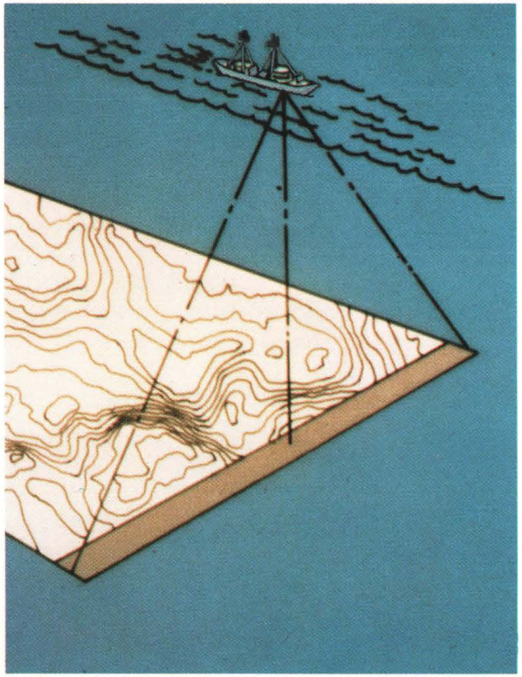
First Step

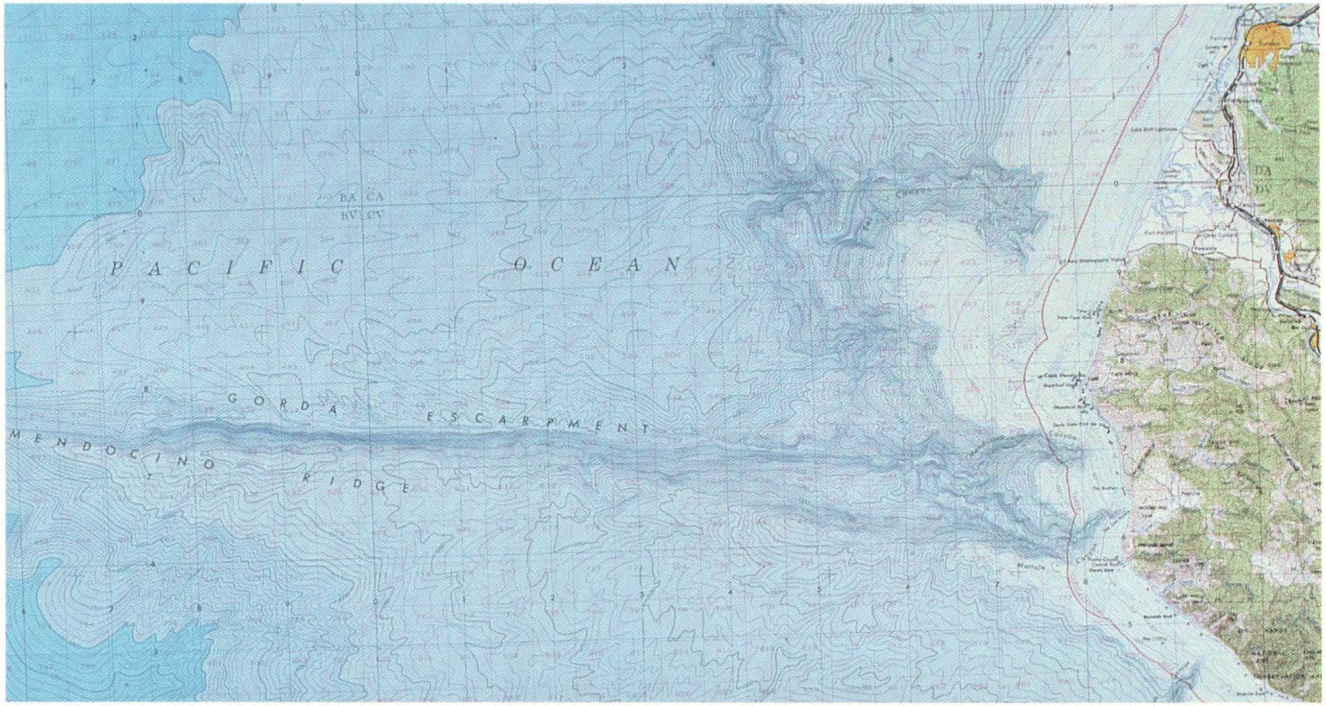
Maps are an essential first step in exploring the frontier area of the Exclusive Economic Zone; they guide the identification, assessment, and eventual production of resources on or beneath the sea floor. Just as the topography of the land surface is defined, the surface of the sea floor must be mapped to understand the dynamic processes that shape its mountains and valleys. Bathymetric swath systems and long-range sidescan sonar systems are tools being used to map the sea floor. Systematic mapping of the EEZ has begun off the west coast of the United States. This area was chosen for the first survey because of its diverse energy and mineral resources. Bathymetric and sidescan data together provide a three-dimensional view of the sea-floor morphology. This view is required to reveal the structure, erosional and sedimentation patterns, and hazards of the lands beneath the sea.



Swath technology uses multiple sonar beams to map a swath of the sea floor.


High-resolution swath bathymetry, produced from the Sea Beam System, of an area off California.


Contours of sea-floor relief are produced aboard the ships.



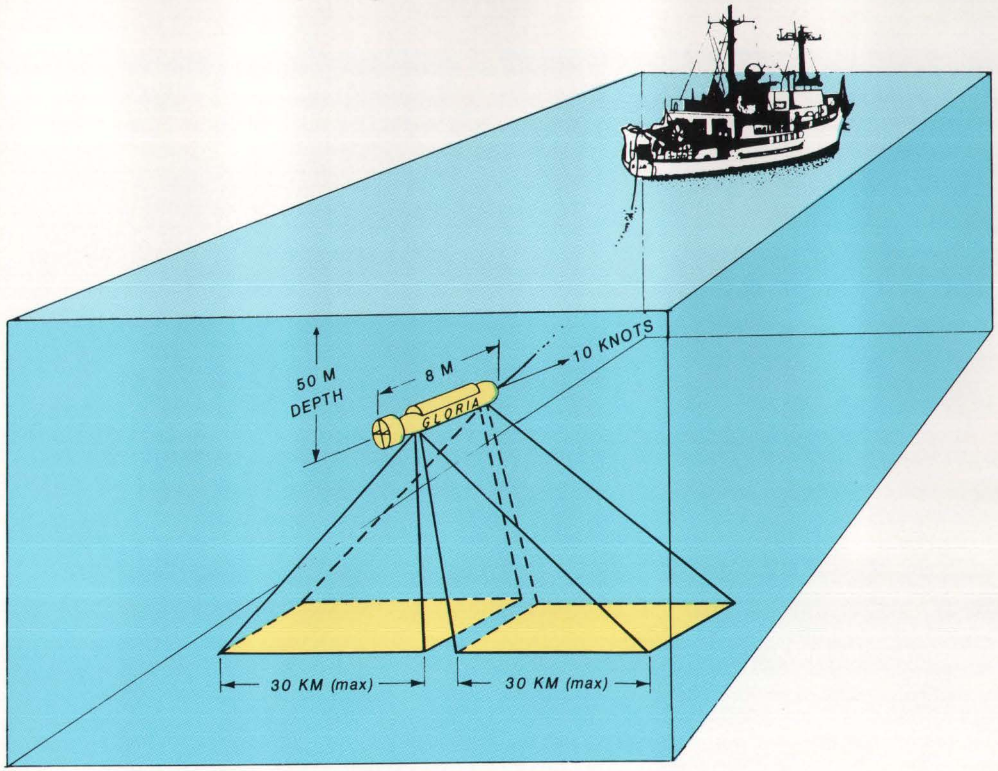
Bathymetric map of an area off northern California from conventional survey methods.

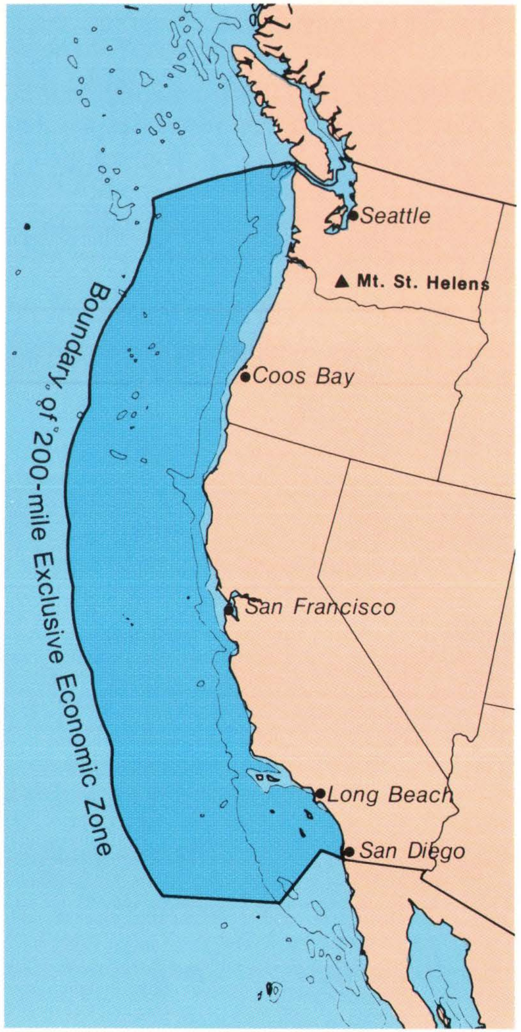
Geologic Characterization

The USGS is using GLORIA (Geological LOng-Range Inclined Asdic), a sidescan sonar system developed by the United Kingdom's Institute of Oceanographic Sciences, to obtain a plan view of the wide expanses of sea floor of the EEZ—from 150 meters water depth to the deepest part in the trenches. Using GLORIA, an area of the size of New Jersey can be mapped in a single day. The GLORIA system produces sonographs similar in appearance to radar images; the sonographs are computer enhanced by techniques developed by USGS space and planetary science programs. When combined in a mosaic, the sonographs present a reconnaissance view of the sea floor that resembles an aerial photograph. Geologists use this view to identify underwater volcanoes with sufficient morphologic detail to note similarities with Mount St. Helens. Over 100 previously unknown volcanoes have been mapped within the EEZ off our west coast. Submarine canyon channels can be traced hundreds of kilometers across the sea floor; through their sinuous, river-like paths, sediment-laden currents are believed to flow far from land. Faults cutting the sea floor and submarine landslides can also be mapped. By using these reconnaissance-scale mosaics, regions can be identified for detailed study to assess resource potential, evaluate dynamic sea-floor processes, and predict conditions with which people, in their activities on and beneath the sea floor, will have to contend.

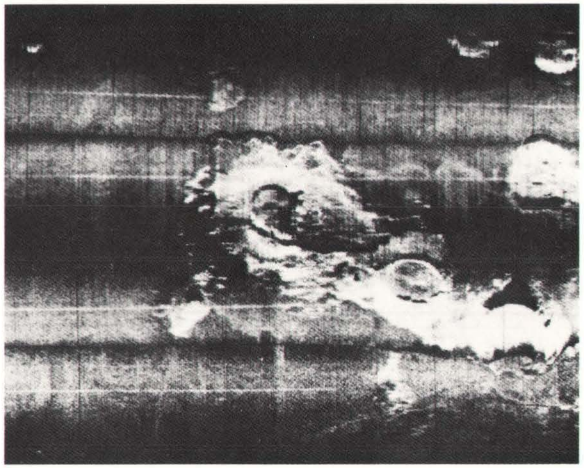
Launching the GLORIA sidescan "fish." The "fish," with a row of 30 transducers along each side, is 8 meters long and weighs 2 tons in air.

The GLORIA "fish," towed behind the ship, maps a swath of the sea floor up to 60 kilometers wide.

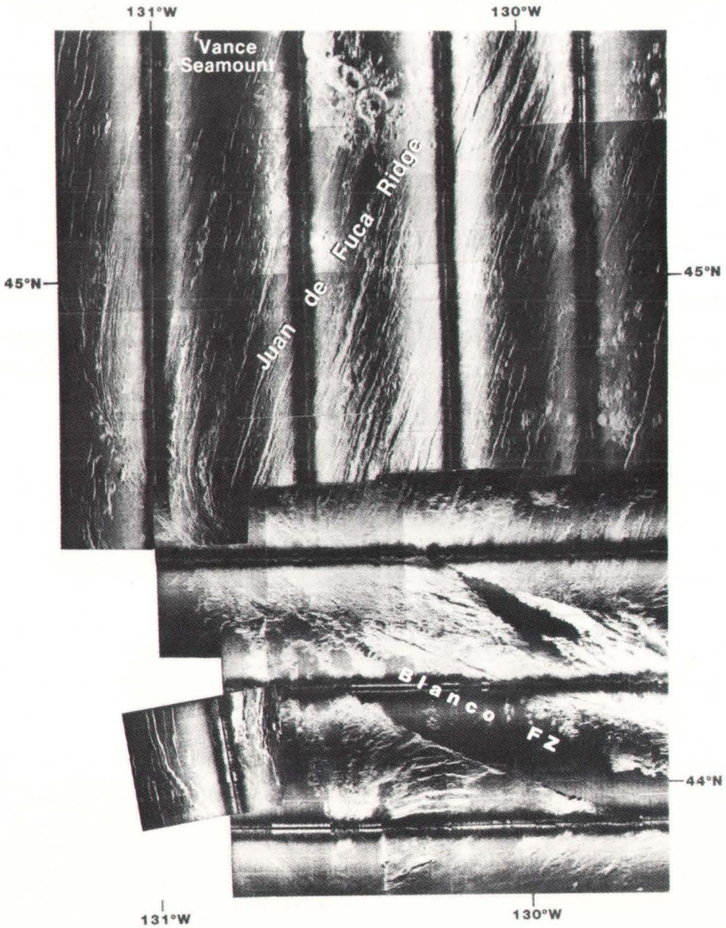




Some 250,000 square miles of sea floor in the EEZ off the U.S. west coast (area in dark blue) have been mapped by the GLORIA sidescan system.



(a)



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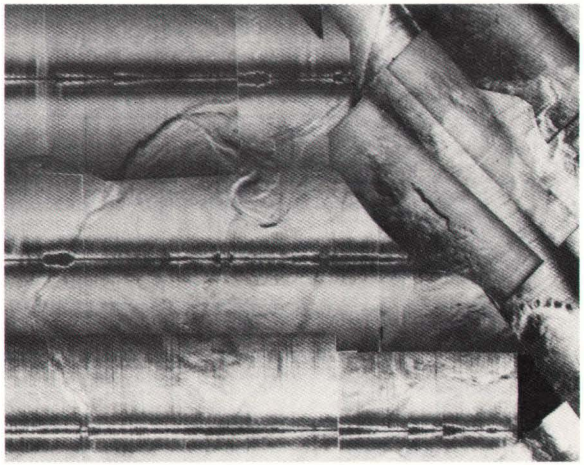
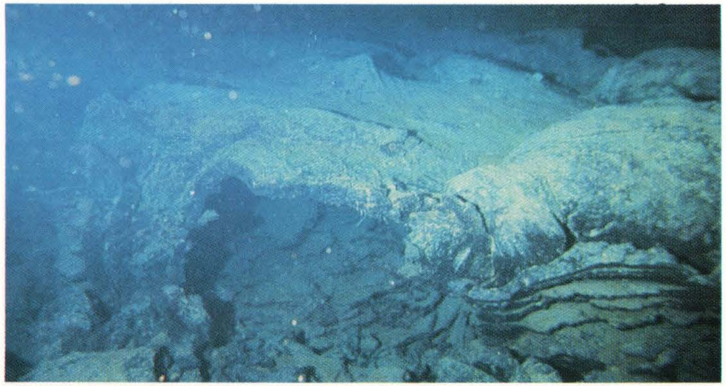


(c)

A GLORIA sonograph shows the cratered top of Taney Seamount off southern California. (a)

A sidescan image of the actively spreading crest of the Juan de Fuca Ridge, flanked on the south by the Blanco Fracture Zone, off Oregon. (b)

The meandering channel of Monterey Canyon, off central California, can be traced across the sea floor using the sidescan data. (c)



A lava flow on the crest of the Juan de Fuca Ridge. →

The EEZ: Oceanographic-Geologic Environment

Sea-Floor Processes

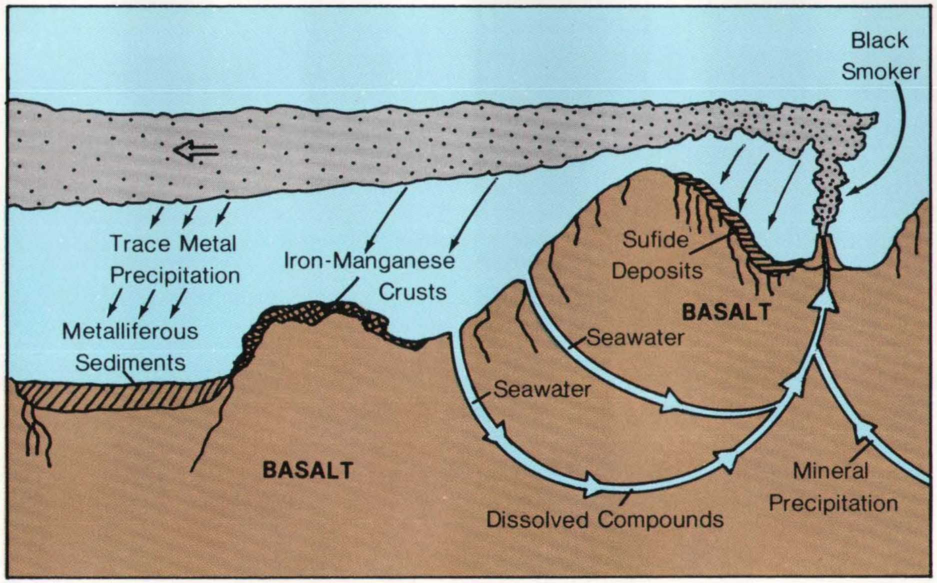
Geologic settings in the EEZ off the conterminous United States are extremely diverse. This portion of our EEZ contains a passive (trailing edge) continental margin, marked by a relatively flat continental shelf; a steeper, high-relief continental slope; and a low-gradient and low-relief continental rise. The EEZ also has an active (leading edge) continental margin, marked by compressional forces that form steep-walled, deep trenches, and an actively spreading oceanic ridge crest where new sea floor is being created. The sea floor in each of these environments is shaped and etched by dynamic geologic processes. Tectonic processes such as faulting actively displace the sea floor, geochemical processes occur as sea water circulates through the rocks and sediments on the sea floor, and sedimentologic processes control the material deposited on or eroded from the sea floor. Hydrothermal venting, which occurs along spreading centers in back-arc basins, represents a basic input of heat and new material into the ocean. Understanding these processes is important to the petroleum, minerals, communications, fisheries, and shipping industries, and to all segments of the population concerned with waste disposal. The sea floor is not a simple tranquil deep, as once thought, but a mix of dynamic regions as yet seen imperfectly through the overlying blanket of water.

Oceanographic Environment

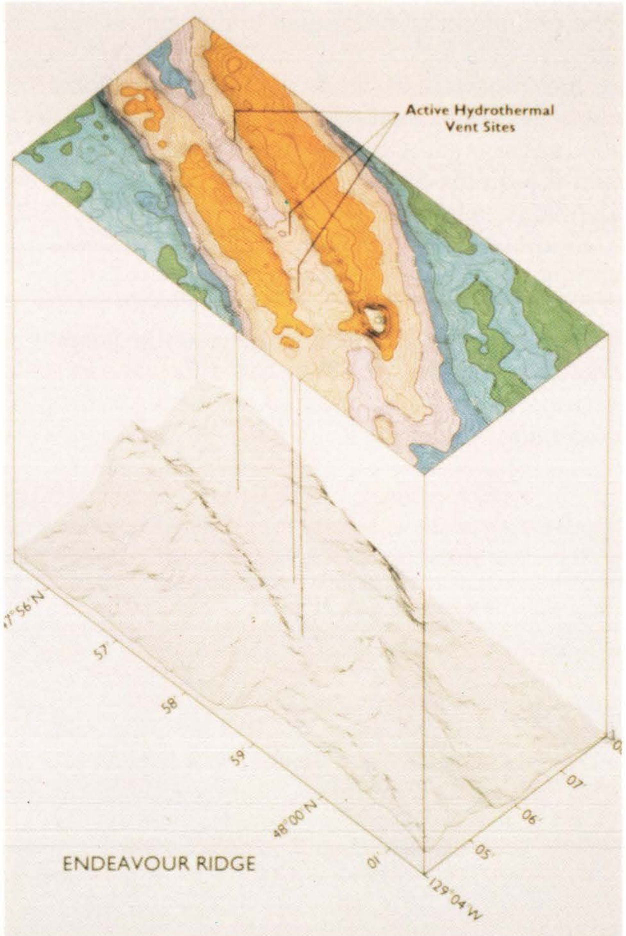
Hydrothermal venting is one of the dynamic processes occurring on the sea floor. NOAA is studying the diverse effects this venting has upon the marine environment and to define and quantify the chemical, geological, biological, and physical oceanographic consequences of the venting of hydrothermal fluids.

Active research on the effects of hydrothermal venting requires an ability to find and sample discharging hydrothermal fluids and gases. To accomplish this, NOAA is developing detailed bathymetric maps of key crestal sectors of spreading centers where active venting occurs or may occur. These specially prepared maps focus on the morphologic features most closely associated with active venting and provide essential information required in occupying and reoccupying specific experimental sites. Much of this initial detailed mapping is being used as a basic research tool; the data are being compiled and used in a variety of formats by government and university marine scientists.

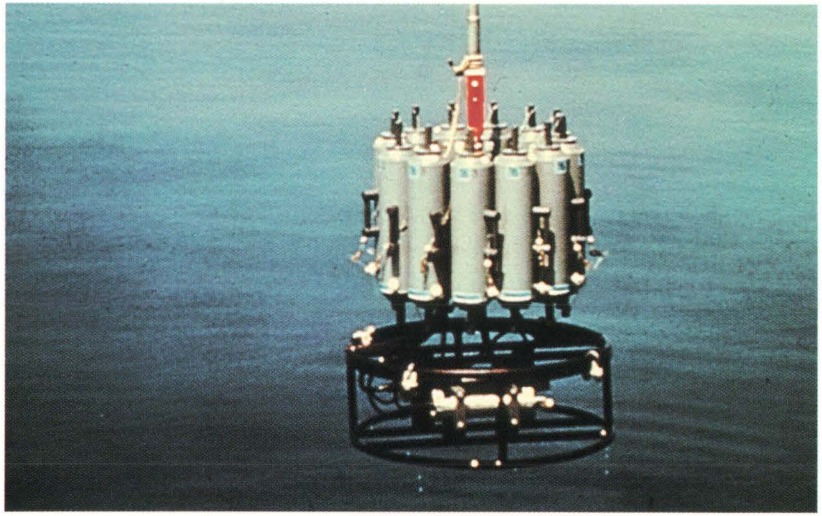
When hydrothermal fluids are released into seawater, changes in oxidation potential and pH cause the precipitation of various metals, some of which are economically important. The precipitated particles are commonly very fine grained and have settling velocities slow enough to permit them to be transported some distance from the site of the active venting. The presence and distribution of these precipitated particles may be traced by determining the distribution of particulate manganese in the water column, over varied distances from the venting sites. Transects made perpendicular to ridge axes are being used to determine the distribution of both particulate and dissolved manganese to identify the approximate locations of actively venting systems. NOAA scientists have recently found significant amounts of both dissolved and particulate manganese in near-bottom waters along the northernmost 150 kilometers of the Gorda Ridge. These measurements, which are part of NOAA's long-term research interests in this area, provide the most substantive evidence to date of active hydrothermal venting on the Gorda Ridge.



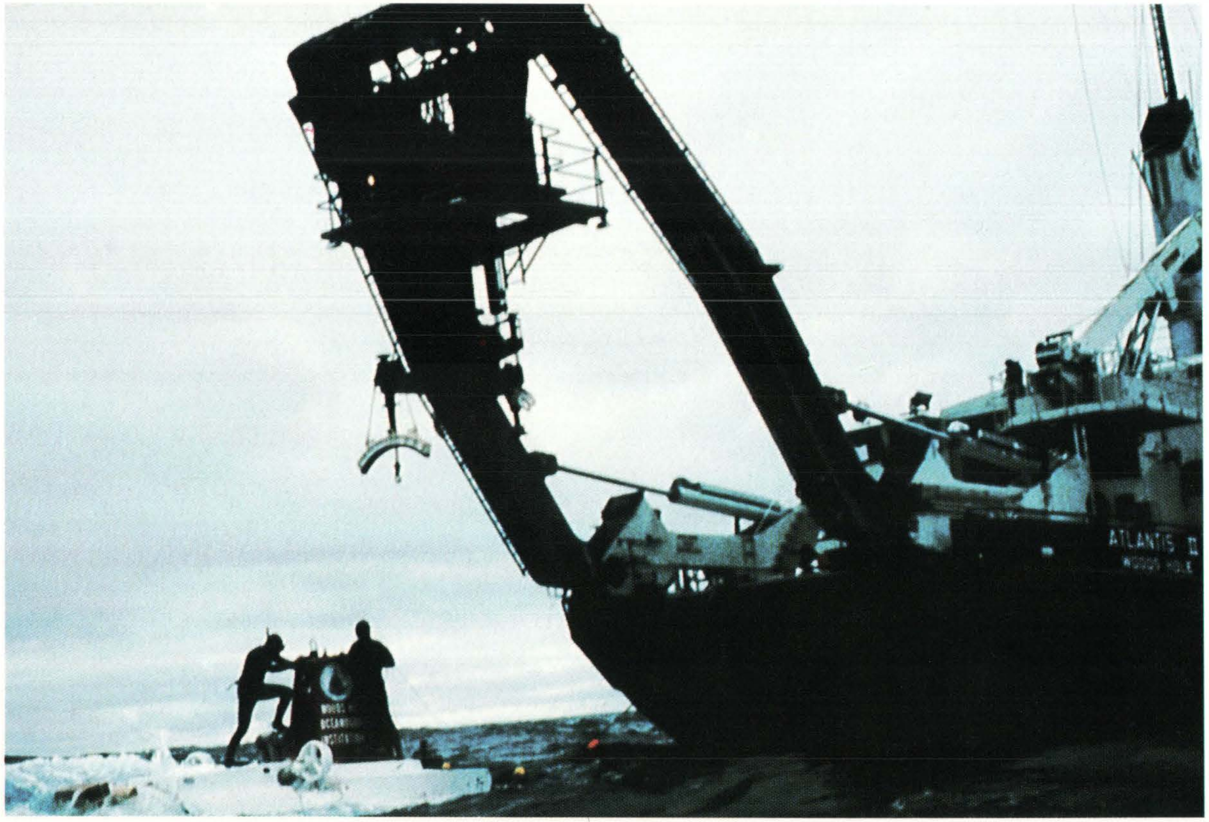
The geochemical processes active at sea-floor spreading centers.



Swath mapping shows sea-floor relief and the sites of active hydrothermal vents.



Samples of the water column are essential for understanding chemical processes near active hydrothermal vents.



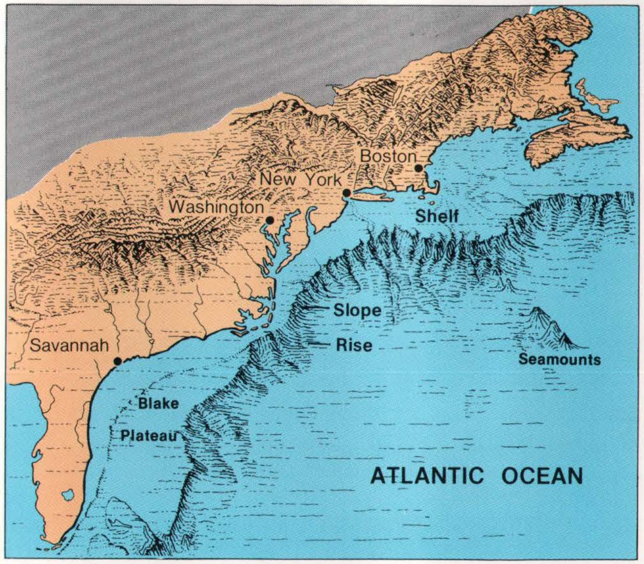
Deep submersible *Alvin* is used to observe underwater geological formations.

Geologic Environment

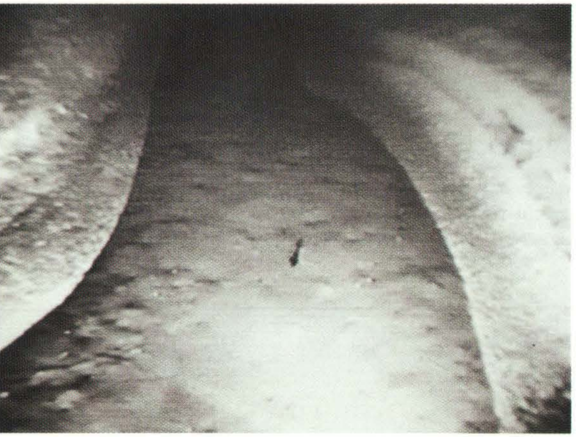
The development and integration of geophysical tools having varying degrees of resolution have enabled USGS geologists to identify and better understand the geologic environment of the sea floor. Just as the Colorado River, which has carved the Grand Canyon in places over 1,000 meters deep, and other rivers have dissected the land surface, the continental slope is dissected by submarine canyons 1,000 meters deep and fed by a dendritic system of gullies reminiscent of South Dakota's badlands topography. Occasionally, density currents laden with sediments rush down the meandering channels of submarine canyons, transporting sediments and depositing them far seaward in large, leveed fan complexes. Deep ocean currents are believed to sculpt the surface sediments of these fans, creating fields of massive bedforms, just as currents in the shallow waters of the continental shelves create moving sand waves.

Furrows 13 meters deep and 5 meters wide have been cut in the consolidated rocks cropping out at the sea floor on lower continental slopes. Scarps over 3,000 meters high flank the Florida carbonate platform on the east and west, and they also show the effects of the erosive processes and currents in the deep sea. Landslides remove material from steep regions of the sea floor and leave massive scars. Active faults that offset the sea floor can be mapped for tens of kilometers and, in places, they deflect the course of submarine channels. Faulting and tectonic processes are important on the crests of spreading ridges and control the locations of submarine eruptions.

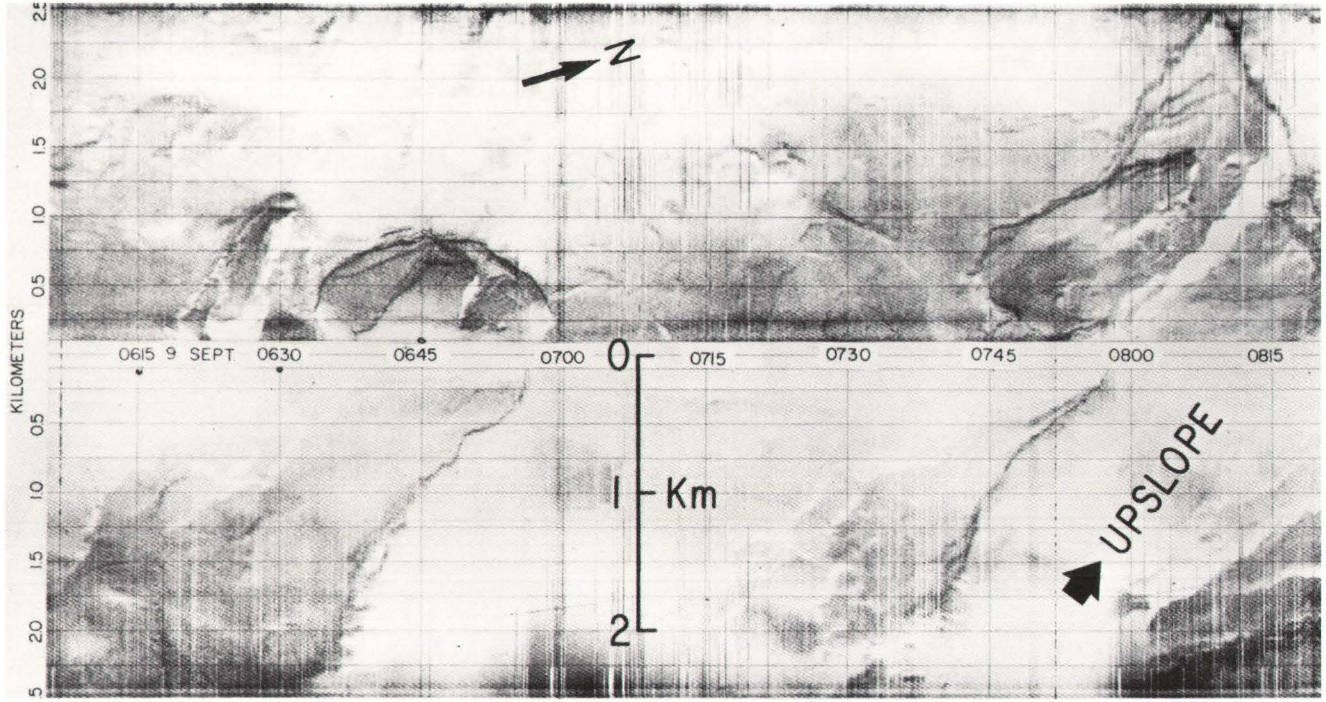
The geochemical processes that occur as sea water interacts with the volcanic rocks of the sea floor are important in determining the formation of mineral deposits. Similarly, the interactions of sea water, sediments, and the sea water trapped between the grains of sediment (pore water) during the early stages when sediments are changed into rock are important in determining the eventual petroleum potential of the rocks. Geologic processes range in scale from volcanic eruptions on features the size of land volcanoes to interactions between sediment particles and water particles. This difference in scale challenges our technology and our understanding of the sea-floor realm.



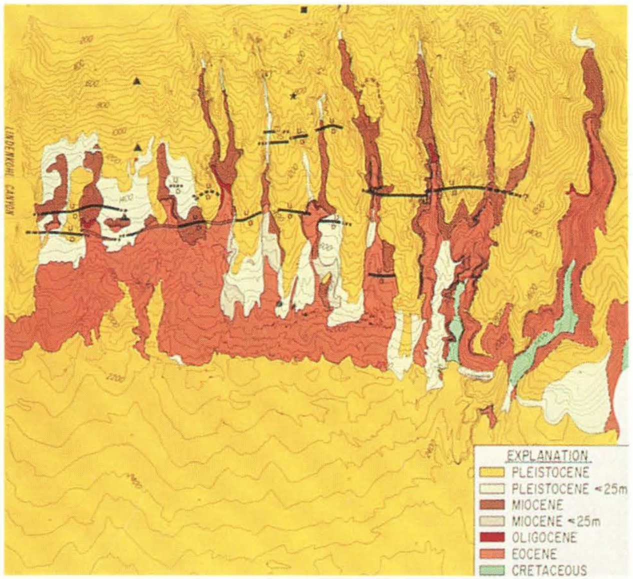
U.S. Atlantic continental margin (a trailing edge, passive type margin) is composed of a broad flat continental shelf, an eroded steep continental slope, and a gently seaward-dipping continental rise.



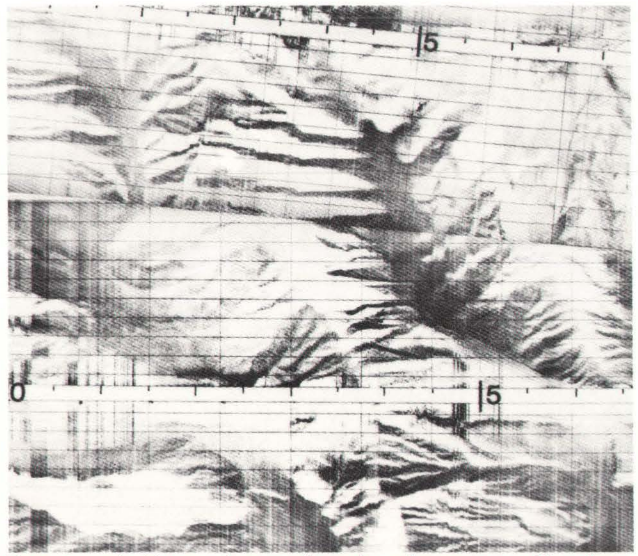
A furrow 10 meters deep and 5 meters wide is cut into the sea floor.



Submarine landslide scars are visible on deep-towed sidescan (Sea MARC I) images on the continental slope off New Jersey.



A geologic map of the continental slope off New Jersey.



Deep-towed sidescan image of a submarine canyon with extensively gullied walls.

The EEZ: Geodetic and Geologic Framework

Setting

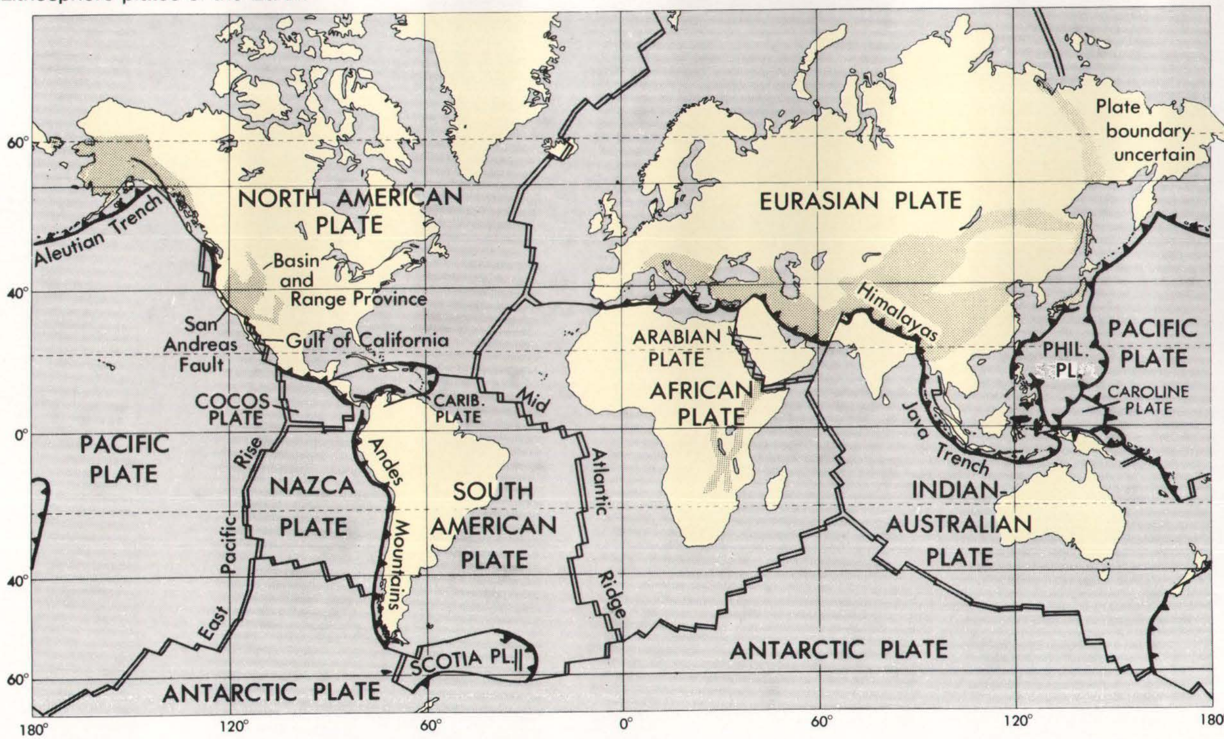
The Earth's surface can be divided into a series of lithospheric plates as defined by the plate tectonic theory developed in the late 1960's. Five different plates are contained in the United States EEZ. The history and interactions of these plates define a wide spectrum of tectonic settings, from the creation of new crust at spreading ridges to the destruction of crust in trenches. Understanding these settings and their varying geologic evolution provides greater insight into the distribution of energy and mineral resources within the EEZ.

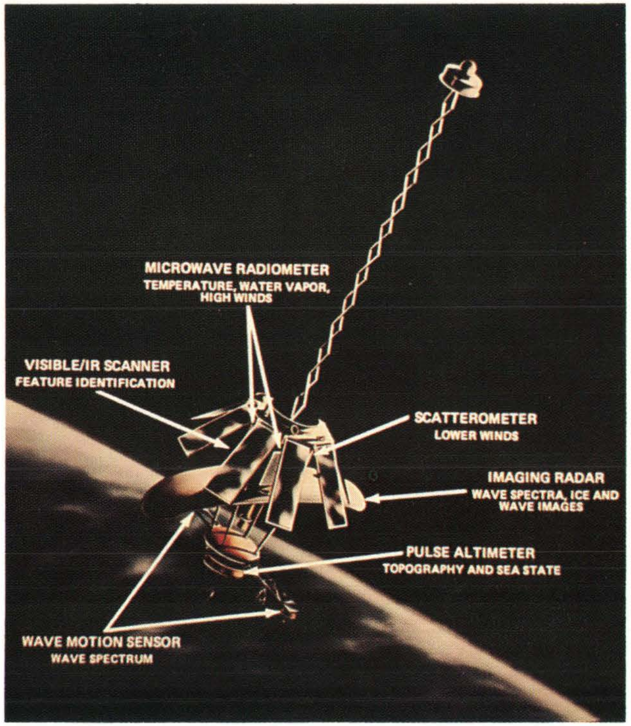
Geodetic Framework

Precise definition of lithospheric plates and of their global motion has been aided by recent advances in technology. NOAA, in cooperation with other agencies, is using space geodetic techniques, such as lasers and natural radio energy sources (quasars), for a more precise definition of the shape of the Earth. The results of these techniques, which measure horizontal and vertical positions on the surface of the Earth, are applied in studies of the global motion of crustal plates. Other investigations are using satellite altimetry data to study the undulations of the sea surface, which were found to correlate with sea-floor topography. The gravitational attraction of massive sea-floor features such as seamounts, trenches, ridges, oceanic rises, and fracture zones produce "bulges" on the sea surface that can be mapped by satellite. NOAA has produced 32 overlays of sea-surface topography profiles for 16 maps of the General Bathymetric Chart of the Oceans Series. In less-known areas, the satellite altimeter has revealed many undetected features of the sea floor; nearly 100 previously undiscovered seamounts were found in the South Pacific, clearly demonstrating the effectiveness and potential of this powerful reconnaissance tool.

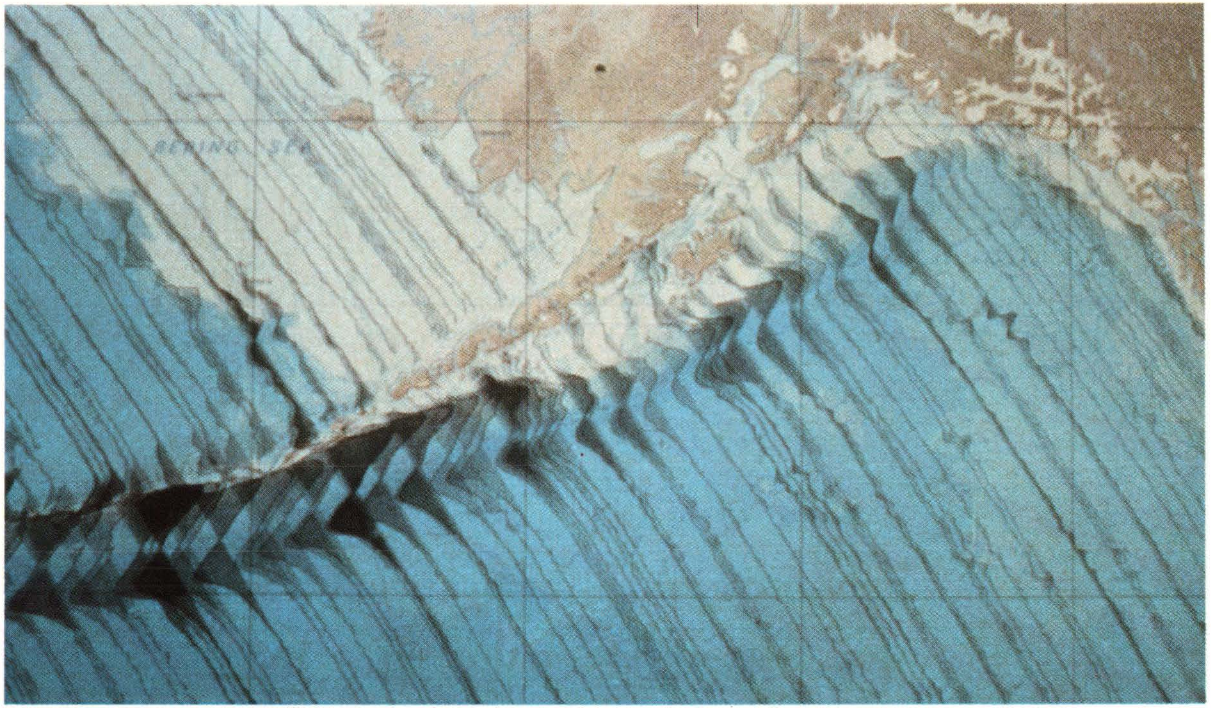
Work conducted in the 1960's and 1970's by NOAA and its predecessor agencies, as part of the International Decade of Ocean Exploration (a program administered by the National Science Foundation), included map sets of ocean bathymetry, geomagnetics, and gravity as part of research programs involving the geologic framework of the oceans.

Lithosphere plates of the Earth.

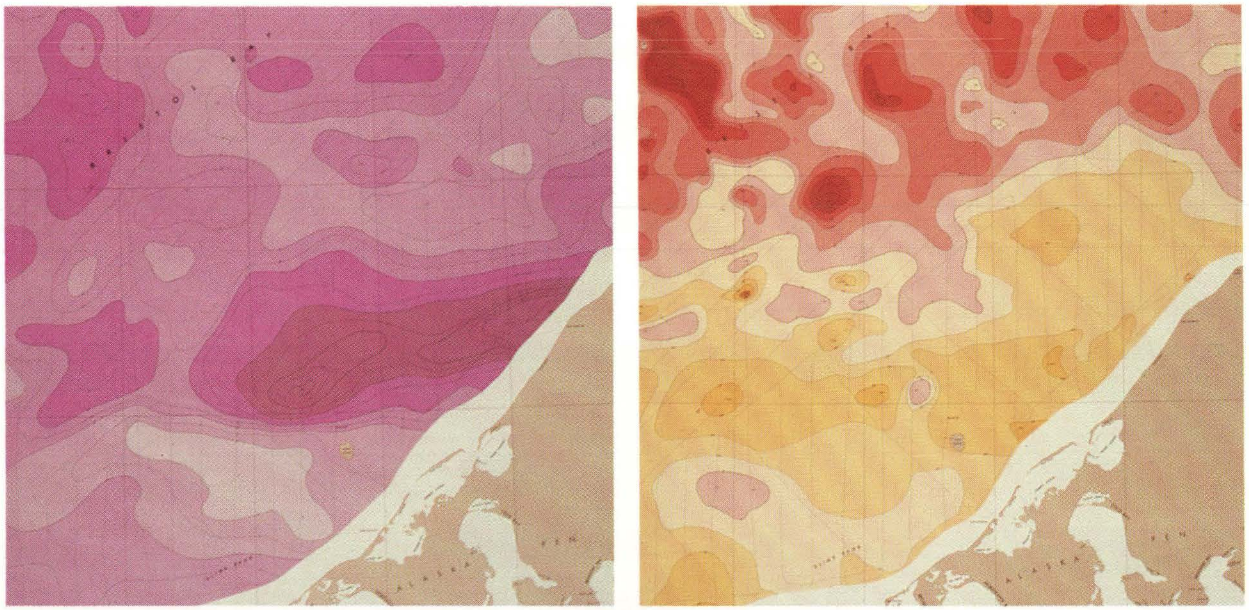




Global-wide phenomena can be observed from satellites in Earth-orbit.



Data from altimeters on satellites reveal major undetected features on the sea floor.



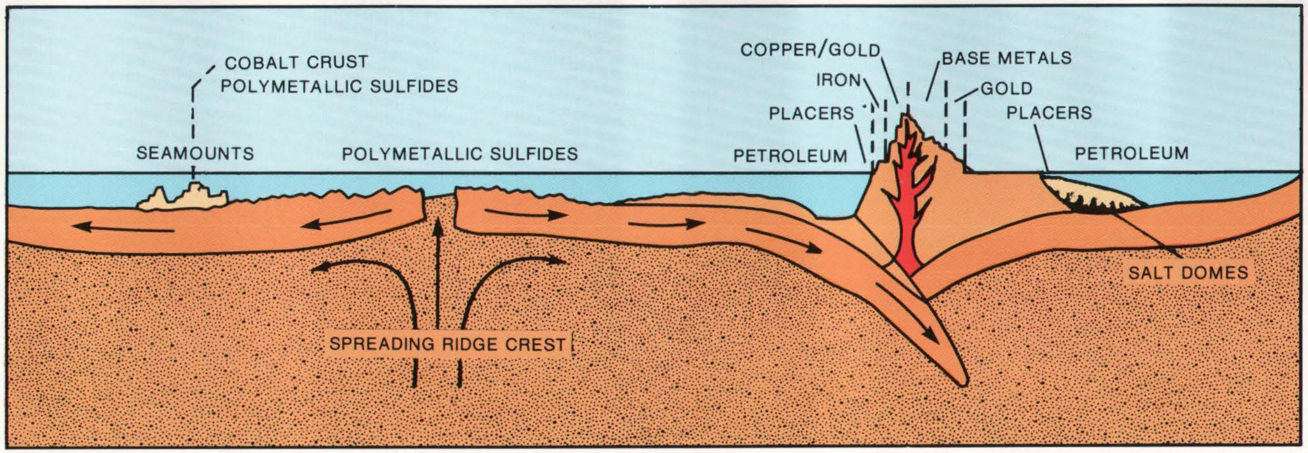
Maps of gravity (left) and magnetic (right) anomalies show EEZ areas with resource potential.

Geologic Framework

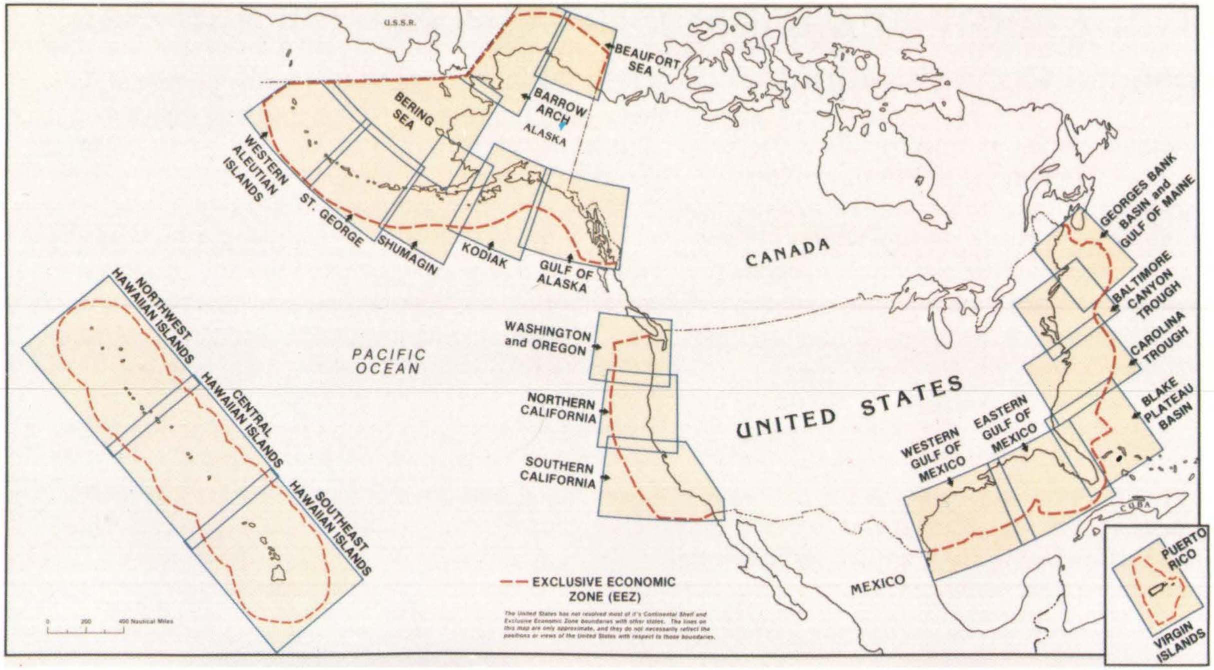
Adjacent to the shoreline in waters of varying depths are major basins, whose thick sedimentary sequences may contain energy resources. Deep-penetration seismic reflection profiles collected by USGS scientists are used to map the structure and distribution of these basins. The passive margins of the Atlantic and North Slope of Alaska contain rifted basins formed over 100 million years ago as the lithospheric plates of the Earth pulled apart. The Gulf of Mexico has a thick wedge of sediments that are actively being deformed by diapirs of salt which flowed upward from a 170-million-year-old layer of salt that was deposited shortly after the Gulf formed. This accumulation of sediments and the abundant traps, formed by the piercement structures of salt, contribute to the importance of the Gulf as a source of petroleum. The trench, island arc, and back arc of the Alaskan region contain many basins believed to have petroleum resources. Understanding the environments in which these sediments were deposited is vital in evaluating resource potential. Paleoenvironments of the continental margin can range from shallow-water carbonate reefs to deep-water submarine fans. Sand and gravel layers deposited in submerged beaches or filling buried channels within the sedimentary wedge of the margin may also contain placer deposits of critical and strategic heavy minerals.

The geologic framework of the plate boundaries also is important in locating and understanding the distribution of mineral resources in the EEZ. Understanding the structure of an actively spreading ridge crest is critical to interpreting the mineralization processes whereby polymetallic sulfide minerals are deposited. Geologic framework studies identify the shape and location of magma (molten rock) chambers and how this molten material moves beneath the sea floor. Underwater volcanic eruptions that construct seamounts and some island chains, such as the Hawaiian Islands, also are important in localizing mineralization. The island arcs (of which there are three in the EEZ) are constructed from the recycled rocks and sediments of the sea floor that are consumed at depths beneath a trench. Minerals that were once deposited at or near the sea floor thus are incorporated into the island arcs. The plate tectonic theory explains the dynamic nature of the Earth's crust and allows geologists, by reconstructing plate motions during the geologic past, to demonstrate the evolution of the Earth and its resources.

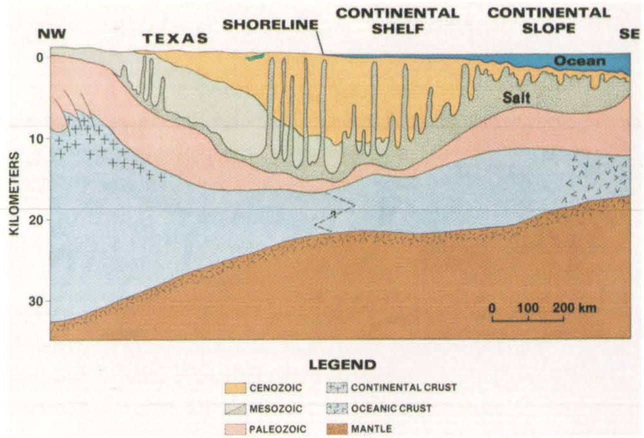
To synthesize our present state of knowledge on the geology and geologic framework of the EEZ, the USGS is preparing the Continental Margin Map (CONMAP) Series. At a scale of 1:1,000,000, these maps will show the currently available data base on the structure, sedimentary framework, and stratigraphy of the EEZ.



Understanding the motion of the Earth's plates and related processes helps geologists understand the distribution of the Earth's resources.

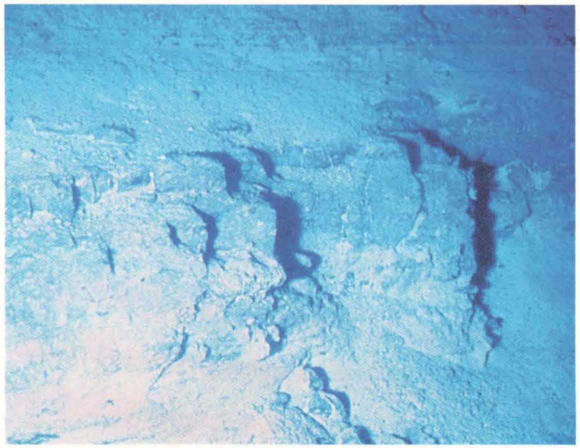


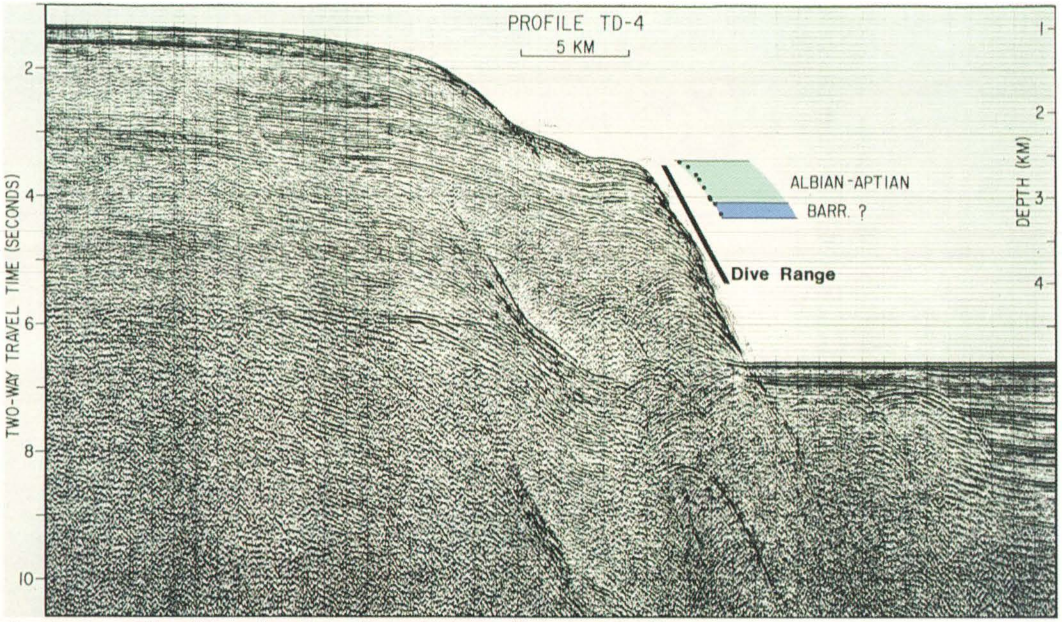
The Continental Margin Map Series synthesizes the available geologic information within the EEZ.



Rising masses of salt deform the sediments in the Gulf of Mexico providing abundant traps for the accumulaton of oil and gas.

Rocks exposed in the eroded edge of the Florida platform.





A seismic profile of the edge of the Blake Plateau off eastern Florida.

The EEZ: Energy and Mineral Resources—Oil and Gas

How They Form

The 30 sedimentary basins within the EEZ of the United States represent major present and potential future sources of oil and gas. The degree of oil and gas resource potential in these basins depends on their physical and chemical history. Organic matter must have been present in the sedimentary rocks of the basin. These organic-rich rocks (source rocks) must have been buried deeply enough so that under conditions of high temperatures and pressure the organic material was converted to hydrocarbons (oil and gas). These hydrocarbons must have been able to migrate to a rock layer (reservoir rock) which had abundant void spaces (porosity) in which hydrocarbons could accumulate. This reservoir layer must have contained traps (places for the oil and gas to accumulate) and have been overlain by an impermeable layer so that the oil and gas did not migrate upward. Further, the traps must have formed prior to migration of the hydrocarbons in order to trap them. If all these conditions were met, a basin will have petroleum resource potential. An unconventional trap for gas may also occur in the oceans where conditions of low temperature, high pressure, and saturation concentrations of gas are present. In this case, a gas hydrate (an icelike crystalline solid) is formed in the sediments and creates a seal for gas to be trapped beneath. Oil and gas are critical commodities for an industrialized nation; obtaining and using them requires that the details of petroleum generation as well as the future resource potential must be understood.

Environmental Considerations

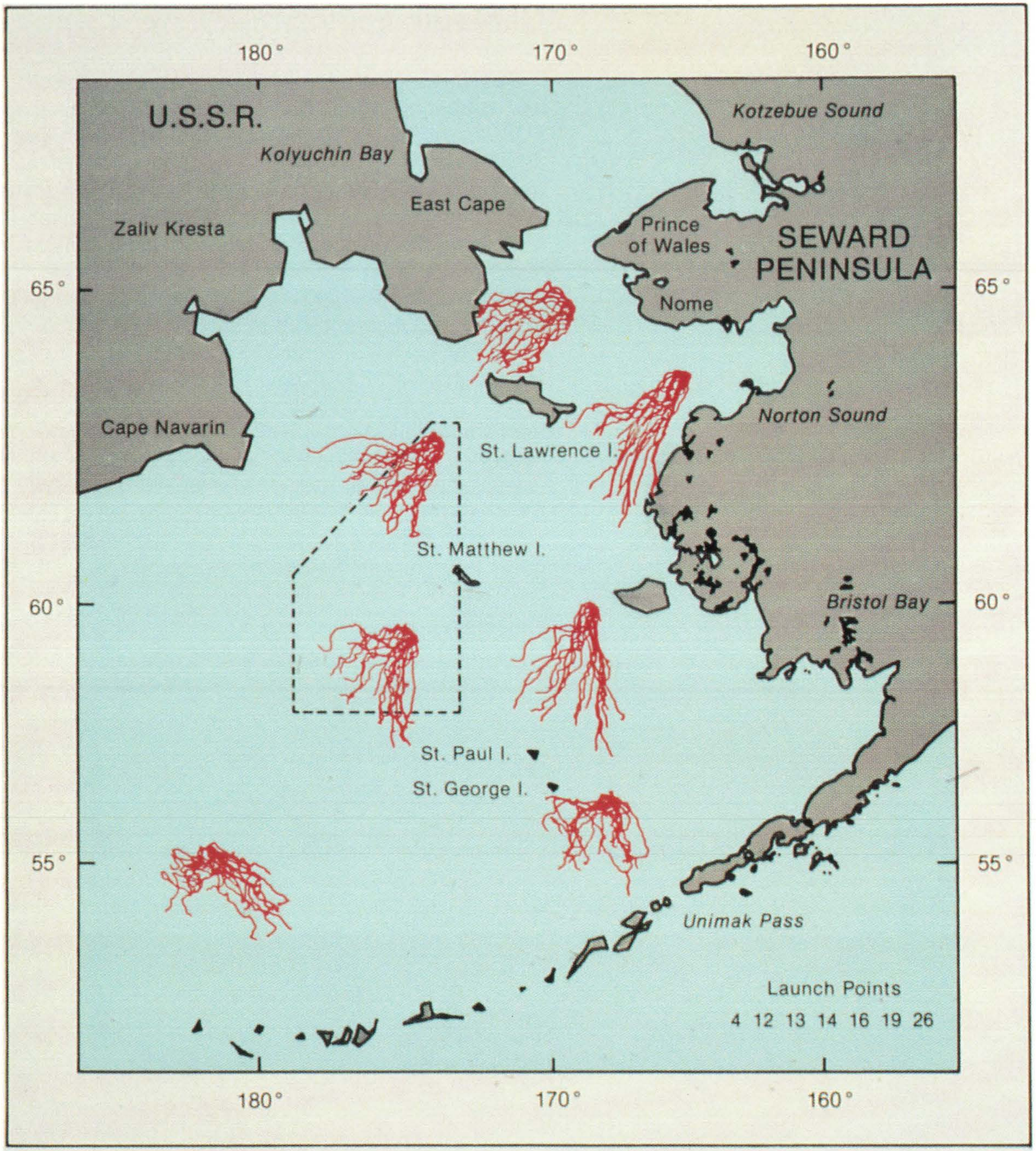
The development of oil and gas resources in the Exclusive Economic Zone, in an environmentally acceptable manner, requires a number of supportive studies. These studies conducted by NOAA include basic weather observations, ocean water and sediment studies, ice and geologic hazards, and the assessment of the impact of the development and production of oil and gas on the sea life.

Climatological atlases have been prepared for all offshore regions of the EEZ to show basic environmental parameters needed to determine the engineering and structural requirements of offshore structures such as drill rigs. These data, when supplemented with site-specific information, are essential for developing the EEZ resources.

The Outer Continental Shelf Environmental Assessment program of NOAA includes detailed studies of the effects of oil and gas development on the coastal waters of the United States. This reimbursible program, conducted for the U.S. Department of the Interior's Minerals Management Service (MMS), is specifically directed toward assessing the impact of oil and natural gas activities on the Alaska EEZ. These studies include publications and data products on environmental hazards, pollution transport, regional biota, habitats, and ecosystems in Alaskan waters; they are being used as the principal source of scientific information for the purposes of lease sales and development decisions by MMS.

Drilling for oil in the EEZ requires a thorough understanding of environmental conditions.

Oil spills in the EEZ, due to accidents or natural causes, can have disastrous consequences.

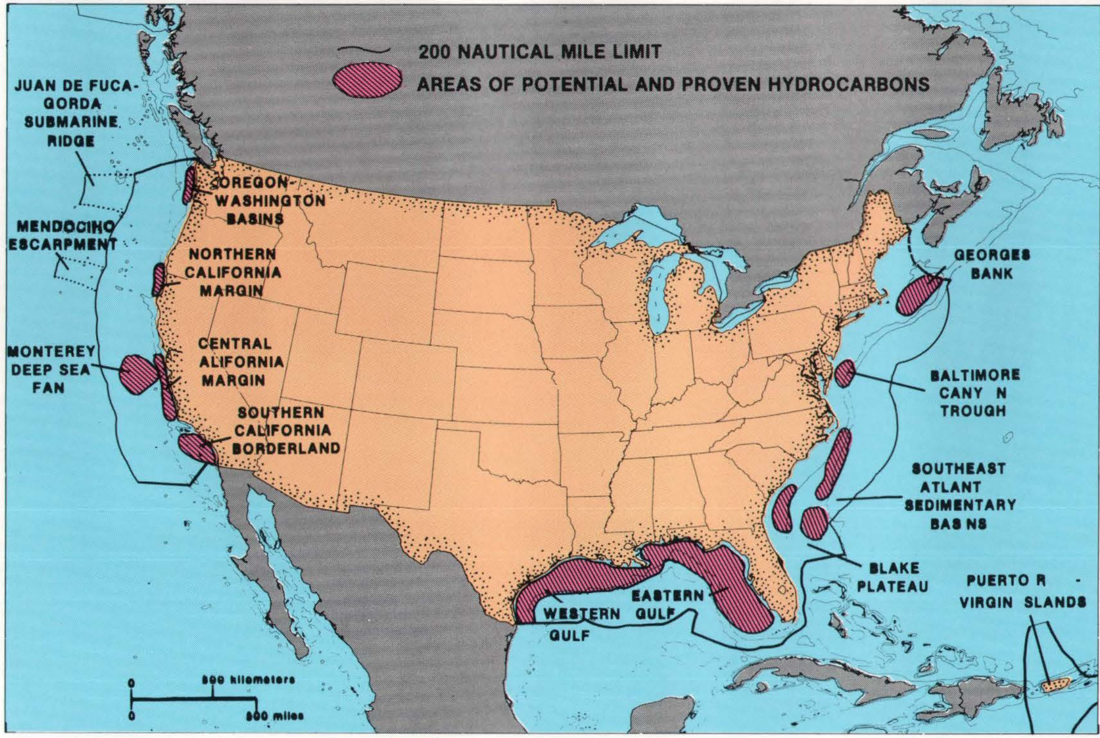


Determining the probability and possible effects of an oil spill will allow us to prevent or mitigate its damage.

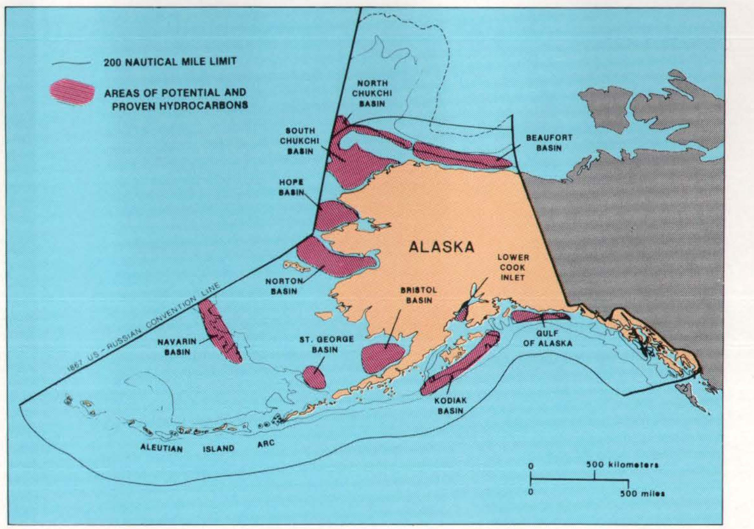
Geologic Factors

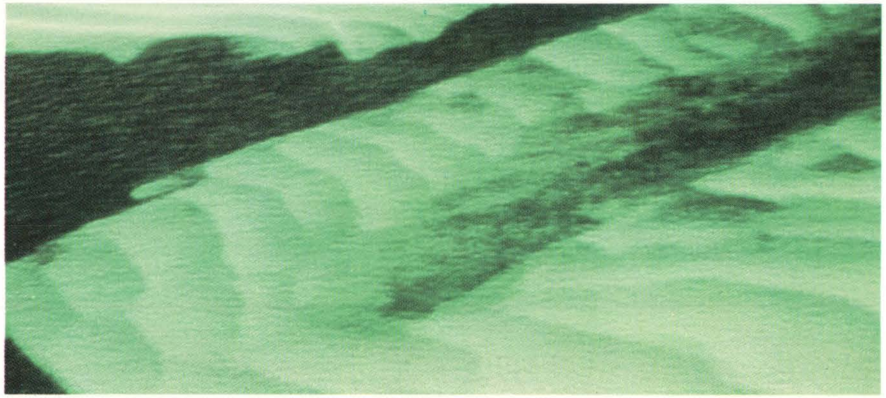
USGS research examines all facets of petroleum, from its origin to final reservoir, as well as assessing resource potential. Today's sea floor can be viewed as a modern laboratory for studying the depositional environments, sedimentary characteristics, variability, and distribution of sedimentary layers which, when buried, will become the source rocks and reservoir rocks of the future. The sea floor also provides a modern analogue for identifying and developing petroleum-producing rocks buried within the Earth's crust. For example, sand bodies on the shelf, the Mississippi Delta, and deep water fans are modern features being studied to learn more about ancient deltas and sand bodies which are part of the rock record on land and contain producing oil fields.

Deep-penetration seismic profiles not only show the shape of buried basins, but also the lateral extent of layers within the basins. The seismic reflection data also document the presence of structural features (diapirs and faults) that serve as traps for petroleum and the differences in the velocity of sound through the layers, which reflect compositional and porosity changes in the rocks within the basins. Composition and porosity are important parameters for determining reservoir potential of the rocks; the petroleum potential of a basin can be determined from this data. Changes in the amplitude of the reflected sound waves can be used as a prospecting tool to indicate the presence of gas. Samples from drilled wells such as the Continental Offshore Stratigraphic Test (COST) wells, shared and analyzed by industry and Minerals Management Service geologists, provide important information on the age, organic content, porosity, permeability, and depositional environment of the rock layers recorded and mapped with seismic reflection profiles. The subsidence history and crustal structure of a continental margin, as determined by the modelling of geophysical data, are important in evaluating the temperatures and pressures to which the rocks have been subjected to determine if conditions have ever favored forming hydrocarbons.

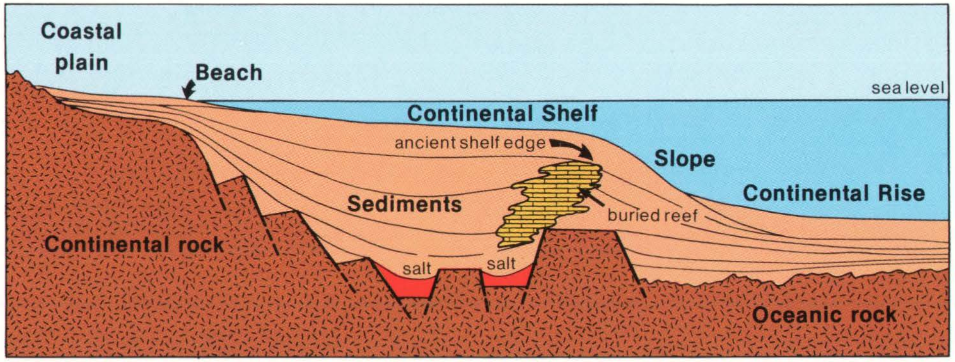


Thirty sedimentary basins with potential oil and gas resources occur within the EEZ.

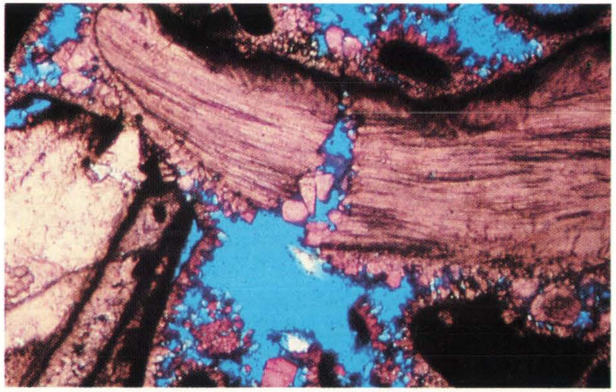




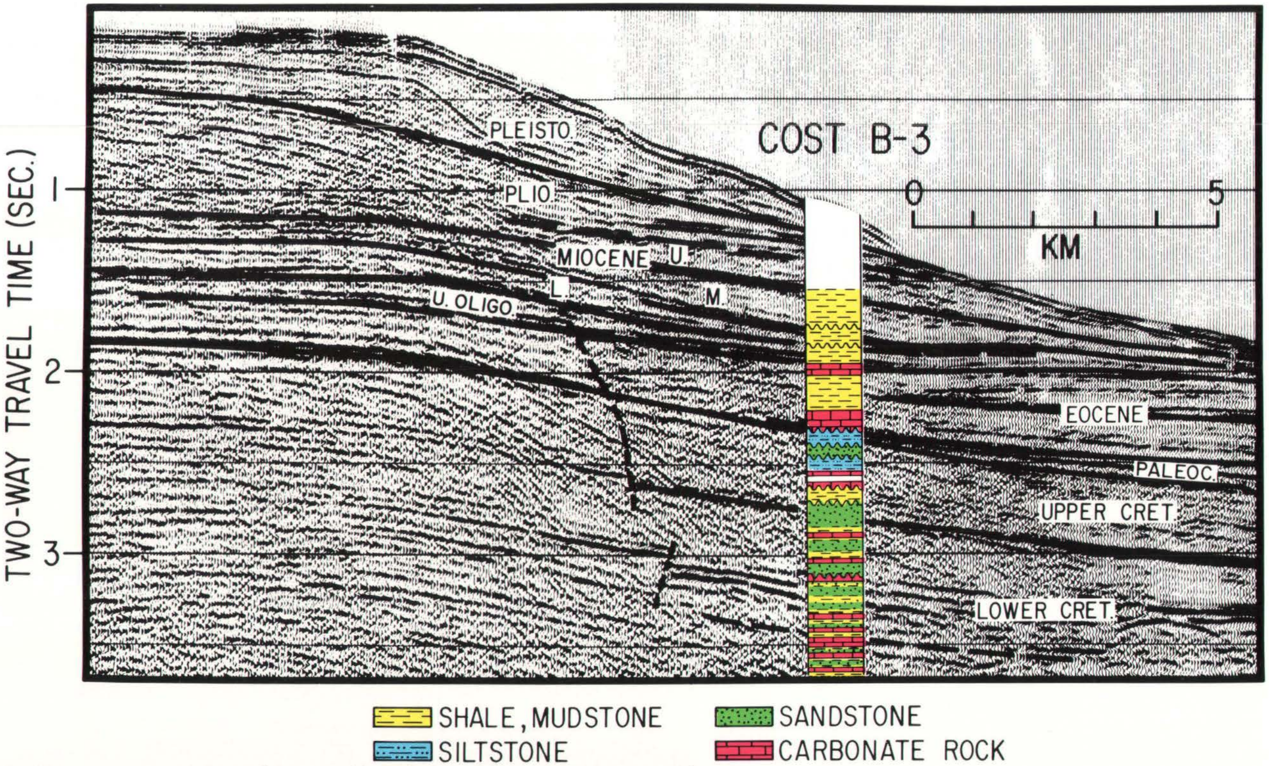
Aerial view of marine sand shoals. Sandstone bodies, when buried, can provide reservoirs for the accumulation of oil and gas.



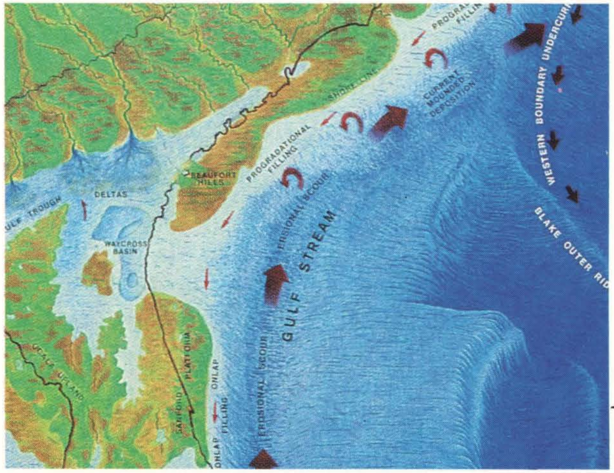
Generalized cross section of the U.S. Atlantic continental margin shows a deep basin, buried beneath the shelf and slope, which is filled with sediments. A buried reef marks an old shelf edge. The basin sediments and the reef are being evaluated for their oil and gas potential.



A microscopic view of the fabric of a rock showing spaces (blue) where oil and gas can accumulate.



Drilled cores into the sea floor provide valuable information for evaluating the resource potential of the continental margin, and the layers identified on seismic reflection profiles.



←Understanding the original depositional environments is important in evaluating the resource potential of rock units.

The EEZ: Polymetallic Sulfide Minerals

How They Form

The crests of the Gorda and part of the Juan de Fuca Ridges are located within or partly within the EEZ off Washington, Oregon, and California. They are part of an ocean ridge system which extends 80,000 kilometers through all the world's oceans. New sea floor is created at ocean ridge crests by active sea-floor spreading as the plates that make up the Earth's surface are pulled apart. Molten rock rises from within the Earth and erupts as lava flows in the axial rift valley. Faults present on the ridge crest provide conduits for cold sea water to percolate downward and react with the hot rocks within the Earth's crust, leaching sulfur and heavy metals such as manganese, zinc, copper, silver, and cadmium. As this water is heated, an active convection cell is set up within the ridge crest and the mineral-laden boiling water is driven upward toward the sea floor as new cold sea water descends to keep the cycle going. As the pressure, temperature, and chemistry of the solutions change as the water rises through the crust, some of the minerals dissolved in the water precipitate on the walls of the fault and on the sea floor. When this hot mineral-laden water reaches the sea floor, it shoots upward in a plume much like an underwater geyser. These fascinating hydrothermal plumes, or "smokers," and their mineral deposits reveal the actual processes of mineral formation. This modern example of mineral formation is vital to a better understanding of the ancient geologic setting of similar massive sulfides long known and mined on land. These

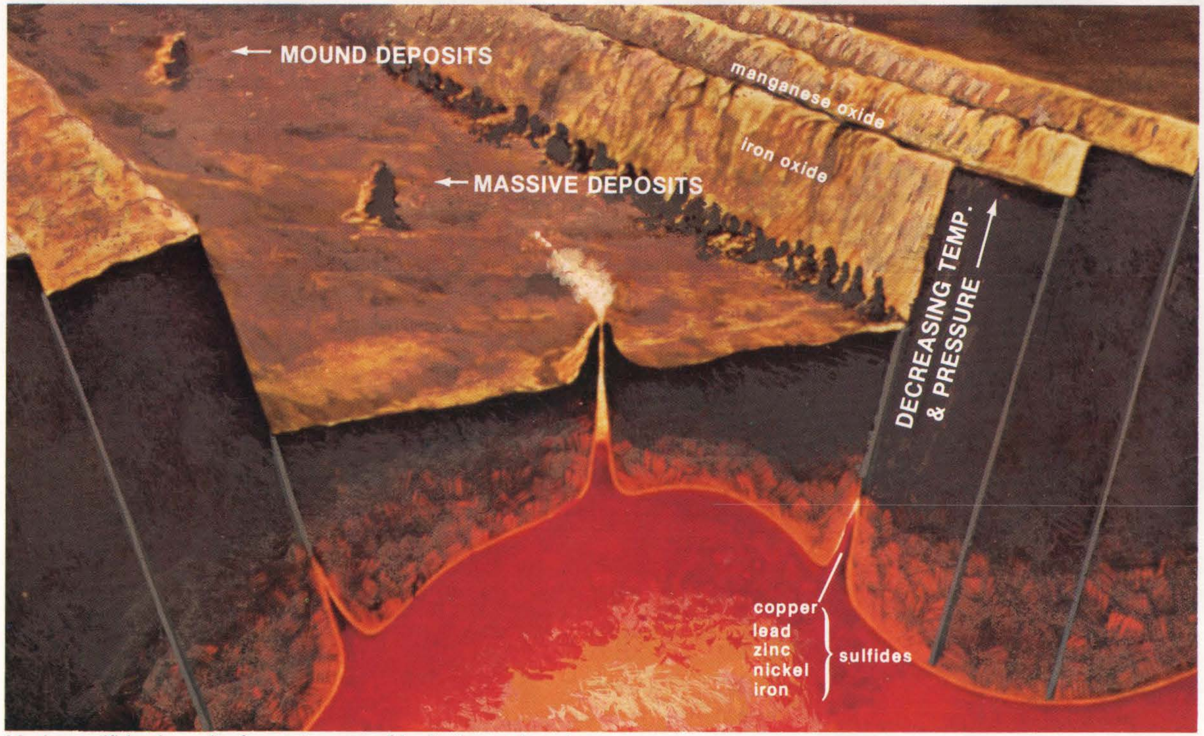
(continued on page 24)

Polymetallic Sulfide System

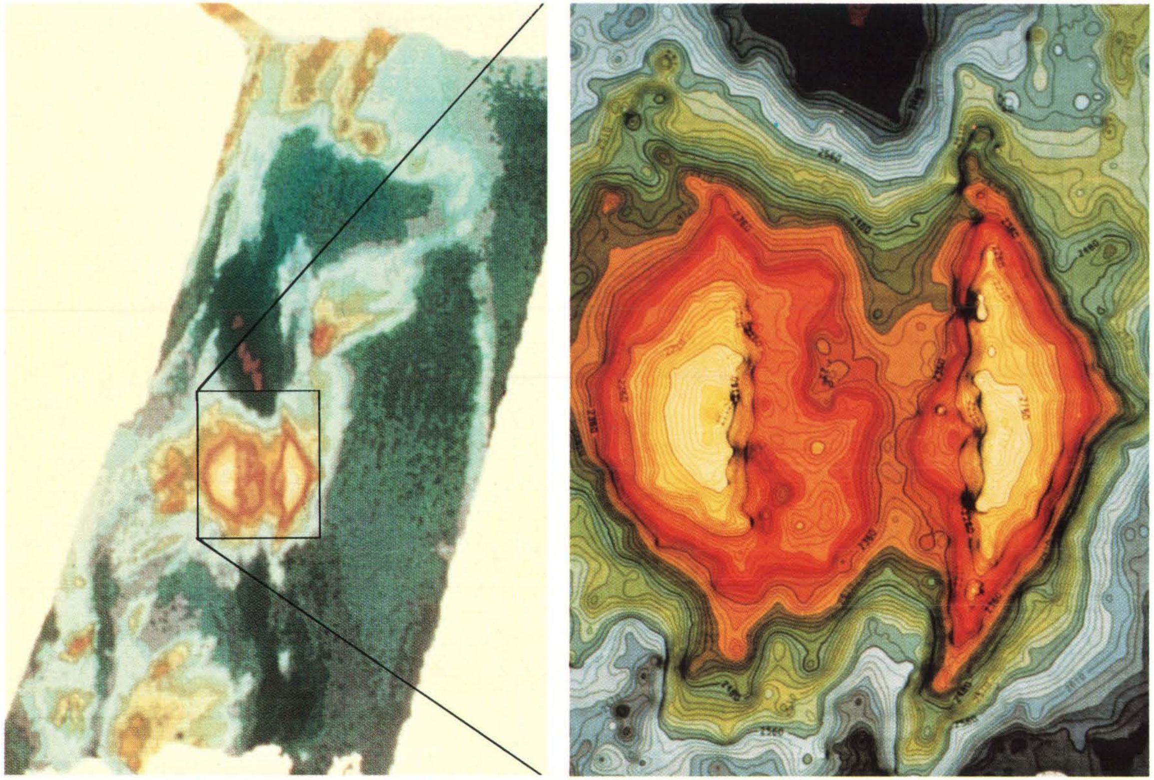
NOAA's interest in polymetallic sulfides is largely related to the need to understand their function in the overall geochemical budget of the oceans. The characteristics of the full suite of consequences of hydrothermal venting also must be understood so that NOAA can effectively assess the probable environmental effects of any use of venting-associated phenomena (such as the polymetallic sulfide deposits, the chemosynthetic organisms, and the heat released into the water) that may be proposed during economic development of the EEZ's sulfide minerals.

As part of the environmental assessment effort, NOAA has conducted research since 1980 on the Gorda and the Juan de Fuca Ridges. These studies focus on the distribution of hydrothermal plumes (as identified by elevated concentrations of helium, methane, manganese, iron, zinc, lead, and silver) and the processes that occur within them (changes from dissolved to particle form, scavenging metals from vent water or sea water, and settling processes of precipitated particles).

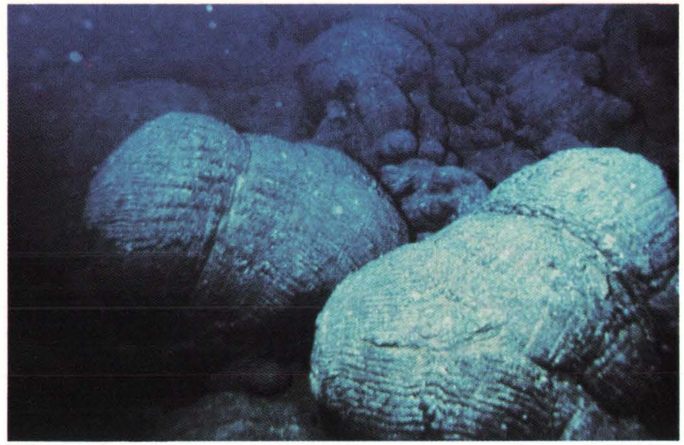
In 1984, NOAA scientists collected fluid and gases from within a hydrothermal vent by using the research submersible *Alvin*. The work was closely coordinated with that by USGS scientists; both parties collected water, sediment, and rock samples, which are being examined in cooperative studies.



Marine sulfide deposits form at areas of hydrothermal vents.



Areal and detailed Sea Beam maps of a bifurcated axial volcano on Endeavor Ridge.



Pillow-lava flows on the crest of the Juan de Fuca Ridge.

Massive sulfide deposits near a hydrothermal vent.

Crabs and clams live near the hydrothermal vents.

Tube worms also live near hydrothermal vents.

How They Form

(continued from page 22)
massive sulfides are believed to have formed at ocean spreading centers and later were "plastered" onto a continent by moving crustal plates.

A totally new community of marine organisms lives in the darkness of the ridge crests (see page 23). These organisms draw their nutrients and energy by chemical reactions (chemosynthesis) from the solutions rising from the rocks, rather than from the sunlight (photosynthesis) as they would do in shallow water. Recently, similar marine organisms have been found on the sea floor off Oregon and in the Gulf of Mexico and are believed associated with water escaping from the sediments and transporting sulfides or methane as nutrients.

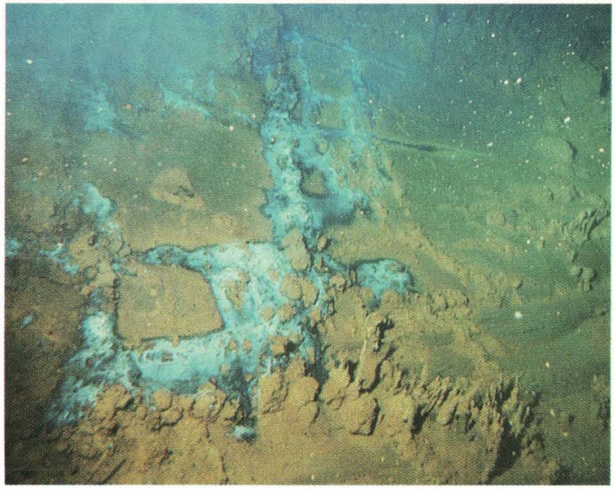
Massive Sea-Floor Sulfide Deposits

USGS scientists are studying the southern end of the Juan de Fuca Ridge to determine the mechanisms and factors controlling the location of sulfide deposits and their variability in time and space. Video camera surveys show the distribution of deposits on the sea floor in the axial valley, which has a linear depression 50 to 200 meters wide and 25 meters deep and was formed by collapse of a lava lake. Deposition of the massive sulfides appears to be related to stages of magmatic activity; deposits are located within and adjacent to this depression. Samples of the sulfide deposits have been collected by dredging and by the deep-diving submersible *Alvin*. Analyses of these samples are used to infer the pressure, temperature, and geochemical conditions during the formation of the minerals. These data are important for comparing these ores formed at or near the sea floor today with similar ore deposits mined on land. Knowledge of the detailed, modern tectonic setting for ore formation is also valuable for locating new ore deposits on land.

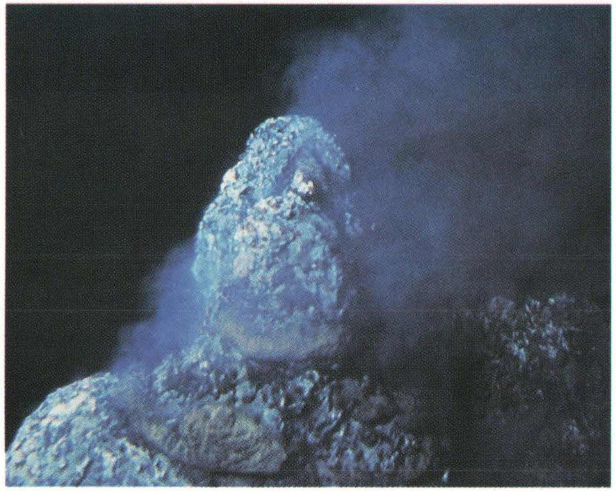
The Gorda Ridge, a slower spreading active ridge crest, is a potential site for ore formation. Expeditions have recovered only low-temperature hydrothermal material with some evidence of sulfides. The sediment-filled Escanaba Trough, the southernmost 90 nautical miles of the Gorda Ridge, may possess interesting similarities to the Guaymas Basin in the Gulf of California where hydrothermal circulation has been identified.

Knowing the thickness of the sulfide deposits is critical for assessing their resource potential. The roughness and slope of the sulfide deposits and the sea floor itself impose severe constraints on the ability of existing technology to drill into the sea floor. USGS scientists working with the rock drill developed by Canada's Bedford Institute of Oceanography have identified some of the drilling problems. Identifying needs for new technology is an important aspect of the program.

Massive sulfides are being extracted at the North Mathiati open-pit mine in Cyprus.

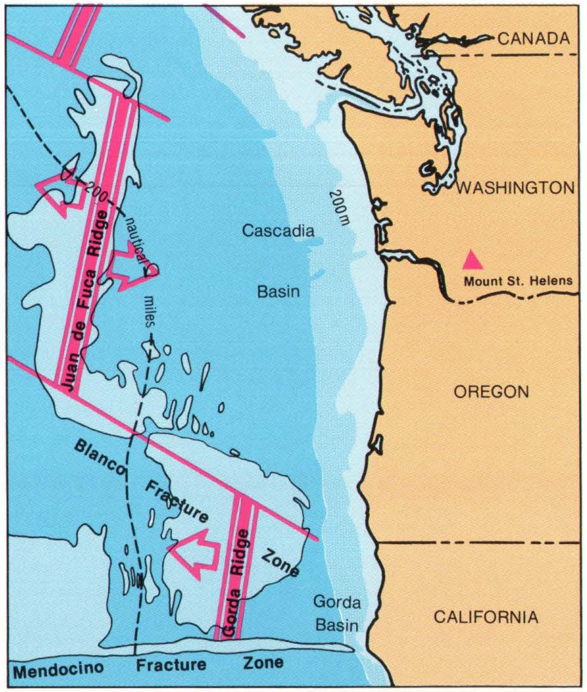


Polymetallic sulfide deposits on the Juan de Fuca Ridge.

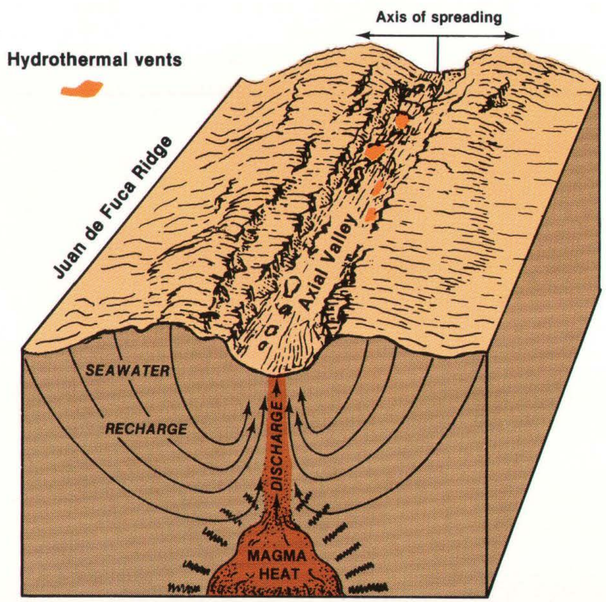


The top of a "smoking chimney" on Juan de Fuca Ridge.

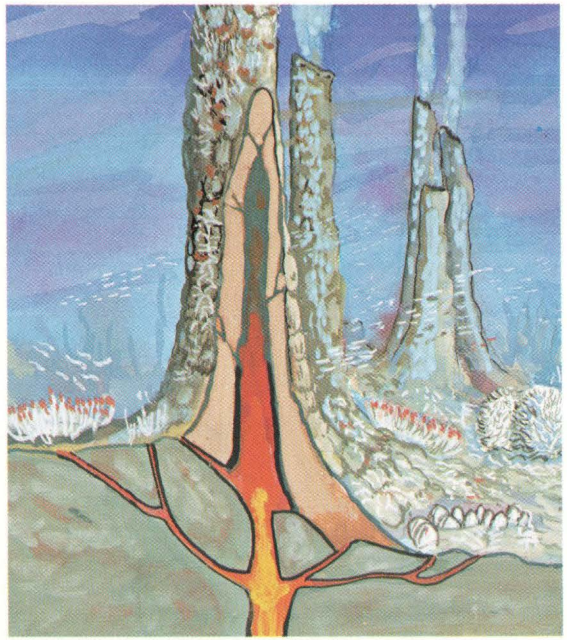
Portion of chimney composed of sulfide minerals.



The Juan de Fuca and Gorda Ridges are active spreading centers off the coasts of Washington, Oregon, and California.



Sea water circulates through the rocks of the sea floor dissolving many minerals and depositing massive sulfide bodies containing zinc, copper, iron, lead, cadmium, and silver.



Hydrothermal vents occur along the floor of the axial valley of the actively spreading ridge crest.

The EEZ: Cobalt-Enriched Manganese Crusts and Nodules

How They Form

Manganese nodules and crusts occur within the EEZ off the east and west coasts of the continental United States, Hawaii, and the Pacific Island territories. Nodules are present on the deep sea floor where sediment accumulation is low, on the flanks and tops of seamounts, and on the Blake Plateau, a wide, terrace-like feature off the east coast of Florida. Manganese crusts, enriched in cobalt, coat the rocks exposed for long periods of time at the sea floor, on the flanks of seamounts, volcanic ridges, escarpments, and island arcs. The manganese, cobalt, nickel, platinum, copper, and molybdenum in these crusts are believed to be deposited onto the sea-floor rocks from sea water in a process that is similar to plating. Trace metals deposited with the manganese make the manganese nodules and crusts a valuable potential resource. To build a base of information on crusts, a catalog is being compiled of the chemistry and locations of all the existing samples of manganese crusts dredged from the world oceans and now housed in institutional collections.

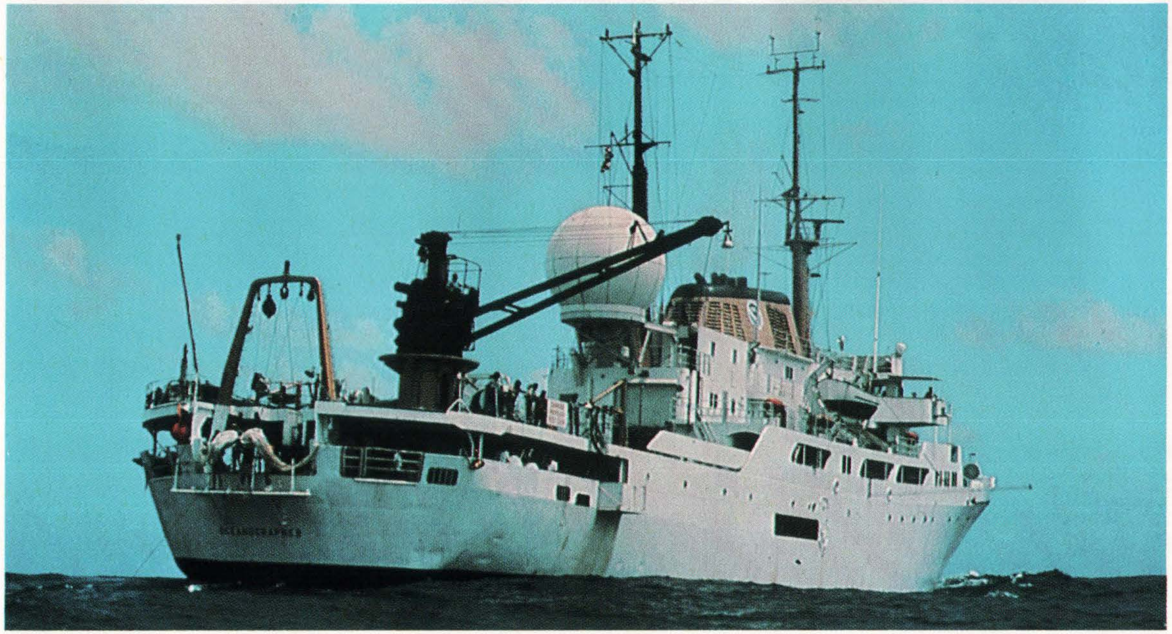
Oceanographic Studies

An understanding of the physical, chemical, and biological processes active in the oceans is important in understanding the formation of manganese crusts and nodules. Sea-floor features must also be mapped in sufficient detail to identify potential resource areas so that planning can begin for the actual mining surveys.

In addition to identifying and understanding these features, NOAA, with the aid of the mining industry, also is developing appropriate environmental safeguards and monitoring strategies, so that when actual mining occurs, it can be done in an environmentally acceptable manner. The primary area of concern is mining's impact on the benthic environment. Several research projects are currently examining the effects caused by the nodule collector device and the benthic plume created by the sediments disturbed as the collector moves along the sea floor.

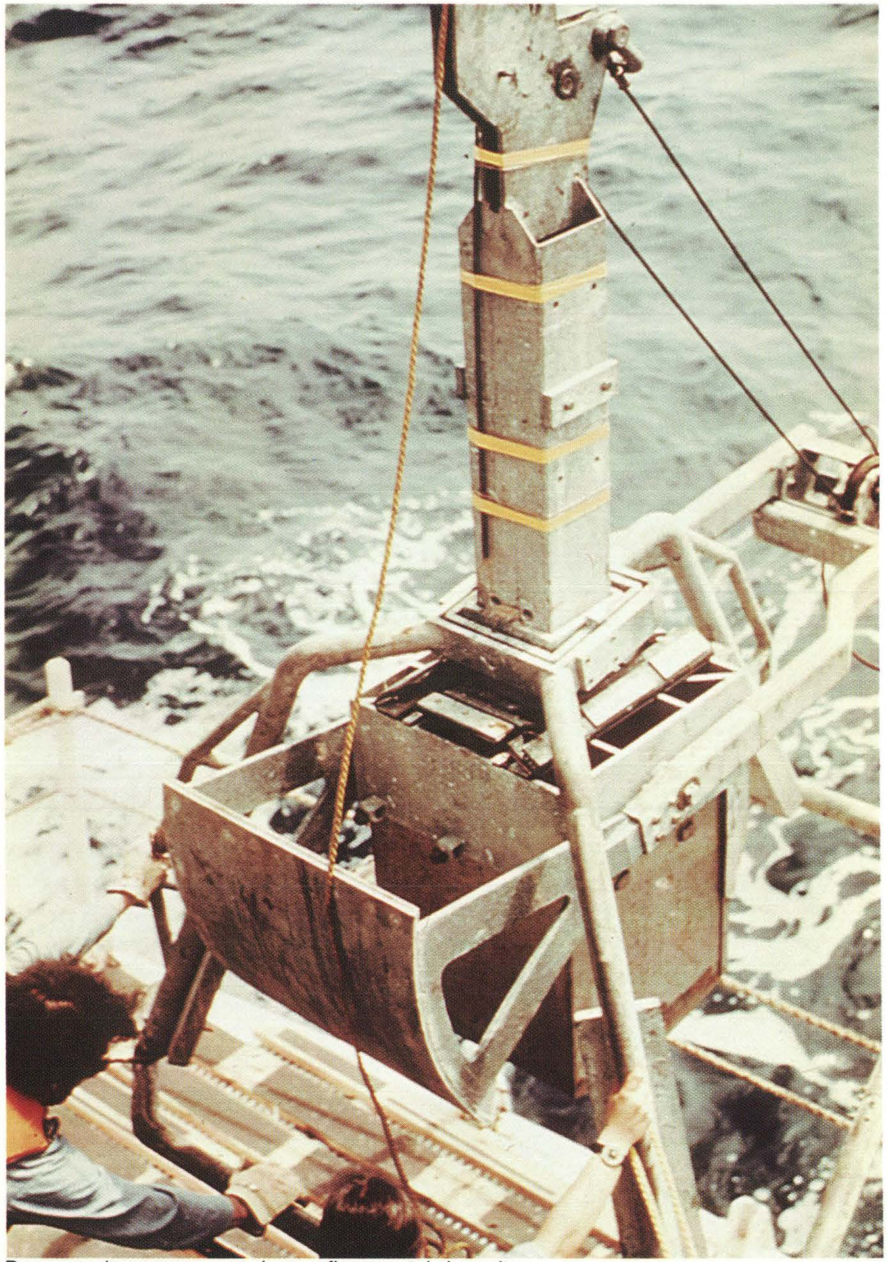
Data from current meters are used to understand ocean circulation and help to determine the potential impacts of ocean mining.

NOAA ship *Oceanographer* surveying ocean mining sites in the Mid-Pacific Ocean.



Nets sample fish and plankton to determine the possible effects of ocean mining on sea life.

Manganese nodules found on the sea floor in the EEZ also contain significant amounts of nickel, cobalt, and copper.

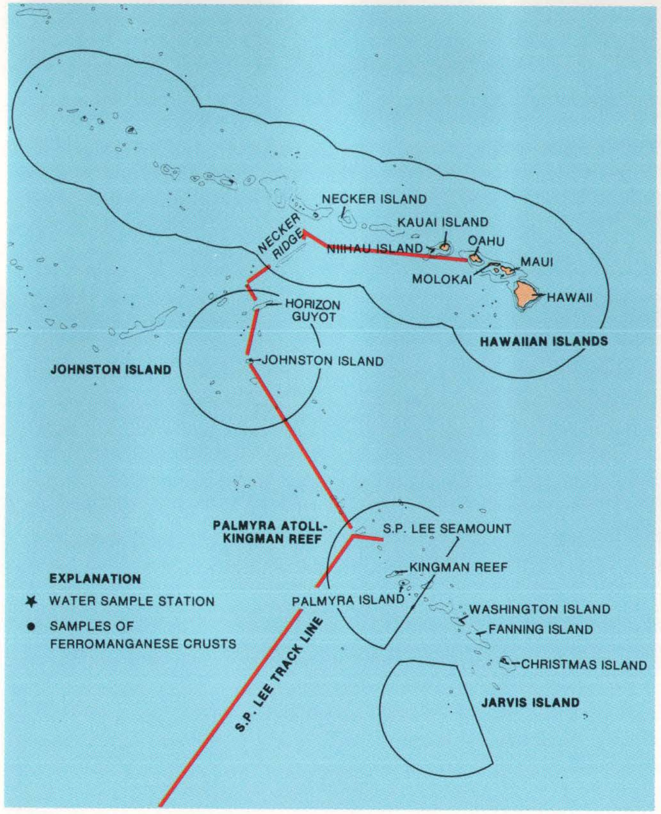


Deep-sea box cores sample sea-floor metal deposits.

Geologic Characterization

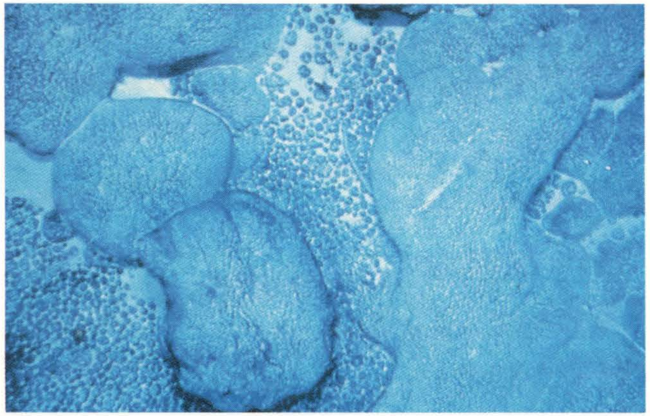
Cobalt-enriched manganese crusts are present throughout much of the EEZ, yet little is known about the conditions controlling their thickness and the variability of their trace-metal content. During a cruise to the Mid-Pacific and Southwest Pacific in 1984, USGS scientists measured the variability and characteristics of cobalt-enriched crusts. The cobalt content varied with water depth; the maximum concentration occurred on rocks located in water depths between 1,000 and 2,500 meters in the Pacific Ocean. This depth range coincides with an oxygen-minimum zone in the water column. The thickness of these crusts varies, but their mean thickness is more than 2 centimeters. The cobalt concentration varies from 2.5 to 1 percent, but the higher values appear to increase toward the equator. To determine the distribution of these crusts, as well as their processes of formation, a continuing research program is underway. High-resolution geophysical profiles show the topography, such as terraces and flat summits on the seamounts, steepness of the slopes, and the presence of sediment. Photos of the sea floor are used to map the distribution of nodules and crusts. Because a low rate of sediment accumulation favors crust deposition, current-meter and sediment-trap data provide information on the amount of sediment falling to the sea floor and the currents that can sweep the sediment away. The flow of water around the seamounts may enhance the speed at which the manganese and other metals are deposited.

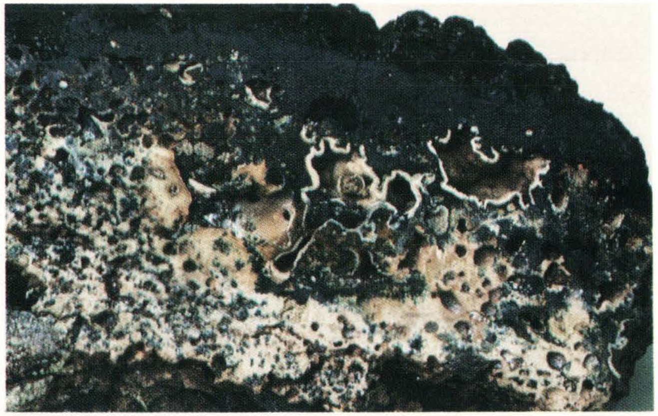
Recovering samples of crusts to measure their characteristics and chemical composition poses problems. Only loose debris or small chunks can be torn from the sea floor by a dredge. After rattling around inside a rock dredge during the mile-long journey from the sea floor to the deck of the waiting ship, much of the crust can be abraded and lost. Perfecting the technology to collect drilled cores from the rocks composing the flanks of the often steeply sloping volcanic features is critical for evaluating the resource potential of the crusts. Trends in the chemistry of stored samples are being studied to look for clues to the processes controlling the deposition and composition of the crusts, and to focus on areas for future study.



Cobalt-rich manganese crusts occur on the flanks of volcanic islands and seamounts. Samples of cobalt crusts have been collected from several volcanic features in the EEZ near Hawaii.


USGS scientists prepare to deploy a rock dredge to obtain samples of cobalt crusts from the flank of a volcano.


Nodules and cobalt crust mantle the rocks on the top of a submarine volcano.


Cobalt crusts 2-4 centimeters thick coat the rocks exposed at the sea floor (black rind).

The EEZ: Placers, Sand and Gravel, Phosphorite

How They Form

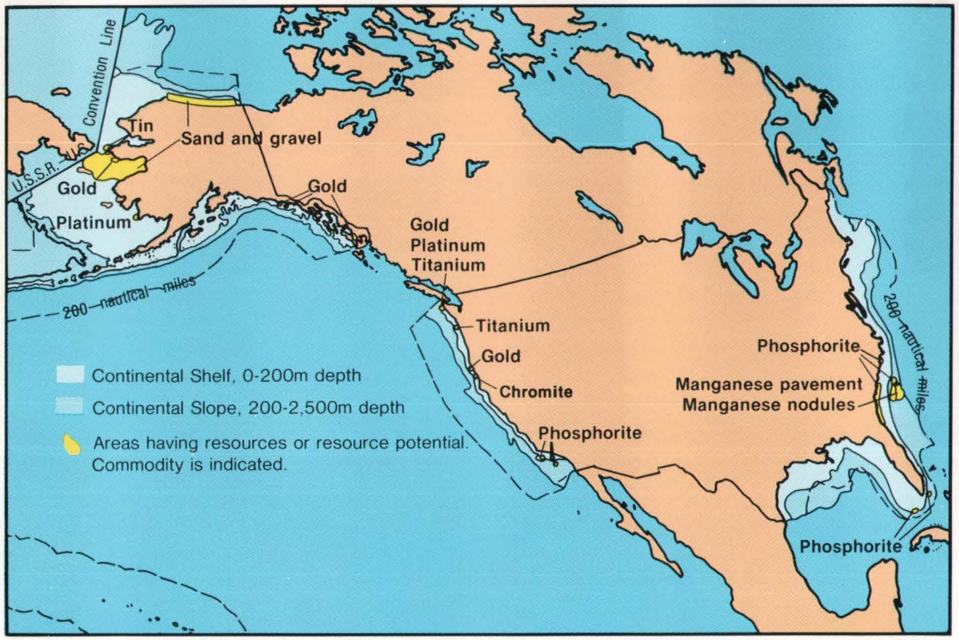
Adjacent to the continent, below the shallow waters of the shelf, deposits such as gold, precious and heavy mineral placers, sand and gravel accumulations, and phosphorites all have resource potential when they occur in sufficient quantities. As rivers erode the surface of the land, they pick up a load of sediment and carry it toward the sea. On reaching the ocean and the relatively flat continental shelf, these rivers drop their coarse-sediment load of sands and gravels. In the shallow water of the continental shelves, the ocean waves and currents rework this material into ridges of sand. Many times during the past, sea level has changed from its present position, such as during the Pleistocene, the last major "ice age." During this interval, much of the ocean's water was locked in ice sheets over a mile thick covering a large portion of North America. As the climate varied between warm and cold during the Pleistocene, the edge of the sea moved back and forth across the flat shelf leaving behind evidence of its passage in the form of beaches like those that are present at the water's edge today. Contained within these submerged beaches and ridges, reworked and winnowed by ocean currents and waves, are lag-layers or placer deposits, rich in gold, tin, platinum, titanium, and chromite. The sand and gravel itself is used for aggregate for the construction industry or for building artificial islands in the Arctic to prevent the ice from destroying drill rigs. Phosphorites, important as fertilizer for agricultural industry, also occur off the east and west coasts of the Southern U. S.

Their Environment

Environmental assessment studies of potential mining of sand and gravel on the Massachusetts continental shelf were conducted by NOAA. NOAA's reconnaissance and assessment of heavy minerals and sand and gravel in this area and elsewhere were done in cooperation with various universities. This work has yielded (1) new ideas on how the heavy minerals are concentrated within the surficial sands of the continental shelf; (2) new technology to remotely detect high concentrations of these minerals; and (3) improved mining technology. By knowing the physical processes controlling the deposits and the regional geology and oceanography, the probability of a deposit in a given area can be estimated. Once a relatively small area is identified as a potential source, the newly developed detection equipment can be used to confirm the presence or absence of placer deposits.

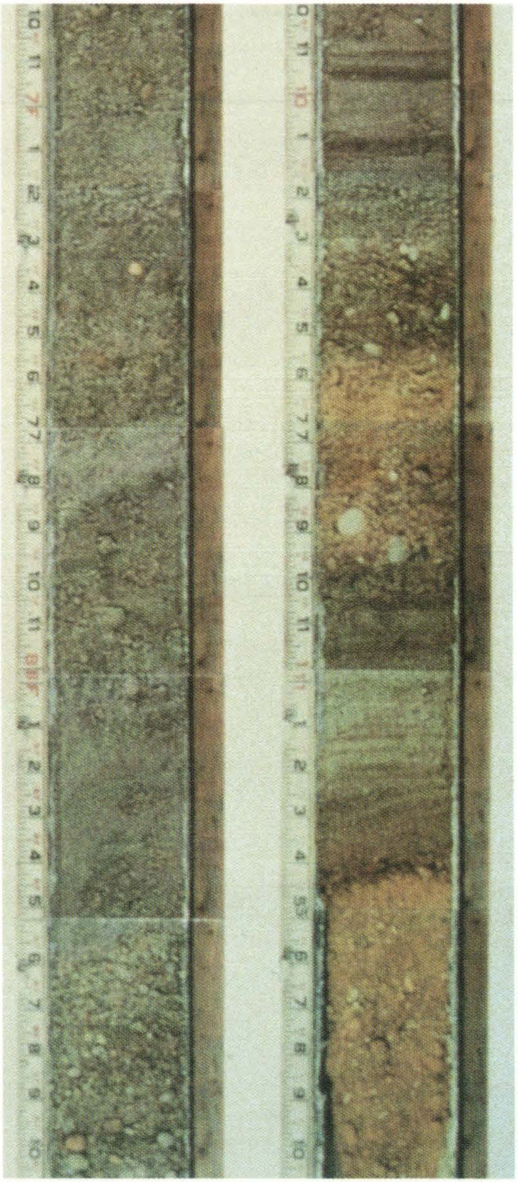
In terms of resource discovery and assessment, NOAA supported several university research projects that developed a model for the formation of phosphate rock. This model suggests a common process for the origin of much of the world's deposits. The process depends on nutrient-rich ocean bottom water being brought to the surface near the edge of a continental shelf by a process called upwelling. Greater knowledge of the regional geology of the continental shelf, global changes in the sea level through geologic time, and the sites of prehistoric upwelling improves the search capabilities within the EEZ for this valuable mineral commodity.

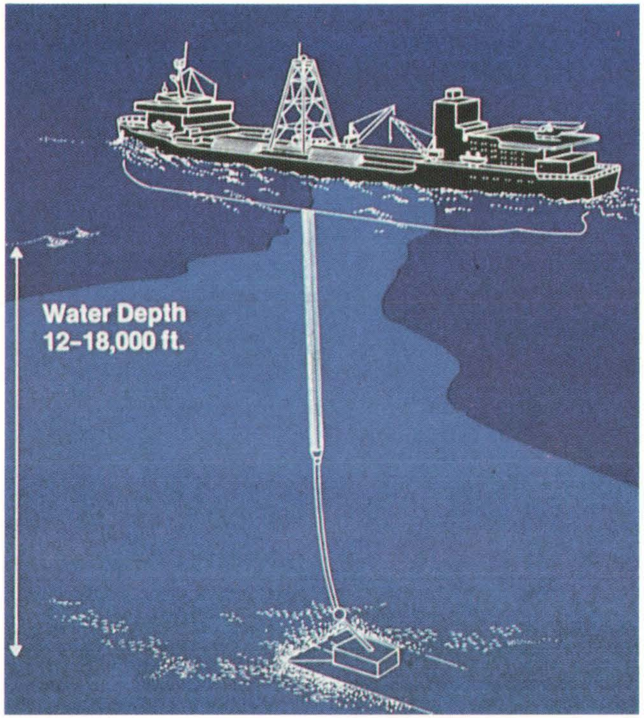
Improved discovery and recovery technology, however, is of little use if the mining operation within the EEZ is of limited economic value. NOAA-supported university research has focused on several studies to determine the economic feasibility of mining operations. These individual studies have produced economic models that can be used in other areas and for other mineral commodities.



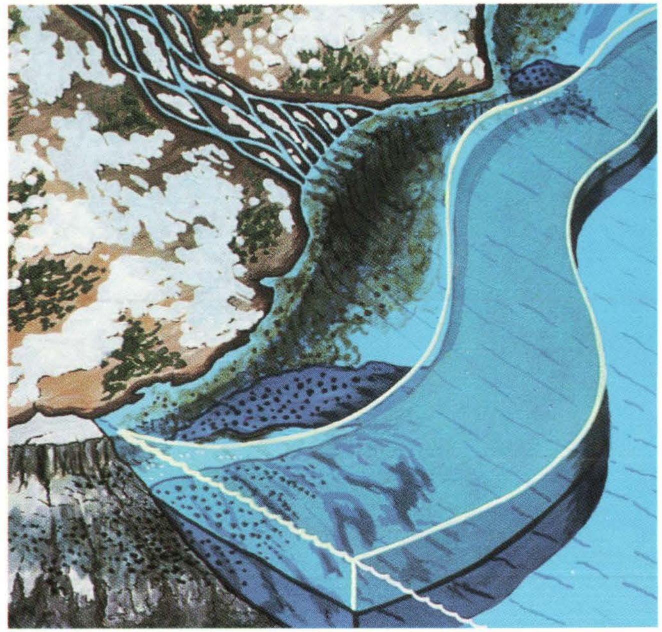
Many areas of the EEZ off the continental United States have high resource potential. Many of these minerals occur in sand and gravel deposits on the continental shelf.

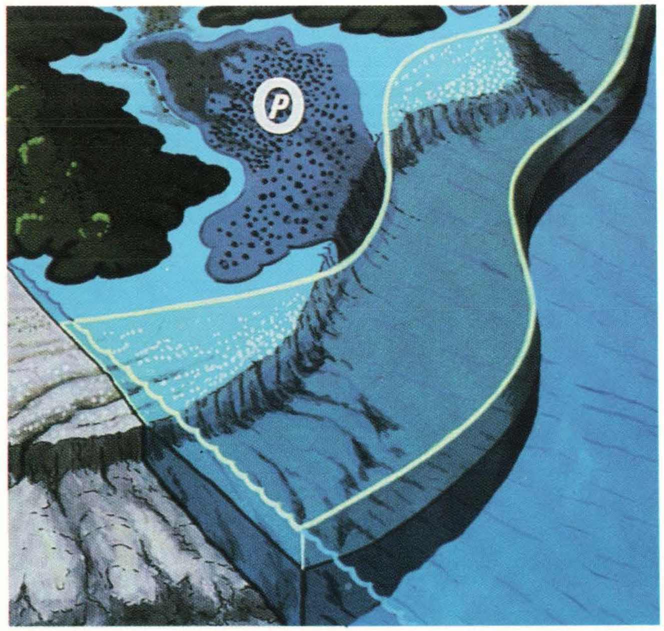
A core through the sea floor shows layers of sand and gravel.





One method proposed for mining operations at sea. Variations of this technique can be used to recover heavy mineral placers, sand and gravel, manganese nodules, and polymetallic sulfides.





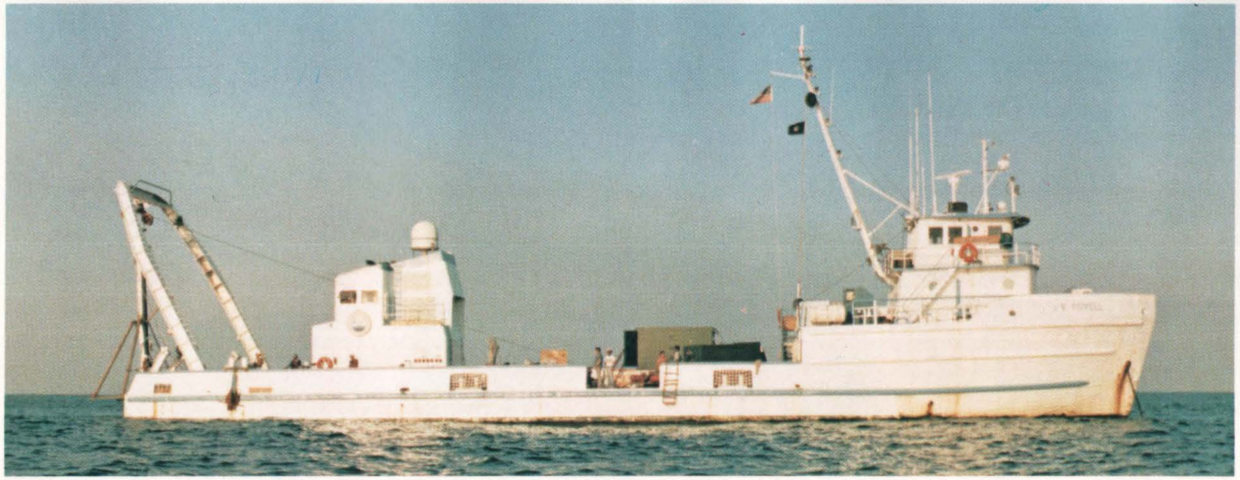
In this idealized cycle of sedimentation on the U.S. Atlantic continental margin, deposition is a direct response to fluctuations in sea level, climate, and water masses on the continental shelf.

Their Characterization

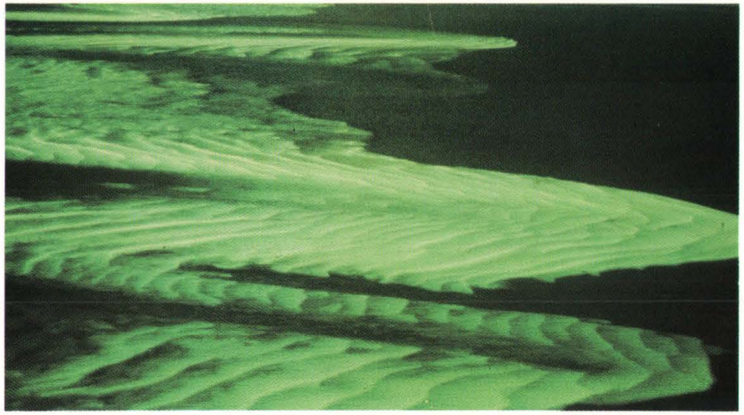
The USGS hard-minerals program is currently forming a digital data base from about 2,000 samples collected over many years from the sand sheet that blankets the U.S. Atlantic continental shelf. These samples were used to determine and map the species, concentration, and distribution of the heavy minerals. Using this historic data as background, areas of high resource potential are being identified for further sampling and study to determine mineral source, processes of deposition and concentration, lateral extent, and economic potential. To facilitate the separation of heavy minerals from the accompanying sands, magnetic separation techniques are being modified for shipboard use and additional new technology is being explored.

In addition to heavy minerals, the sand and gravel of the shelf is important for beach nourishment and as aggregate for the construction industry. The USGS and the Department of Natural Resources of Puerto Rico are cooperating in a study of the distribution and transport processes of the Commonwealth's offshore sand. The construction industry uses sand and gravel on the island. The primary source for this sand and gravel has been the beaches, which also protect the island from the ravages of storms and form a valuable asset for the tourist industry. The beach and the adjacent shelf are a dynamic interrelated environment which must be understood as part of any resource evaluation. To understand the environment, seismic reflection profiles are an important tool used to measure the thickness and distribution of the sand sheet, layers within the sand sheet with placer potential, and also to obtain clues as to the processes that deposited the sand.

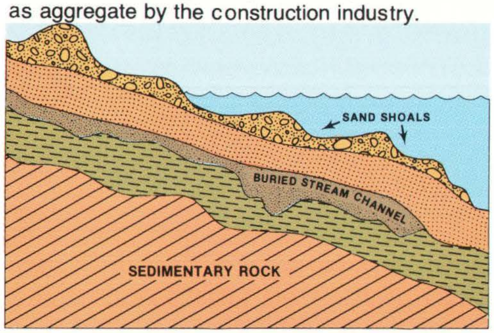
The geophysical data also are used to determine paleoenvironments—to understand the conditions which lead to the deposition of phosphorites. Off the Southeastern United States, the location of the Gulf Stream and the shape of the land have changed as sea level rose or fell during the past 25 million years. Capes or promontories of land that project out into the ocean (for example, Cape Fear or Cape Hatteras), which deflect the flow of currents and cause the upwelling of nutrient rich water, are believed to be important in controlling phosphorite deposition. Using subbottom profiles, geologists have constructed paleomaps of the Southeastern United States to show not only the location and shape of the coast but also where the ocean may have deposited phosphorites both on land during high stands of sea level in paleoestuaries and offshore. The offshore deposits beneath the shelf appear to be an important resource of phosphorites.

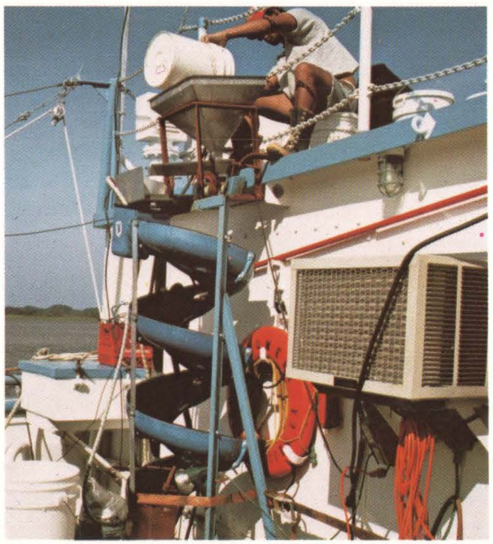


USGS ship *Powell* cores the shelf to determine the → thickness of sands containing concentrations of heavy minerals.

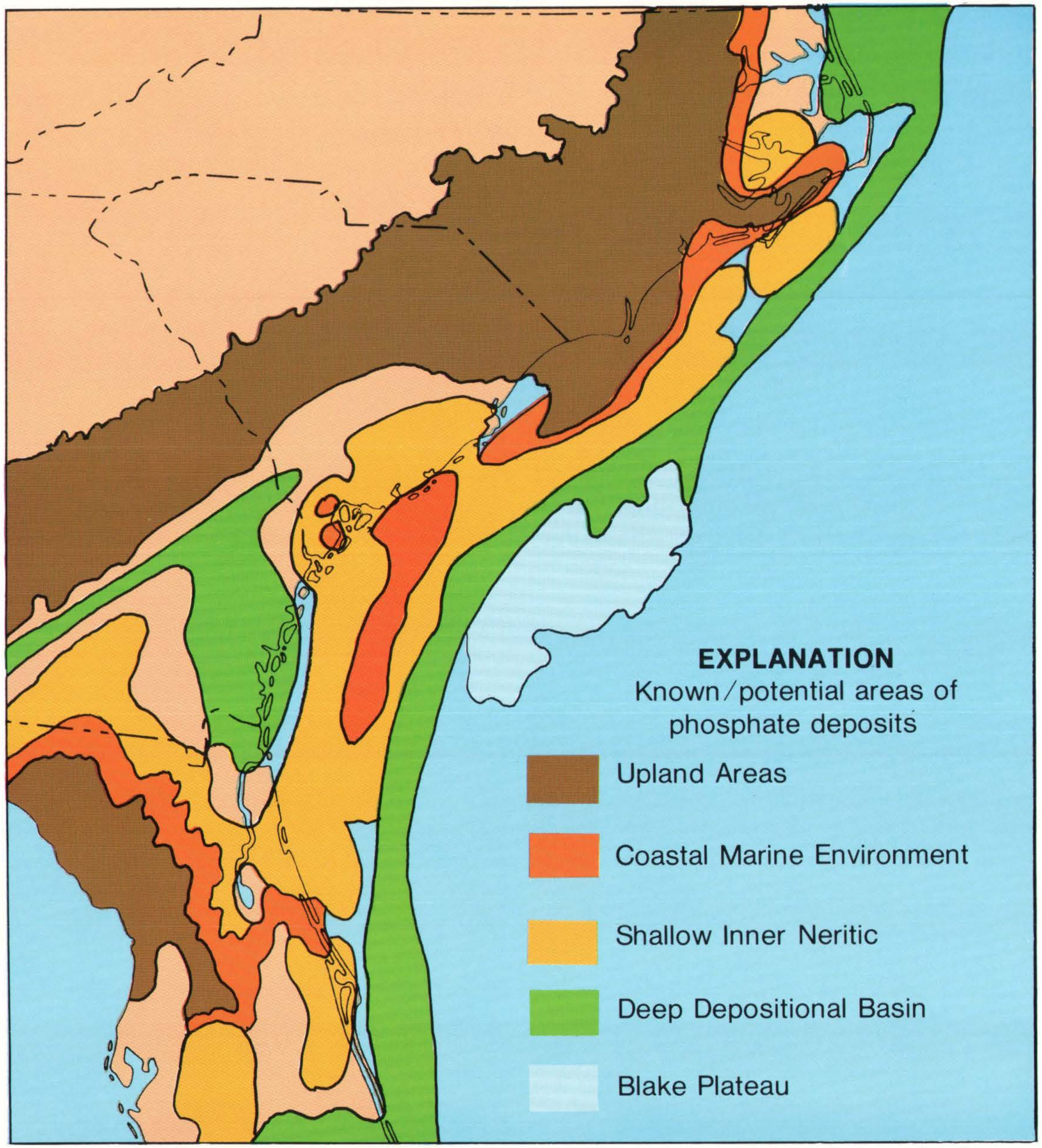


Sand ridges, reworked by ocean currents, occur on the shelf. Sands and gravels also fill channels cut in the shelf during low stands of sea level. Besides containing heavy minerals, these sands and gravels may be used as aggregate by the construction industry.





Sea-floor sediment samples are processed through a 3-turn spiral to concentrate heavy-mineral sands.



In Florida, phosphates occur both on land and offshore, as sea level has changed during the times of their deposition.

The EEZ: Environmental Assessment

Information Needs

The ocean is a dynamic and often hostile environment in which we must work to assess as well as recover the resources locked within the sea floor. Storms and ice can jeopardize our activities by causing loss of ships, drill rigs, or monitoring systems, and may even result in loss of life. Geohazards such as submarine landslides, debris flows, and earthquakes may damage manmade structures placed on the sea floor. Human activities such as dumping waste material, drilling for oil and gas, and underwater mining also can affect the environment, causing harm to the many plants and animals that live in the sea.

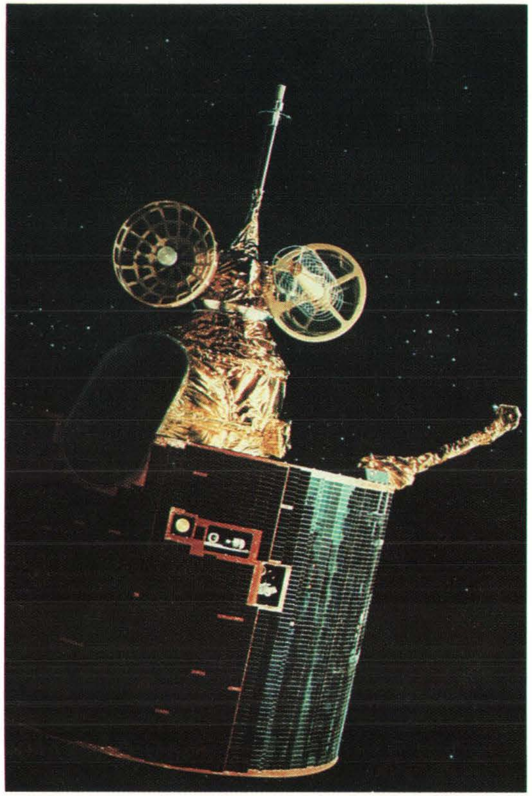
Marine Weather Forecasts and Warnings

The increased activity centering on assets in the EEZ requires a better knowledge and resolution of environmental conditions, including characteristics of the air-sea interface, the water column, the water-sediment interface at the sea floor, weather (wind, temperature, visibility, and atmospheric conditions), sea-state (wave height and direction), and accurate ice forecasts. Without timely and accurate forecasts, lives are in jeopardy and valuable property is at risk. Efficient design of offshore structures and operations (drilling, sampling, and surveying) requires a long-term series of observations to produce reliable statistical models and accurate return frequencies. Because of the increase of activities in the EEZ associated with the expanded exploration and development of offshore resources, especially in the hostile regions of Alaska, accurate forecasts are essential.

Accurate weather forecasts are among the most important information products needed to operate in the EEZ. NOAA's weather observations from land and sea provide the basis for forecasting on a variety of scales ranging from global to local. Accurate marine observations are essential for short-term operations, long-term climatology, and statistical studies.

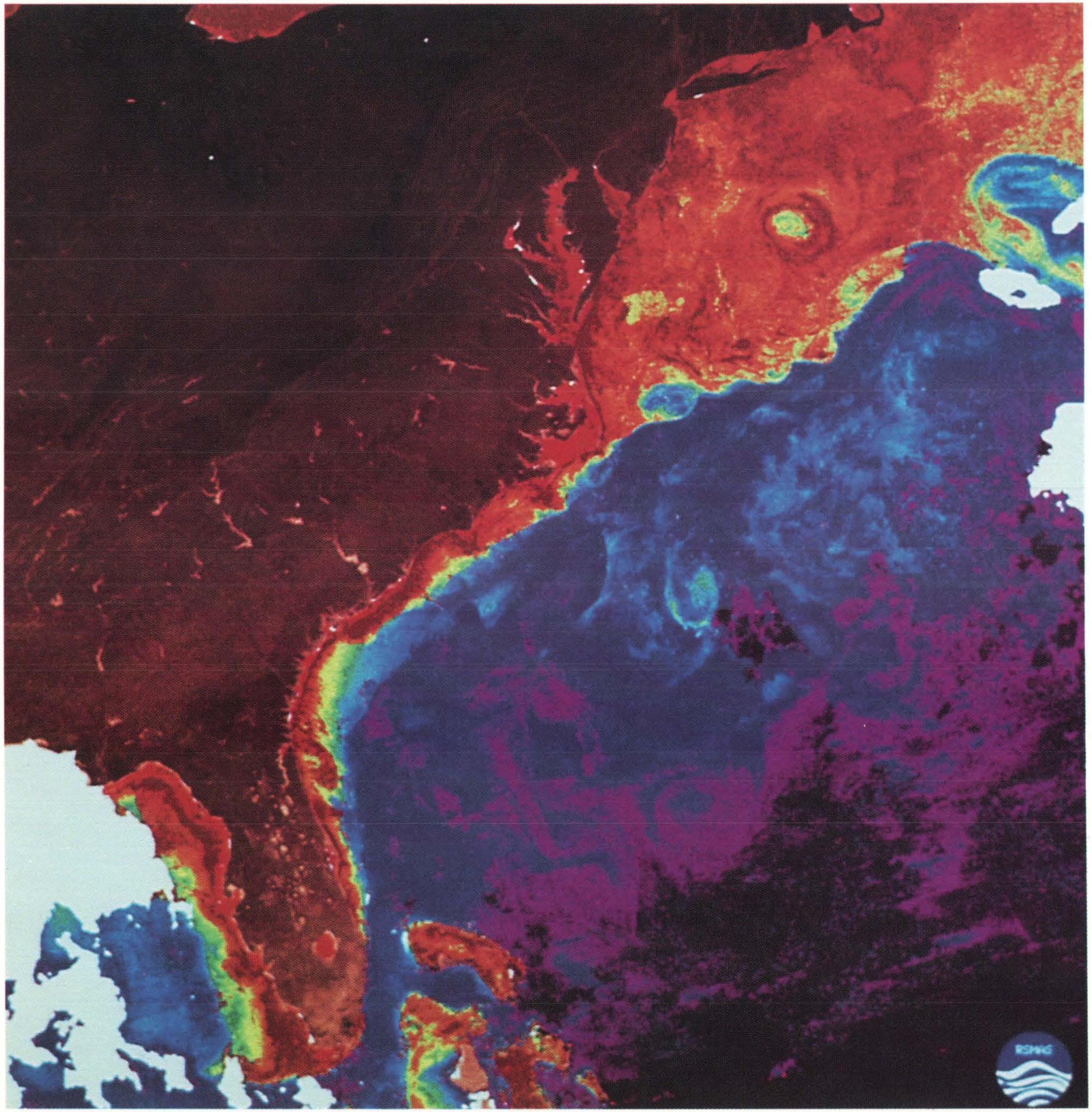
The real-time data needed to produce accurate forecasts include observations from satellites, ships, offshore platforms, and weather buoys. The basic observations are relayed to users through radio communications, and products are developed from these data at national centers. The products are subsequently available via radio facsimile and NOAA offices located in coastal regions provide special briefings.

Environmental data buoys and other marine weather observations aid in predicting the weather expected in the EEZ.



Satellites observe weather patterns in the EEZ and transmit data for analysis.

NOAA ship *Davidson*.



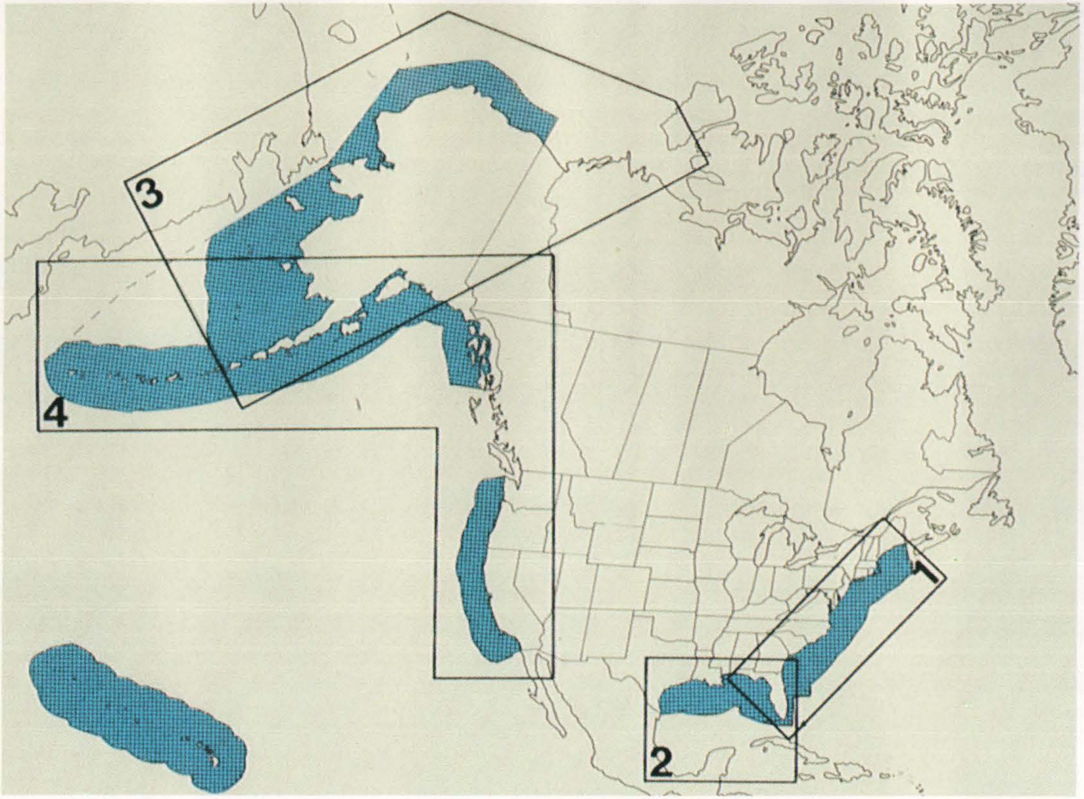
The abundance of phytoplankton in the oceans can be observed decreasing seaward from the coastline on the color scanner imagery.

Strategic Assessments

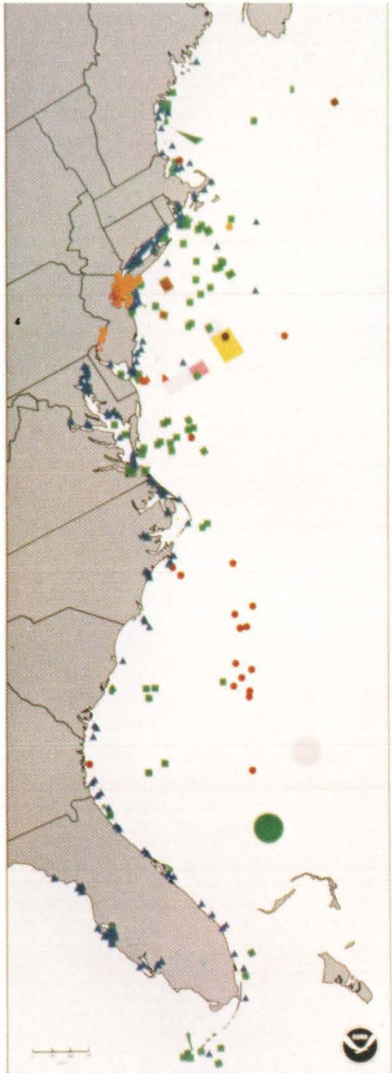
In anticipation of increasing interest in developing resources in the EEZ and in anticipation of the inevitable conflicts among users of these valuable resources, NOAA is conducting a program of comprehensive, strategic assessments of the EEZ. The assessments are "strategic" because they develop information of a nature and at time and space scales appropriate for setting or modifying national objectives for developing and conserving resources in the EEZ of the United States. They are intended to complement, not replace, the detailed "tactical" analyses required to make site-specific decisions.

An important part of this program is the production of a series of four atlases of important regions of the EEZ: (1) the East Coast; (2) the Gulf of Mexico; (3) the Bering, Chukchi, and Beaufort Seas; and (4) the Gulf of Alaska and West Coast. The atlases present, on consistent base maps (scale 1:4,000,000), information on the space-time distribution of selected characteristics of each region including: (1) physical environments; (2) biotic environments; (3) living marine resources; (4) economic activities; (5) environmental quality; and (6) political boundaries and jurisdictions.

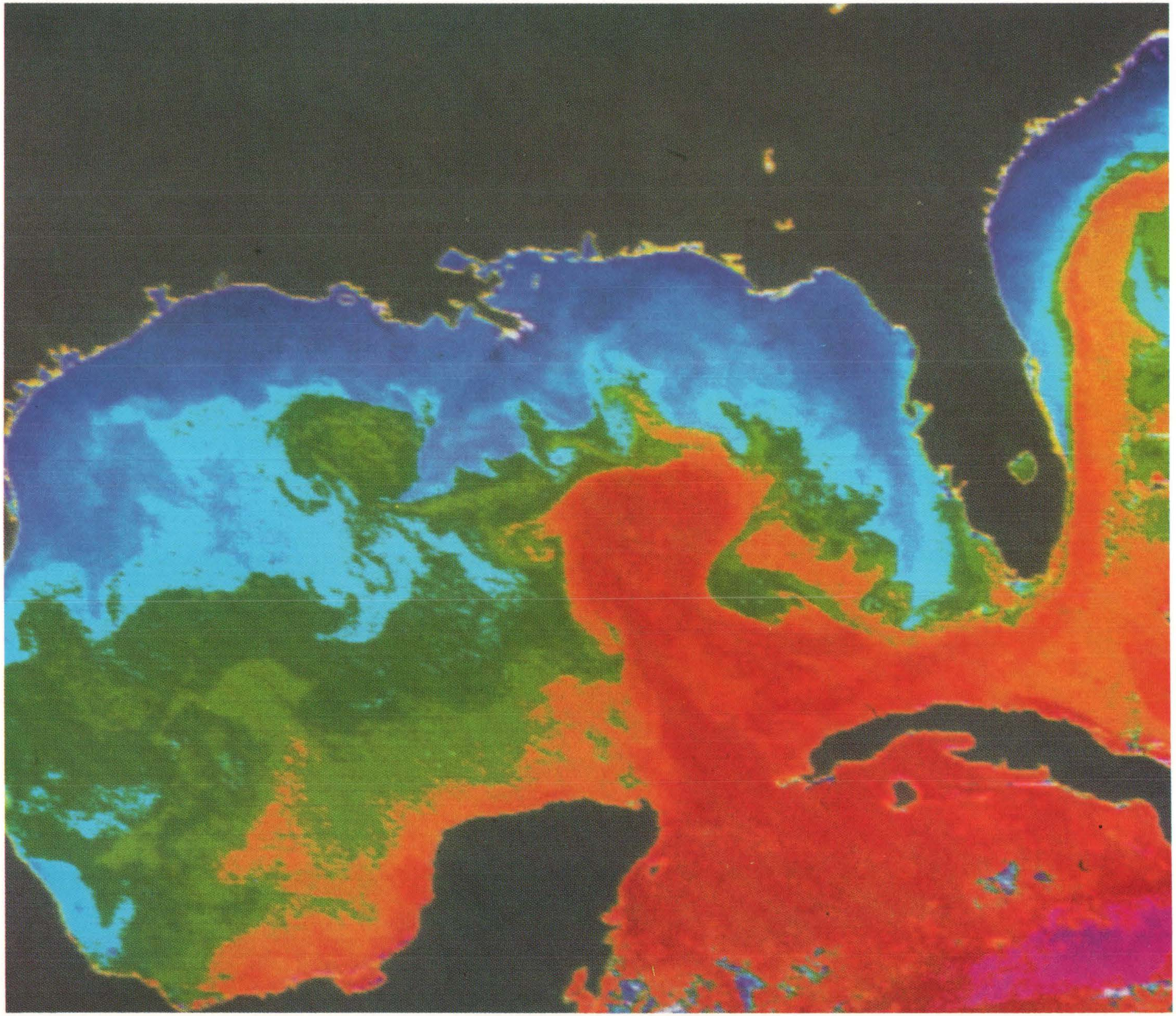
These atlases communicate diverse and complex information to planners and decisionmakers, and they provide the basis for developing data bases and assessment methods for identifying and evaluating multiple resource-use issues in the EEZ. NOAA is developing a set of data bases and analytical methods to provide an operational capability to assess quickly and comprehensively multiple resource-use problems throughout major regions of the EEZ.



Regions in the EEZ covered by strategic assessment atlases.



Ocean Dump Sites

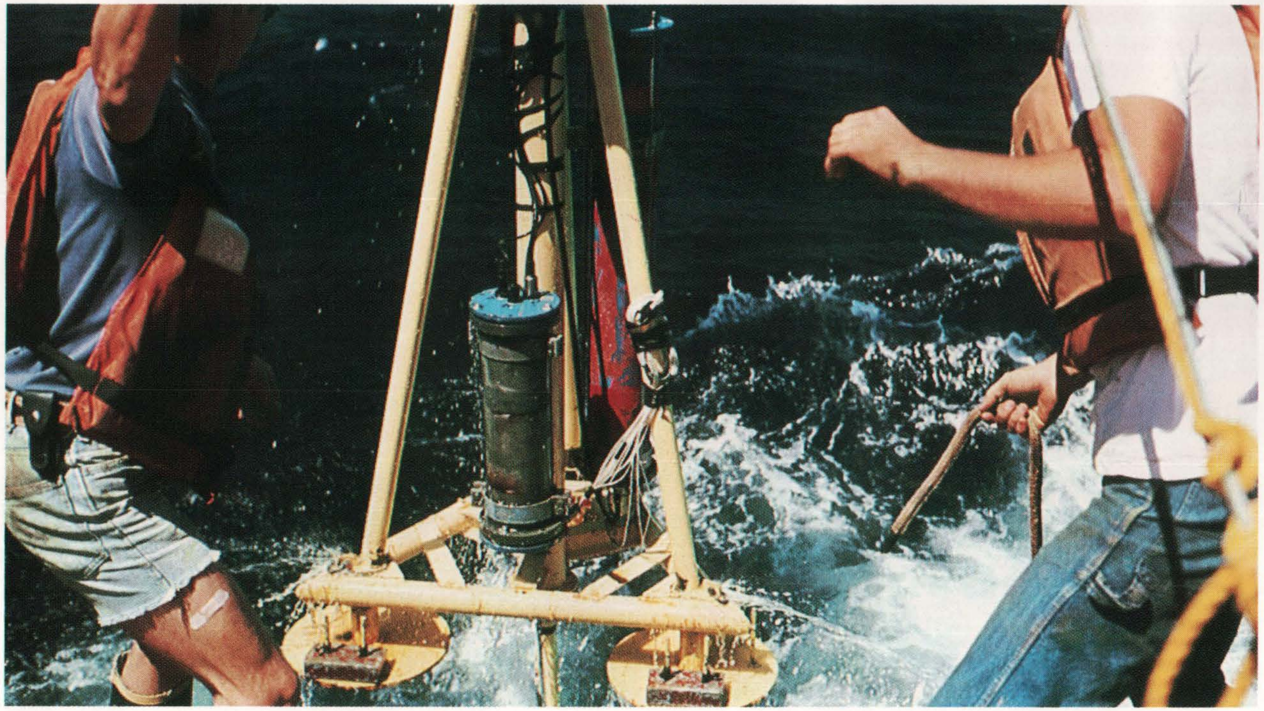


Temperature patterns in the Gulf of Mexico observed from the experimental coastal-zone color scanner.

← The ocean is used for waste disposal, including these varied dump sites off the Atlantic Coast.

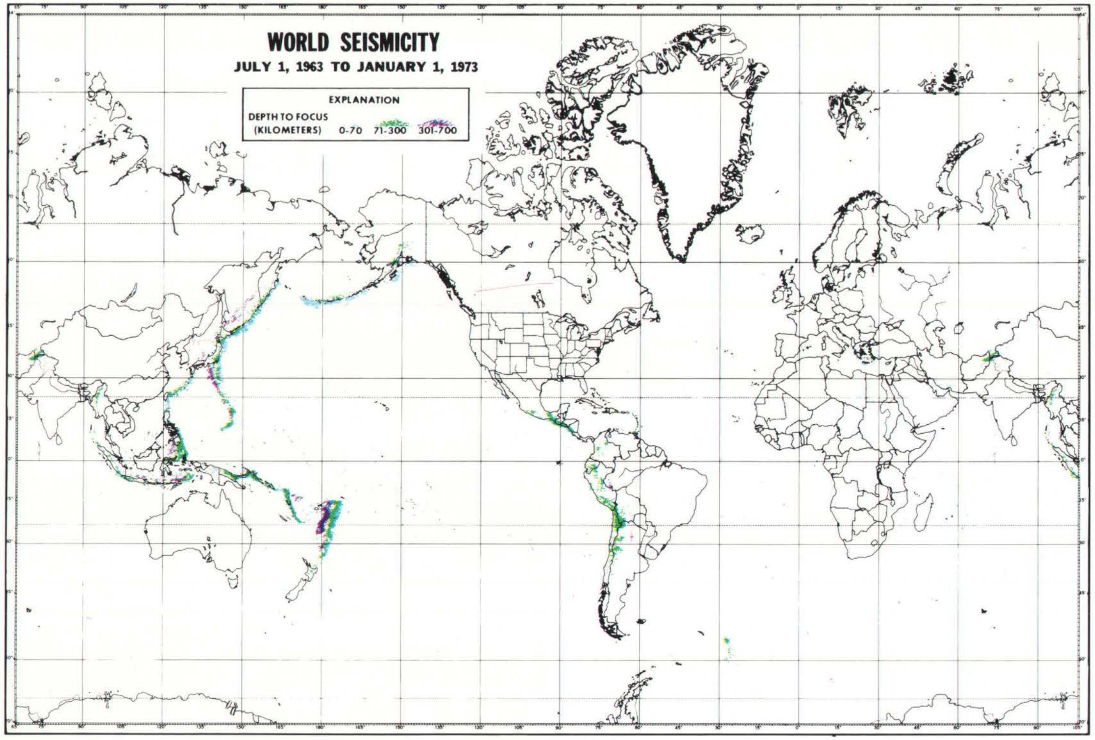
Geohazards

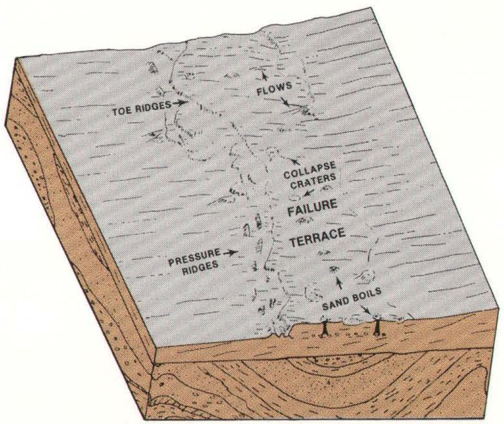
The plates that make up the Earth's crust are bounded by zones in which earthquakes occur, reflecting the motion of plates and the release of stress as the rocks slide by each other. This shaking can cause piles of sediment on the sea floor to lose their strength and slide downslope into deeper water. Steep slopes, burrowing by organisms in steep canyon walls, rapid deposition of sediments, gas in the sediment, and internal waves generated along density interfaces in the ocean also contribute to sediment failure. Submarine landslides are hazards to drilling and to manmade objects such as submarine telephone cables placed on the sea floor. USGS sidescan sonar surveys document submarine landslide scars and the chaotic piles of sediment deposited downslope. Instruments have been designed that can be left in the sea floor to measure changes in pressure within the sediments and the strength of sediments in order to predict when failure will occur. In the shallow water of the continental shelf, repetitive sidescan sonar surveys show the migration of sand waves, such as the sand wave field on Georges Bank, in response to storm driven currents. Knowing the movement of sand over the sea floor aids planning pipeline routes across the shelf. Tripods with clusters of instruments are left on the sea floor to measure the velocity of currents in the water, the clouds of sediment stirred up from the bottom, and the temperature and salinity of the water. Sediment traps collect the amount and kind of sediment raining through the water column onto the bottom. All of these parameters are important in measuring the dispersal of pollutants if they should accidentally be introduced into the sea or as part of a planned activity such as drilling. Constructing maps of geohazards and engineering parameters of the sea floor are a necessary basis for judgments governing the multiuse of the sea-floor resources in the EEZ.



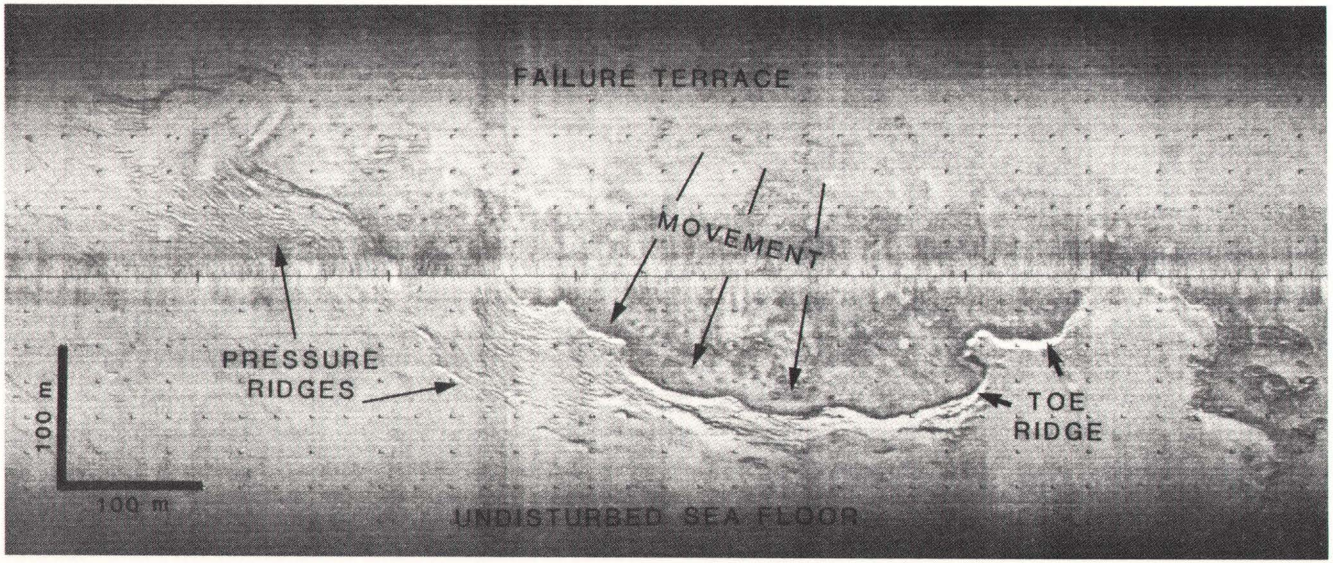
This piesometer and other instruments are placed in the sea floor to measure changes in pressure in the fluids between the grains of sediment. These measurements help geologists determine whether the sediments are potential sites for landslides.

Earthquakes shake the sea floor, especially near ocean ridges and trenches, and often cause sediments to fail and move downslope.



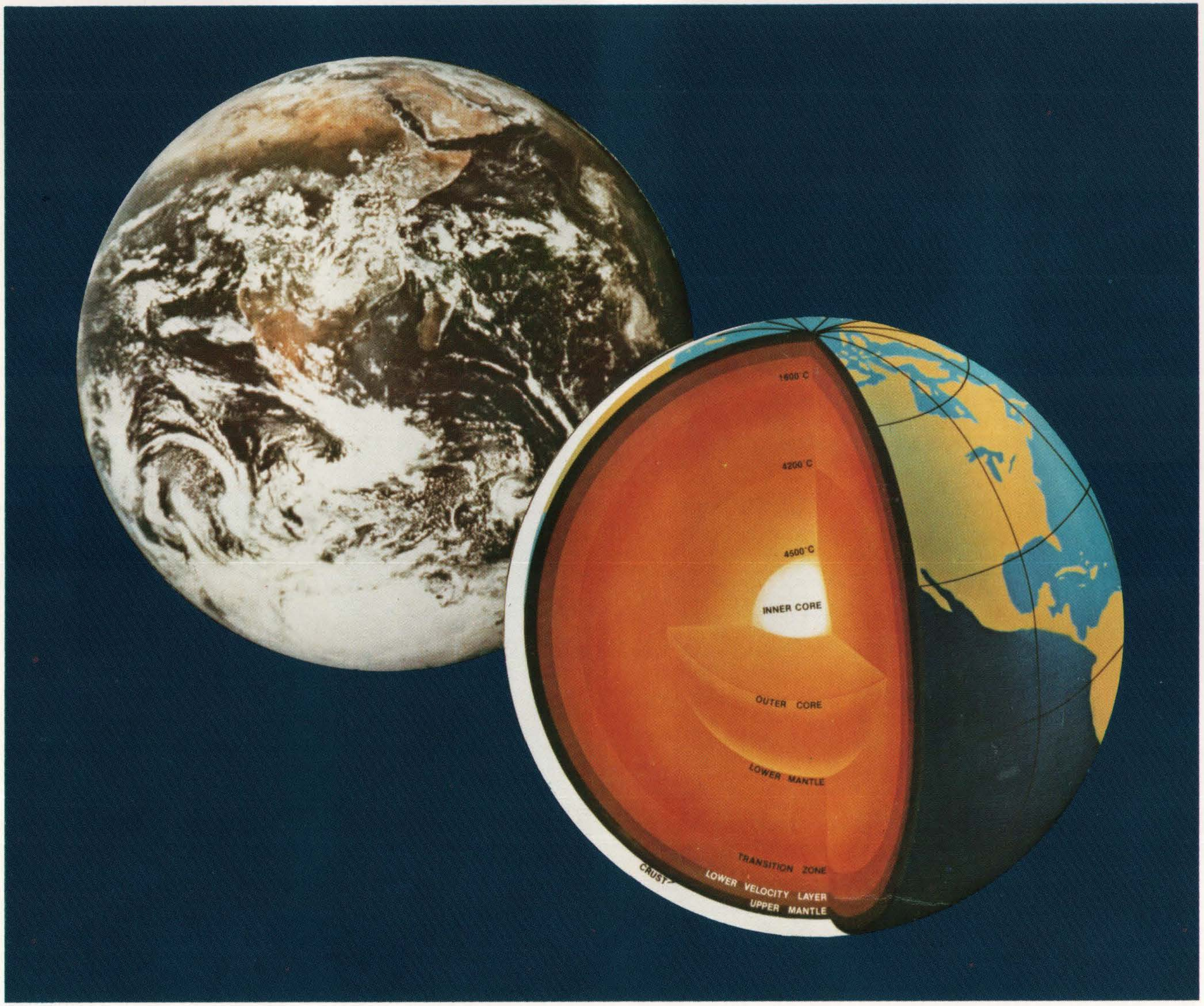


Submarine landslides are potential hazards for objects placed on the sea floor, such as cables and drilling platforms. Slumps move sediments considerable distances, often on slopes as small as 1 degree.



Summary

- The EEZ encompasses an immense underwater world which is complex and multifaceted.
- The nonliving resources of the EEZ hold much promise for the future.
- Our technology and vision will grow as we explore the far boundaries of this new marine frontier.



As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.