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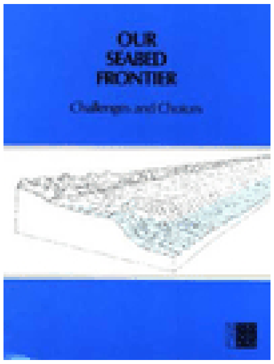

Our Seabed Frontier: Challenges and Choices

Committee on Existing and Potential Uses of the
Seafloor, National ResearchCouncil

ISBN: 0-309-59599-1, 150 pages, 8.5 x 11, (1989)

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Our Seabed Frontier

Challenges and Choices

Report of the Committee on Seabed Utilization in the Exclusive Economic Zone
Marine Board
Commission on Engineering and Technical Systems
National Research Council

National Academy Press
Washington, D.C. 1989

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the panel responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The program described in this report is supported by Cooperative Agreement No. 14-12-0001-30416 between the Minerals Management Service of the U.S. Department of the Interior and the National Academy of Sciences. This project resulted from an initiative by the U.S. Geological Survey.

Library of Congress Catalog Card Number 89-63099
International Standard Book Number 0-309-04126-0
Additional copies of this report are available from: National Academy Press 2101 Constitution Avenue, N.W. Washington, D.C. 20418

Printed in the United States of America.
First Printing, November 1989
Second Printing, July 1990

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Preface

The establishment of the U.S. Exclusive Economic Zone (EEZ) by Presidential proclamation in 1983 "for the purpose of exploring, exploiting, conserving and managing natural resources" (see Appendix A) presents the nation with an opportunity and a challenge to wisely use its diverse resources. In addition to living resources, such as fisheries, this vast region contains extensive and potentially valuable mineral and energy resources, and is used for many other purposes, such as waste disposal, pipelines, cables, and military uses.

The opportunities for resource recovery and other uses carry with them the challenge of determining the most appropriate development and management policies for such an extensive and complex area. A prerequisite to formulating adequate policies for managing this region in the nation's best interest over the long term is comprehensive understanding of the region's sediments and seabed processes. Understanding of these processes will depend on a variety of data-gathering systems and techniques. Finally, all potential uses of the region need to be determined, along with the environmental effects of these uses on the ocean's environmental systems.

Following a series of exploratory discussions between the Office of Energy and Marine Geology of the U.S. Geological Survey (USGS) and members of the Marine Board, the National Research Council appointed a committee under the Marine Board to undertake an interdisciplinary study of the EEZ seabed. The committee's objectives were to assess the state of knowledge of seafloor properties and processes as they relate to future utilization of the U.S. EEZ seabed.

THE COMMITTEE

Committee members were selected on the basis of their expertise in energy and mineral resource exploration and development, ocean engineering and technology, marine biology and geology, oceanography, and marine policy. The committee was assisted by liaison representatives from federal agencies conducting ocean-related programs: the United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the Environmental Protection Agency, the Bureau of Mines, the Minerals Management Service, the Navy, and the Department of Energy. The principle guiding the committee, consistent with the policy of the National Research Council, was not to exclude any information, however biased, that might accompany input vital to the study, but to seek balance and fair treatment.

SCOPE OF STUDY

The committee was charged to assess the state of knowledge of seafloor properties and processes related to future utilization of the EEZ seabed. To accomplish this goal, the committee

- identified existing uses of the seabed;
- assessed seabed sediment characteristics and processes bearing on these uses;
- determined the state of practice of technologies for obtaining data about the seabed;
- determined potential uses of the seabed and their associated engineering and technological requirements;
- identified research needed to provide an improved technical basis for the use of the seabed; and
- identified policy issues and actions needed to provide an improved management basis for use of the seabed.

The committee interpreted these tasks broadly to include analysis of policy-related constraints and requirements for expanding EEZ uses in the future. This report does not attempt an economic analysis of resource development, except as economic considerations enter into general assessments of the potential for development of a particular resource. The focus of the report is on the existing scientific and technical data base, future needs for information, and the technologies for acquiring it.

The committee's investigations focused on the EEZ seabed, which includes the zone of steep physical, biological, and chemical gradients above the sediment-water interface (order of 10 m) as well as the substrata below to the depth of use. The area adjacent to the nation's coastline called the "territorial sea" was excluded from the committee's purview because present federal and state laws and programs focus on development and management of this area.

METHOD OF STUDY

Following initial meetings by the committee and agency liaison representatives to identify issues to be studied, a workshop was held at Keystone, Colorado, in September 1987 to allow addi tional input by participants from academia and industry. In preparation for this meeting, a preliminary report was drafted by the committee to define the issues and provide a basis for discussions. During the Keystone meeting, committee members, agency liaisons, and other invited participants developed papers on 11 topics during workshops at this symposium. These papers formed the foundation for this report, along with subsequent contributions by committee members and other experts. Preliminary information from the Keystone conference was presented at the EEZ Symposium sponsored by the USGS and NOAA held in Reston, Virginia, November 17–19, 1987. Additional committee meetings were held to discuss and develop new material for the report.

A working paper[1] prepared by the Marine Board's Committee on Technology Requirements for the EEZ Utilization was used to develop the section in this report on mineral exploration and development.

The committee's findings and recommendations are based on presentations made to the committee, discussion and deliberations, and the professional experience of the committee members.

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[1] Committee on Technology Requirements for the EEZ Utilization. 1987. Technology requirements for assessment and development of hard mineral resources in the U.S. Exclusive Economic Zone. Working Paper. Marine Board, National Research Council, Washington, D.C.

ORGANIZATION OF REPORT

Chapter 1 provides a historical and topical overview of the subject area. Chapters 2, 3, and 4 present detailed scientific and technical information on the seabed environment, seabed uses, and technologies for gathering data. Chapter 5 synthesizes the scientific and technical information presented in Chapters 2, 3, and 4 to provide a suggested framework for site evaluation and an overview of technology systems for investigating the seabed. Chapter 6 treats issues related to regulation and management of the EEZ and to federal and state government policy in the EEZ. The major conclusions and recommendations of the committee that follow from its investigations are presented in Chapter 7. The Executive Summary provides a synopsis of the report.

Acknowledgments

The committee gratefully acknowledges the generous contributions of time and information provided by government liaison representatives and their agencies and the many individuals who participated in the data-gathering processes inherent to the project. The liaison representatives were Norman Caplan, National Science Foundation; Robert S. Dyer, Environmental Protection Agency; Herman Enzer, Bureau of Mines; John B. Gregory, Minerals Management Service; Joseph H. Kravitz, Office of Naval Research; Bradley J. Laubach, Minerals Management Service; Herbert Hermann, Naval Facilities Command; Millington Lockwood, National Oceanic and Atmospheric Administration; Bonnie A. McGregor, U.S. Geological Survey; George W. Saunders, Department of Energy; Joseph R. Vadus, National Oceanic and Atmospheric Administration; and Raymond C. Witter, Space and Naval Warfare Systems Command. Special thanks are extended to Linda Glover, Office of the Oceanographer of the Navy, who provided technical review of the section on surveying and mapping; Dana R. Kester, University of Rhode Island, who revised the section on waste disposal; John LaBrecque, Lamont Doherty Geological Observatory, who contributed to the chapter on technology and data acquisition; George H. Ludwig, University of Colorado, who wrote the section on data management; Brian Hughes, consultant, Takoma Park, Maryland, who contributed to the section on cables and military uses; and Robert C. Tyce, University of Rhode Island, who contributed to the section on surveying and mapping. Heide Mairs, of the University of Rhode Island, offered extensive assistance in the early stages of the project.

Contents

Executive Summary

In 1983, the United States extended its "sovereign rights and jurisdiction" over the natural resources of the ocean out to 200 nautical miles (nm). This "Exclusive Economic Zone" (EEZ) presents new opportunities and challenges for coordinating and managing exploration and development of a geographically vast (over 3 billion acres) and topographically complex frontier region.

The ocean's resources are relatively untapped. The role of the oceans in transportation, communications, and disposal of waste; as a source of food, energy, and mineral resources; and as an aesthetic and recreational asset is likely to increase world wide under the pressures of demographic and economic growth. This study focuses on the present and future uses for the seabed of the U.S. EEZ, with the objective of stimulating efficient and environmentally sound utilization of its resources.

The investigations of the committee resulted in two major conclusions. First, it is highly probable that the present uses of this region will increase in the next 20 years. These uses include exploration for and development of oil and gas resources, waste disposal, emplacement of cables for civilian and military purposes, harvesting of fisheries resources, recovery of certain hard minerals, and the designation of cultural and aesthetic resources, such as marine sanctuaries. Expanded use of the EEZ seabed for a broader spectrum of mineral exploration and development, other biological resources, the development of ocean energy systems and technologies, and recreational activities is less likely in the near term, but will become more important over the long term. The second major conclusion of this study is that for all foreseeable uses of the EEZ seabed, improved coordination and increased joint planning efforts among federal and state governments, industry, academia, and public interest organizations are necessary to ensure efficient, orderly, equitable, and environmentally sound development of this vast region.

The utilization of the EEZ presents a variety of technological challenges. Much of the future development will depend on having the necessary tools to survey, map, probe, sample, and monitor the seabed. Improved technology will also be needed for most of the actual uses—whether to mine and process minerals, bury cables and pipelines, or dispose of waste. A carefully conceived and coordinated plan for EEZ development can ensure that the United States will retain leadership in offshore technology for scientific research, resource recovery, and other long-term activities, while minimizing degradation of the environment.

The Exclusive Economic Zone is a national resource of unprecedented dimensions. What we do in the United States EEZ over the next 10 to 30 years will have long-range economic and environmental implications not only for our nation, but for significant areas of the globe. It is clear that all future uses of the EEZ must take into account possible negative ecological impacts with a view toward managing this area in the best interests of present and future generations.

APPROACH OF STUDY

This study assesses the state of knowledge of the seabed as related to future activities within the U.S. EEZ and concludes that all projected industrial, commercial, public, and military development prospects will require expansion of both basic and applied data about the characteristics and processes in the ocean environment and on the seabed. The frontier deepwater and arctic areas of the EEZ are especially complex, in terms of geologic settings and oceanographic conditions and processes, compared to areas where previous development activities have been conducted. Expanded utilization of these regions must be based on a thorough understanding of seabed characteristics and processes at prospective sites and the likely consequences to the environment of each use.

The seabed regimes within the U.S. EEZ are composed of virtually all types of ocean seabed features and processes. The diversity of conditions, together with the remoteness of the seabed, creates a complex and challenging environment. A multidisciplinary approach is necessary to understand the seabed processes in frontier areas, to increase our knowledge about the genesis of ore bodies, and to monitor the impacts of human activities.

In this report, the committee identifies the major present and potential uses of the EEZ seabed, the technical and nontechnical constraints to their development, and their likely impact on the seabed environment. Information and technology needs for each use are assessed in terms of achieving the most efficient use of existing research and technical resources and setting priorities for future research programs and technology development. Information needs for monitoring the effects of present and planned activities on the marine environment and ecosystem are also determined.

The committee considered the problems associated with managing the large amounts of data gathered on the EEZ seabed and makes preliminary recommendations for ensuring the broadest accessibility and dissemination of data by all users.

Management structures are proposed for planning and coordinating research and development activities in the EEZ and for resolving potential conflicts among future seabed uses. The committee also evaluates existing federal policy and regulatory frameworks with respect to their role in limiting or encouraging expanded use of the EEZ seabed.

USES AND RELATED ISSUES

Following are brief descriptions of present and future uses of the seabed along with summary assessments of the major technical and nontechnical issues and needs for each use area.

Oil and Gas Resources

In terms of strategic importance and economic value, the exploration for and production of offshore oil and gas resources will remain the most important economic activity in the U.S. EEZ into the next century. Currently, about 12 percent of total crude oil production and 25 percent of total gas production is produced offshore and it is estimated that U.S. dependence on these resources will continue to increase each year as land reserves decline. While current technology is adequate to develop nearshore oil and gas resources, many technical constraints face the offshore oil and gas industry as it moves farther onto the continental slope and into unexplored arctic regions. The environmental hazards of operating in deep and ice-infested waters are considerably greater, and overcoming them will be far more costly than previous offshore oil and gas development operations.

Development of these areas will be affected not only by technical progress but also by nontechnical factors, such as fluctuating world oil prices, the impact of unstable political regimes in oil-producing countries, and a domestic regulatory climate subject to public pressure to protect offshore lease areas. Equally significant will be the extent to which government and industry cooperate to achieve a proper balance between meeting the nation's energy needs and environmental concerns and maintaining a competitive and technically innovative domestic oil and gas industry.

Mineral Resources

Except for construction materials, such as sand and gravel, and some placers, it is unlikely that substantial amounts of hard mineral resources will be commercially recovered from U.S. EEZ deposits within the next decade. Depressed market prices, together with high costs of mining in marine environments, create an unfavorable economic environment for development of most seabed mineral resources.

Future national needs for certain strategic materials could spur development of offshore mining industries for selected critical materials that are now imported by the United States, such as cobalt, chromium, manganese, and the platinum group metals. Because lead times of up to 15 years are required for developing commercial seabed mining systems, it seems prudent to establish the scientific and technical base necessary to assess and recover strategic or critical materials should national interests require them in the future. An integrated long-term (five to ten years) program of technology development and analysis of data base requirements is needed to perfect the tasks for comprehensive assessment of hard mineral resources in the EEZ seabed. Basic research is also needed in mineral sampling and recovery technology requirements for exploitation of deepwater deposits.

Waste Disposal

The coastal and ocean waters surrounding the United States have been used for disposing of municipal and industrial wastes for many years, particularly sewage sludge and dredged materials. Recent legislation places restrictions on such practices and, in some cases, requires phasing them out in the next few years. However, comparisons between land and ocean disposal options frequently indicate that marine disposal is less expensive and less environmentally damaging than land alternatives, which leads many experts to believe that marine disposal of dredged material and sewage sludge is likely to increase in the next 10 to 20 years, despite present public disapproval. Future pressures on land-based repositories may also increase incentives to explore the use of subseabed geologic formations for permanent repositories for containerized low volume, highly toxic, and radioactive wastes.

Devising environmentally acceptable ocean waste disposal strategies depends on understanding the 3physical and chemical oceanic processes and how they affect sedimentation and mobility of contaminants. Distinguishing and isolating contaminated from uncontaminated material and specifying appropriate disposal methods for each type is another major requirement for developing sound seabed waste disposal practices.

Innovative engineered approaches to isolating and disposing of wastes in the ocean need to be tested and evaluated through pilot or demonstration projects in order to determine their effectiveness. For instance, placement of wastes in excavated pits or trenches that are then capped by clean sediment could be one of the most effective means of isolating certain toxic materials from the food chain.

Future use of the EEZ seabed for waste disposal will depend on socioeconomic pressures, innovative technologies that won't compromise the use of other marine resources, and better understanding of the processes of dispersal and deposition of waste particulates. Additionally, a comprehensive national policy for selecting long-term waste disposal strategies that includes evaluation and comparison of land-and ocean-based options and their impacts on the marine, terrestrial, and atmospheric components of the ecosystem would provide a framework for making wise choices about waste disposal.

Communication Cables and Military Uses

Increasing use of the EEZ seabed for the installation of commercial submarine cable systems and a number of military applications is driven primarily by advances in fiber optics and digital transmission, as well as improvements in the technology capability for secure emplacement of various devices in or on the seabed. Commercial communications cables constitute the majority of ocean cable installations. The military uses the EEZ as an operational arena, as a laboratory for researching, developing, testing and evaluating operational systems and techniques, and to train personnel. Military activities in the ocean are expected to continue indefinitely with cables, sensors and transducer systems likely to increase as their technological applications are improved.

Geological processes and the composition of the substrate are the most crucial physical conditions affecting emplacement, maintenance, and survivability of ocean cables and seabed military systems in the EEZ seabed. Improved geophysical survey equipment, sediment sampling, and in situ testing, along with more effective procedures for interpretation of geotechnical data, would yield benefits to both military and commercial operations in the seabed.

A major issue related to the expansion of military uses of the seabed is the conflict between military applications and commercial, recreational, and/or environmental interests. Military uses often preclude civilian use of an area for reasons of safety, interference, or security. An additional problem associated with military uses of the EEZ seabed has been the imposition of military classification restrictions on some categories of data. Recent changes in Navy policy have reduced some of the requirements for classification. Because of the likely expansion of the military presence in the EEZ seabed, it is important that potential conflicts with other uses be anticipated and that policies be developed for resolving them.

BIOLOGICAL RESOURCES

Living resources associated with the EEZ seabed fall into one of two categories—commercially important fishery resources and organisms of special scientific interest or of potential importance as biotechnological or genetic resources. The United States is one of the world's largest consumers and importers of seafood products. There is potential for expansion of the domestic fisheries industry into deeper waters to capture a larger share of this market. Although most experts believe that traditional fisheries are being harvested at or near maturity, some of the resources of the continental slope can be harvested by extending existing technology into deeper water.

Many bacterial species found in chemically unusual marine environments are logical candidates to study for their ability to degrade toxic chemicals, and some marine benthic invertebrates are potential sources of pharmaceutical agents in the treatment of cancer, AIDS, and other diseases.

Research on living marine resources needs to be focused on improving our understanding of the bases of biological productivity and its variations and the effects of human activities on these processes, especially in deep water. Newer techniques of assessing population sizes of deepwater animals and bacteria, based on remotely operated vehicles, better sensors, acoustics, and improved data interpretation may alleviate present assessment problems. Such fundamental knowledge of biological and living resource processes will contribute to expansion of domestic fisheries, to the development of new biotechnology products, and to protecting the quality of marine environments.

Ocean Energy Systems

Ocean energy systems and related technologies are in very early stages of development, and their commercial feasibility awaits more favorable economic conditions. The most likely candidate for development in the near future that will affect the EEZ seabed is ocean thermal energy conversion

(OTEC), a process that harnesses the temperature differences between surface and deeper waters as energy. The first commercial OTEC installations will probably be shore-mounted facilities on islands with the intake pipe extended to nearby deepwater sources, possibly into the EEZ. Moored OTEC facilities will require information on the physical properties of steeply sloping seafloors that border U.S. subtropical and tropical islands and have access to deep, cold water relatively close to their shorelines. In some configurations, the electrical energy would have to be transmitted to shore by seafloor cable, creating a need for detailed seafloor information along the cable route.

Commercial feasibility of any ocean energy systems depends on more favorable economic conditions than presently exist, mainly higher oil prices. These systems are therefore not likely to be developed in the near term.

Cultural and Recreational Resources

Cultural and recreational resources of the EEZ include marine archaeology, treasure seeking and commercial salvage, recreation, and marine sanctuaries. It seems likely that new and improved seafloor exploration technology and availability of affordable submersibles will stimulate interest in both marine archaeology and submarine tourism.

The identification and protection of unique underwater areas and habitats in U.S. waters has to date been a limited effort. In order to designate and manage a marine sanctuary, a substantial amount of information is needed on the resources and the physical environment of the area. Federally sponsored mapping and exploration programs in the EEZ could include the identification of potential marine sanctuaries in their activities. Early identification of such areas would forestall potential conflict among competing uses by including sensitivity to environmental considerations in advance planning for the development of other resources.

TECHNOLOGY AND INFORMATION ISSUES

Assessment of the constraints to engineering development and the impacts of EEZ use at specific sites may require, depending on the use, a systematic, integrated approach involving investigation of oceanographic, geologic, geotechnical, and biological data to develop a site performance model for predictive capability related to a specific use or combination of uses. Such an approach could involve mapping, sampling, and measurement of seafloor conditions and processes through a variety of in situ sampling, monitoring, and laboratory techniques tailored to seabed use questions. Acquiring information essential for achieving efficient and nondestructive use of the EEZ seabed will require expanded or, in some cases, new tools and technologies for exploring and gathering seabed data.

Surveying and Mapping

A variety of acoustic and optical technologies are presently available for collecting bathymetry, bottom imagery, and subbottom sediment data. However, each survey system has its own operational characteristics, particularly in terms of resolution and coverage rates. Improvements are needed to make surveying methods and use of the results more efficient, particularly in balancing survey data quality with survey costs, both in dollars and in time. Additionally, the use of digital acquisition techniques and the ongoing development of real-time data image enhancement will result in improved survey and mapping effectiveness. The mapping priorities and geographic areas of interest to all potential EEZ user groups will require further definition as a first step toward cost-effective and efficient sharing of mapping activities, survey and ship time, and equipment.

Geotechnical Investigation Systems

Detailed knowledge of seabed sediments will require measurements by sampling, in situ testing, and experimental testing. Various systems for data acquisition are highly developed for water depths less than 300 meters, but little development has occurred for systems that can be used in the Arctic or in offshore regions where water depths exceed 300 meters. Technology needs for geotechnical and geological data acquisition include improved sampling and in situ testing equipment for use in frontier areas, field monitoring of installations, and laboratory experimental modeling.

Monitoring of the Seabed

The environmental consequences of expanding activities in the EEZ seabed are difficult to predict. A monitoring program would establish environmental baseline information that could be used for such predictions. Monitoring of environmental impacts is particularly important in relation to seabed waste disposal, oil and gas exploration and production, and mining.

The required monitoring will fall into three categories: (a) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed; (b) process-related monitoring to understand major EEZ seabed processes; and (c) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and to determine their environmental consequences. Monitoring priorities and strategies should be established within the framework of a national EEZ program.

Technology Development

Mapping and surveying, geotechnical research, and monitoring programs will benefit from expansion of existing technology or development of new equipment and techniques for gathering data on the seabed. Efficiency of present activities related to mapping and surveying the EEZ can be improved through application of existing and emerging technologies and optimization of their use. New tools can be developed to directly indicate the presence of valuable resources and to monitor processes. Monitoring capabilities would be improved by the ability to record data from buoys using satellites.

Technology development for acquiring information must be closely related to plans for utilizing the EEZ seabed. Requirements for data and specifications for equipment to acquire, manage, and analyze such data need to be defined in terms of specific user needs. The complexity, cost, and time frames required to improve existing technology and develop new data acquisition systems for EEZ frontier areas will require prioritization of needs for technology development based on a cooperative planning effort among academia, industry, and the federal government.

GOVERNANCE AND POLICY ISSUES

The variety of uses envisioned and the amount of data and information needed to plan and manage the rational conservation and development of the EEZ seabed require joint planning and coordination by government, industry, and academia. Effective and efficient programs for systematic mapping and surveying, development of technology to gather seabed data, identification and resolution of potential use conflicts, and development of approaches for multiple uses of certain areas depend on successful cooperation among a broad range of public and private entities with varied views.

A broad foundation will be necessary upon which to build an institutional framework capable of developing and managing the EEZ seabed resources. Such a framework needs to be based on a commitment to a national EEZ seabed plan that delineates programs for basic and applied research, technology development, and industrial and environmental policy developed in cooperation and consultation with representatives of state and federal agencies, marine industries, research institutions, and public interest groups.

RECOMMENDATIONS

The study resulted in ten recommendations on general and specific issues related to future uses of the seabed; research, information and technology needs; environmental concerns; and coordination and planning The committee's formal conclusions and recommendations are presented in Chapter 7. The committee recommends

1. creating a national joint planning and coordination process for the EEZ;
2. pursuing federal and state agreements for planning and implementing EEZ activities;
3. designing policies and research programs specifically addressing development of hard mineral resources;
4. formulating a comprehensive national waste management policy that includes ocean disposal options;
5. designating an agency to coordinate EEZ seabed research activities;
6. establishing a formal government/industry/academia EEZ program for determining priorities for seabed surveying and mapping, and for developing technology related to these activities;
7. developing technology necessary to gather geotechnical and geological data related to projected uses of the EEZ;
8. fostering exchange of data through a comprehensive data management system;
9. establishing a national EEZ environmental monitoring program; and
10. identifying unique areas of the seafloor that deserve long-term protection.

1

Seabed Jurisdiction and Utilization

The Presidential proclamation of 1983 on the Exclusive Economic Zone (EEZ) brought to the nation's attention the enormous potential of the waters and seabed surrounding the United States. The primary goal of this study is to assess the state of knowledge of the seabed as it relates to future activities within the EEZ and to stimulate efforts aimed at the efficient and environmentally sound use of this vast area.

ESTABLISHMENT OF THE EEZ

Almost since this country was founded, the federal government has asserted control over its contiguous ocean regimes. Thomas Jefferson laid claim to a three-mile territorial sea in 1793, the Truman Proclamation of 1945 asserted jurisdiction over the natural resources of the continental shelf, the Outer Continental Shelf Lands Act (OCSLA) of 1953 established regulations for developing OCS mineral resources, and the Magnuson Fisheries Conservation and Management Act of 1976 (MFCMA) claimed a 200-mile fisheries conservation zone.

In 1983, President Reagan signed a proclamation confirming U.S. sovereign rights and control over all living and nonliving resources within 200 nautical miles of the U.S. coast in an Exclusive Economic Zone. This proclamation focused national attention on the resource potential of the vast waters and seabed surrounding the United States and its island territories, and set the stage for expansion of resource identification and recovery and other uses of this area.

AREAL DEFINITION

The area encompassed by the EEZ brings within the national domain 3.9 billion acres of submarine land—approximately 1.7 times the 2.3 billion acres of onshore U.S. territory (Figure 1-1). By any measure, it is huge: it is also largely unexplored, poorly understood, and contains many diverse and fragile environments.

The EEZ territory extends from the edge of the territorial sea, at 3 nautical miles (nm), to a distance of 200 nm seaward of the coastal baseline (Figure 1-2). Although the territorial sea was extended to 12 miles in 1989, no state boundary has been increased to this distance (Booda, 1989). Thus, seabed uses discussed in this study are those operations and uses that occur beyond the territorial 3-mile limit. Coastal areas within 3 miles, where human activities associated with the marine environment are concentrated—including bays, estuaries, and rivers—are excluded.

The seabed, the specific portion of the EEZ addressed by this study, includes the zone directly above the sediment-water interface (order of 1 to 10 m), where important physical, chemical, and biological gradients associated with the bottom occur, and the sediment strata to the depth of

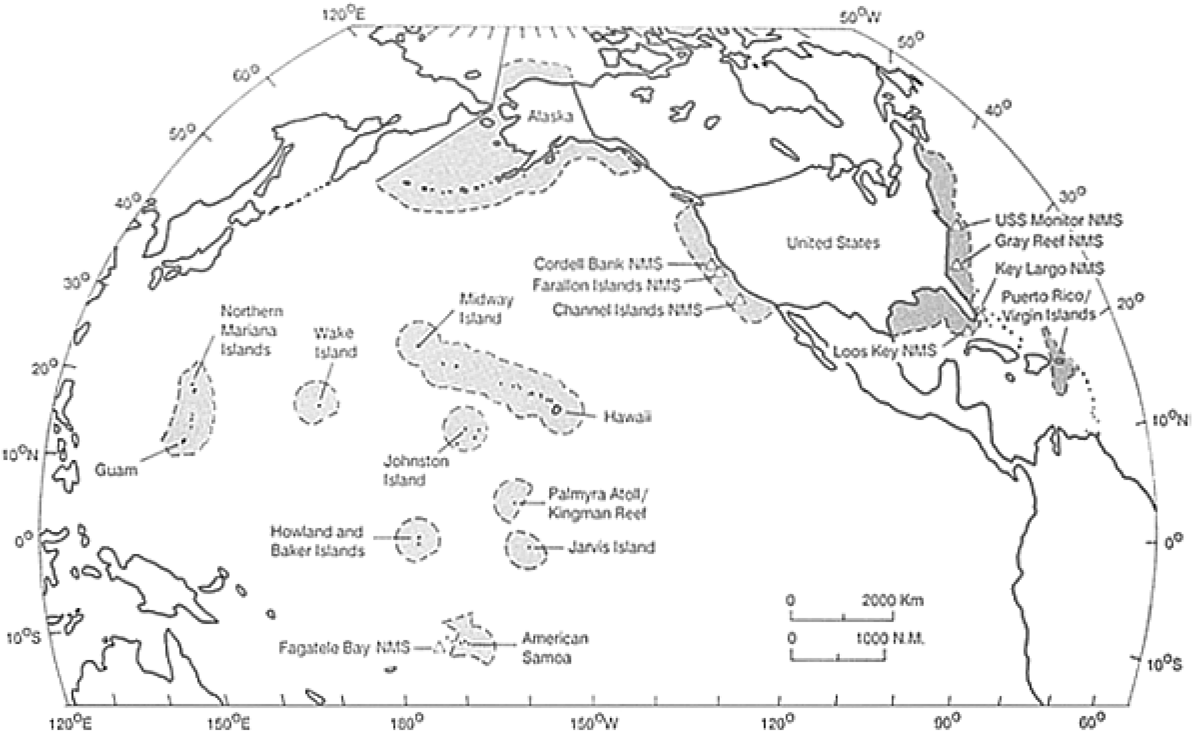

Figure 1-1
The Exclusive Economic Zone of the United States and its trust territories.
Source: McGregor and Lockwood, 1985, p. 2

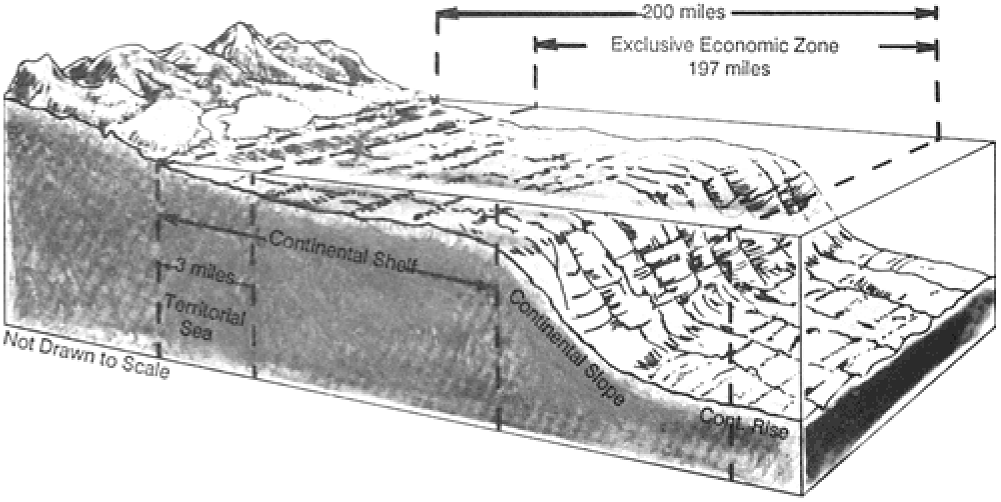

Figure 1-2
The EEZ extends from the limit of the territorial sea (3 nautical miles [nm]) to 200 nm from the baseline. This idealized cross section of the continental margin shows the major physiographic provinces (shelf, slope, rise). The actual inclination of the continental slope is typically about 4° to 6°; however, the slope is usually incised by canyons and channels with steeper local slopes. Source: After McGregor and Lockwood, 1985.

potential use (meters to hundreds of meters). The character of deeper sediment or crustal features, such as oil-bearing strata, are not directly considered in this report. As indicated in Figure 1-2 and explained in greater detail in Chapter 2, seabed regimes within the U.S. EEZ include virtually all types of ocean seabed features and processes.

From these two definitions of the EEZ and the seabed, the diversity and complexity of the EEZ seabed regime can be appreciated. Its range includes relatively shallow water on the continental shelf where the seabed is affected by currents and wave action, sloping areas with steep submarine canyons rivalling the Grand Canyon where massive submarine landslides are potential hazards, areas continually reshaped by currents and "benthic storms" near the deep sea floor, and high latitude areas where ice processes dominate.

These varied characteristics and the remoteness of the seabed make a complex and challenging environment for people to work in. Indeed, the inherent remoteness of the EEZ seabed and difficulty in making direct observations are the principal differences between working on "dry" land and in the ocean. It is only within the last 20 to 30 years, and especially the last 10 years, that an appreciation of the complexities of the seabed in these frontier areas has begun to emerge. Most of what is known about the shape of the seabed, including the configuration of the deeper strata, comes from remotely acquired acoustic data. Detailed information about the properties of the sediments comes from widely spaced sampling sites. In addition to the difficulties of observing and sampling the seabed, it is also extremely difficult to monitor the behavior of the sediments over a long period of time.

RESOURCE UTILIZATION

Over the last four decades, human activity in what is now known as the EEZ has increased substantially. Uses of the seabed that will be discussed in this report fall into three broad categories (summarized in Table 1-1):

1. extractive uses—activities involving removal of resources from the environment;
2. intrusive uses—those that disrupt the seabed or may degrade the environment; and
3. benign uses—activities that take up space but do not impact the seabed or environment.

In the extractive category, the two most significant resource recovery activities are extraction of oil and gas, and benthic fisheries. The offshore oil and gas industry has advanced to a high level of

Table 1-1 Summary of Seabed Uses in the EEZ

Extractive uses	Intrusive uses	Benign uses
Oil and gas Living resources Minerals Energy systems	Pipelines, vessels (potential spills) Waste disposal (dredged material, sewage, industrial waste) Acoustics (active) Dumping (munitions, municipal waste), scuttling	Instrument deployment security systems, navigation, research, monitoring Sanctuaries, archaeology Recreation Habitats

technical sophistication, and hydrocarbons can now be recovered in even the 'frontier' areas of deeper water (over 300 m) and the Arctic. A flurry of interest in seafloor mining was generated by rapid advances in ocean technology during and after World War II, the post-war economic boom, and discovery of seabed minerals (especially the nodules and crusts rich in cobalt, manganese, nickel, and copper found in some areas of the seafloor). However, with a few notable exceptions, such as sand and gravel mining, and recent gold mining off Alaska, the offshore mining industry remains undeveloped, though recovery of seabed minerals is considered likely to become economically feasible in the future.

A significant intrusive use of the seafloor is as a base for pipelines and cables. Oil and gas operations need pipelines to transport the raw material (or, in some cases, power from offshore terminals) to shore, and designing, constructing, and siting them in potentially unstable areas pose challenging engineering problems. Another increasing use of the seafloor is for communications and power transmission cables—both for commercial uses and military and national security applications. Except in shallow shelf waters where they can be buried, cables generally rest on top of the seafloor, where they are vulnerable to disruption by activities such as trawling for bottom fish, and by natural processes, such as erosion or slumping.

There has been some dumping of sewage sludge and hazardous wastes in offshore waters beyond the territorial sea, but legislation has been proposed to substantially curtail these activities. However, it is likely that future pressures will force consideration of certain ocean regimes for disposal of selected waste products. Various proposals for disposal of industrial and radioactive wastes may be revived in the future, and technological developments could make the concept of burial in subseabed sediments a viable alternative to land-based disposal.

Considering the accidents and improper practices that have resulted in environmental disasters in the past, the challenge of utilizing this expanded area becomes one of how to balance using its resources with ensuring its protection. Oil spills resulting from tanker accidents, offshore oil well blow-outs, and medical wastes washing ashore have provided graphic examples of the kind of harm that can result from human activities in the ocean. Fortunately, the negative impacts have been mostly localized, contained, or caused minimal long-term damage. The opportunity still exists to establish environmentally sound procedures for extracting living and nonliving resources; for using the seafloor and substrate for communication cables, pipelines, and waste disposal; for conducting research; and for preserving critical habitats and recreational and cultural areas.

Expanded utilization of the EEZ in general, and the seabed in particular, will present technological problems, management issues, and environmental concerns. For example, much of the future development will depend on tools to survey, map, probe, sample, and monitor the seabed. Improved survey and mapping techniques will enhance the ability to identify seabed processes. Sampling, measurement, and monitoring technology will be necessary to obtain the detailed information required for quantified analyses of seabed processes. Improved technology will also be needed for most actual uses—whether to mine and process minerals, bury cables and pipelines, or dispose of waste.

In the face of increasing pressures to use the EEZ seabed for activities like these and for other presently unforeseen uses, conflicts are inevitable. Their resolution will involve accommodating multiple uses or establishing priorities in the national interest. The original intent of this study was to assess engineering aspects of major uses of the seabed. However, early in its deliberations the committee determined that seabed use involves other issues as well. The study's outlook was therefore expanded to examine both technological and nontechnological issues surrounding all potential uses.

The U.S. EEZ is a precious national resource of unprecedented dimensions, and actions taken to develop its resources over the coming decades will have important economic implications for future generations and could have long-range ecological effects.

2

Seabed Processes and Research Activities

In order to appreciate the problems and challenges associated with uses of the EEZ seabed, it is necessary to understand its environment, the processes affecting it, and the complexities of its highly variable regions. In this chapter, some important features of the EEZ seabed, the processes that affect its utilization, and research that has been undertaken to understand it are discussed.

SEABED CHARACTERISTICS

The U.S. EEZ embraces a vast range of seabed morphology, water depths, tectonic and transport processes, sediment types, and environmental conditions. Topography varies from relatively flat on the shelf and lower continental rise to very rugged on steeper slopes and canyons. Depths vary from the shallow continental insular shelves, where surface waves affect the seabed, to regions where depths exceed 4,000 m. The EEZ seabed encompasses passive and active tectonic margins and volcanic regions where a variety of tectonic processes, along with other environmental forces, such as currents, surface waves, tsunamis, earthquakes, and ice scouring affect the seabed and reshape and rework its sediments. Seabed materials include rock outcrops, boulders, coarse sands and gravels, biogenic sediments, carbonate reefs, phosphate deposits, silts, clays, gassy sediments, permafrost, hydrothermal crusts, and manganese nodules.

These diverse conditions create a highly variable environment with important implications for expanded seabed utilization. While it is possible to assess most seabed conditions and predict many seabed processes, there are still some processes that are poorly understood.

Regional Features

The EEZ includes a relatively flat shelf adjacent to the coast, a steeper (5° to 10°) continental slope often incised by canyons that provide conduits to deeper water, and a gently sloping continental rise (see Figure 1-2). There are many variations of this simplistic model, depending on tectonic processes and other factors (Figure 2-1). For example, the Atlantic seacoast region is a passive margin with little tectonic activity, a wide shelf, and thick deposits of sediments, and is similar to the classic model shown in Figure 1-2. The active margin along the Pacific seacoast is quite different. The shelf is generally narrow, and dynamic tectonic processes beneath the Pacific EEZ have resulted in greater physiographic variability than in other areas of the U.S. continental coast. Around the volcanic islands of Hawaii and the Pacific trust territories are narrow shelves consisting of coral reefs and volcanic aprons that extend to abyssal depths. Offshore of large rivers such as the Mississippi are thick deposits of underconsolidated and gassy sediments, canyons, diapirs, and large fan deposits of sediments in deeper water (Figure 2-2). Other important regional features include the area off the western coast of Florida, where there are carbonate sediments, and the arctic regions of Alaska, where permafrost, deepwater gas hydrates, and ice packs affect the seabed.

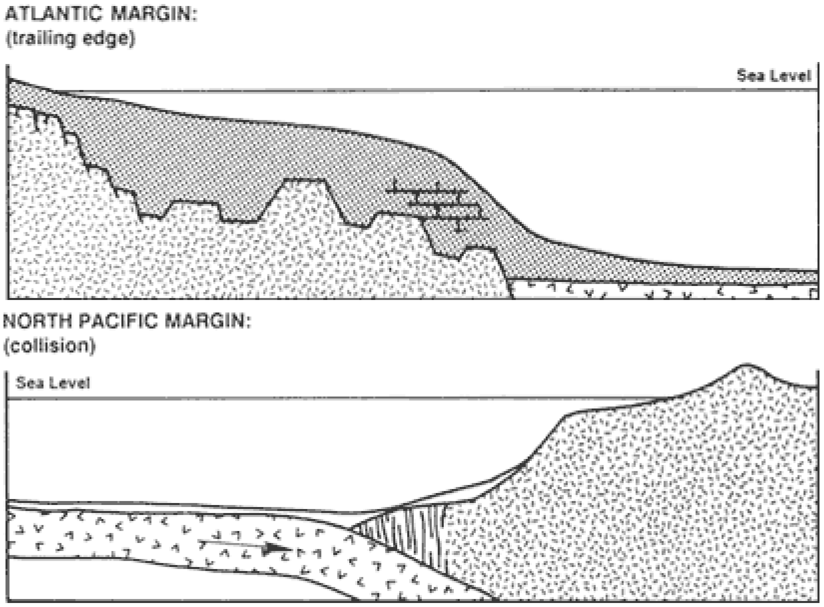

Figure 2-1
Typical idealized cross sections of physiographic provinces of the Atlantic and Pacific continental margins of the U.S. EEZ. The Atlantic coast is characterized as a passive margin with little tectonic activity, a wide shelf, and thick sediment deposits. The Pacific coast is composed of an active margin, or subduction region, with a relatively narrow shelf, thin sediment cover, and significant tectonic activity. SOURCE: After McGregor and Lockwood, 1985.

EXTERNAL ENVIRONMENTAL EFFECTS

Major environmental forces affecting the ocean floor include seismicity and active faulting at ridge crests and active margins; tsunamis, hurricanes and storm-related waves and currents in shallow waters; bottom currents in deeper water; and ice keel gouging in the high latitudes. In order to use the seabed, it is necessary to be able to predict the frequency, magnitude, and duration of these processes, and to understand their impacts on the seabed and on ocean bottom structures.

Earthquakes

Earthquakes are a particular concern along the active margins of the west coast, Puerto Rico, Guam, the northern Marianas, and along the Aleutian trench in the North Pacific. The seismic history of arctic seas is poorly documented. The Atlantic coast is mostly inactive, although recent (1984) earthquakes have been documented by the USGS Earthquake Information Center. The Gulf of Mexico historically has had only one earthquake of any magnitude, and is considered fairly safe from earth shock (Teleki et al., 1979), although the existence of growth faults ringing the Gulf may indicate potential for earthquake activity in the future.

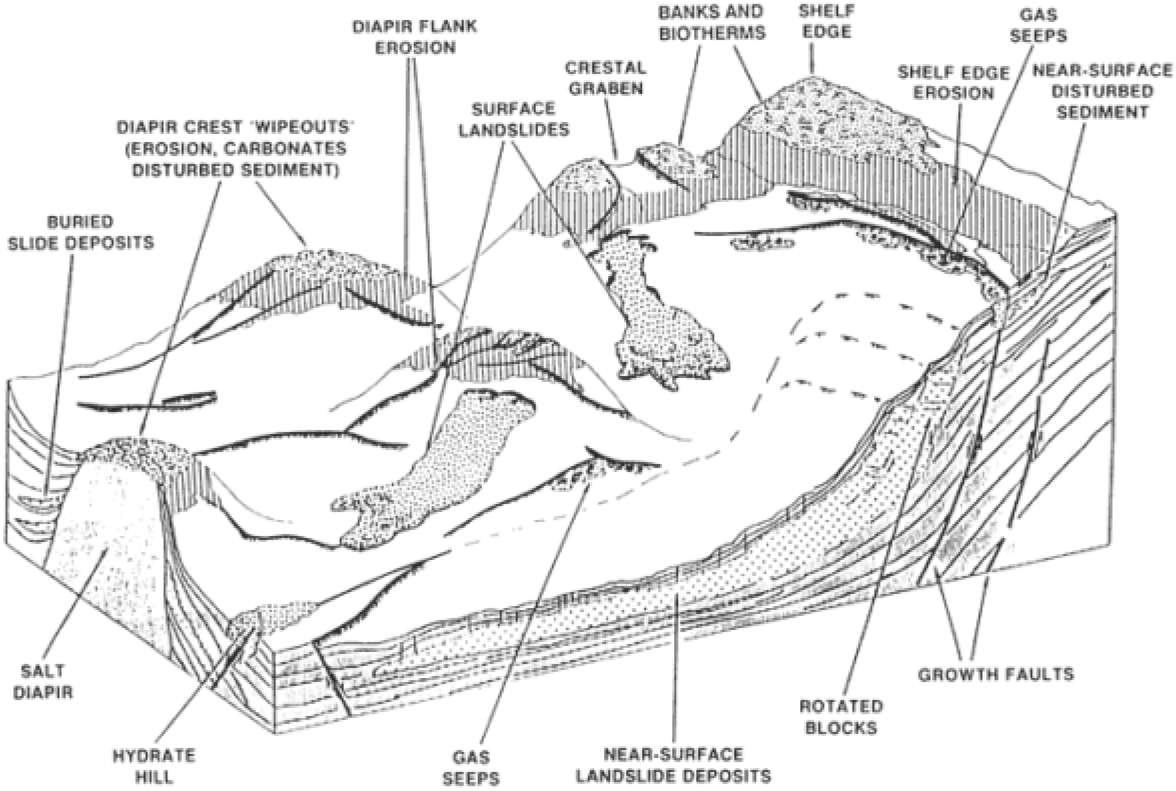

Figure 2-2
Principal geologic features of the outer continental shelf and upper continental slope offshore Louisiana and Texas.
SOURCE: After Campbell et al., 1986.

Damage due to shaking by earthquakes can be great, primarily resulting from the mass wasting (downslope movement of a large volumes of sediment) that occurs with slope failure. Normally stable slopes can fail when subjected to accelerations caused by earthquakes, and any structures, pipelines, or cables in the vicinity may be displaced or fail.

It is difficult to ascertain how widespread and frequent seismically induced seafloor failures are, because so little is known about the geology of the sea floor in most of the EEZ. Furthermore, knowledge of sediment response to strong ground motion accelerations is incomplete. Data on ground acceleration, velocity, displacement, event duration, and frequency are required for the design of large structures (Bea, 1978).

Tsunamis

Tsunamis are long-period, open-ocean waves thought to be caused primarily by submarine landslides triggered by earthquakes or induced by shallow-focus-depth earthquakes or submarine volcanoes. Tsunamis are particularly dangerous because they are unpredictable, travel at great speeds, and build up very high waves when they shoal in shallow waters (a wave less than 1-m high in deep water may become a 30-m wave when reaching shore). Effective warning systems have been implemented, especially on Pacific islands, that reduce the human risks from these events. The areas most susceptible to these waves are along the west coast, the Pacific islands, and Alaska. Although damage to coastal areas by tsunamis is well documented, their influence on the seabed is not.

Hurricanes and Storm-Related Waves

Most hurricanes can be predicted well in advance with satellite remote sensing. Adequate data exists on the high winds, waves, currents, and storm surges associated with hurricanes. The data base for storm-related extreme wave conditions, however, contains much more hindcasted data than measured parameters. While data coverage is good for the east and west coasts and the Gulf of Mexico, it is sparse for the Arctic. Many existing wind-wave hindcast models are developed for specific geographic areas and storm conditions. Surface waves affect the seabed in shallow water, where the pressure and water motion impinges directly on the seabed and can lead to mass failures and erosion. Internal waves may play an important role in deeper water, but little data is available on these.

Currents

In most of the EEZ, near-bottom currents exist at various scales of motion, duration, frequency, and magnitude. Currents result from tidal forcing circulation, major oceanic-scale current systems (such as the Gulf Stream), wind setup, and storm surge. While continental shelf circulation has been the subject of extensive research, (Butman et al., 1979), currents on the slope and rise are just beginning to be deciphered. The topography in the EEZ, especially on continental margins and seamounts, influences the magnitude and direction of currents (Heezen and Hollister, 1984). Episodic currents confirmed on the east coast continental rise are capable of suspending and transporting sediment by "benthic storms" that can occur several times a year (Hollister et al., 1984).

Ice-Bottom Interaction

Ice gouging is an important concern in the Arctic. Enormous forces are imparted to the seabed when large ice masses, pushed by winds and currents, contact the seafloor (Figure 2-3). The depth of most gouges is of the order of 1 m or less, but scour depths exceeding 7 m have been documented. In the Arctic Ocean north of Alaska virtually no part of the continental shelf has been spared from reworking by ice. These are very active, seasonal processes that have important implications for seafloor structures, pipelines, and instruments.

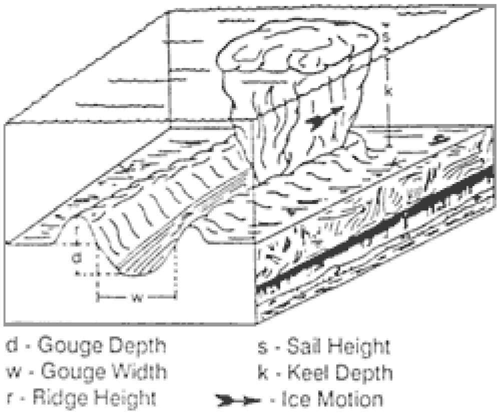

Figure 2-3
Primary features of ice gouging. Gouges can be several meters in depth and many kilometers long. Sediment properties are altered by gouging, and engineering of structures and pipelines must take this process into account. SOURCE: After Barnes and Reimitz, 1974.

NATURAL SEABED PROCESSES

The complex nature of the seabed is the consequence of an array of processes occurring in these regimes over millions of years. In addition to the forces already discussed, the seabed is shaped by the processes associated with the rise and fall of sea level during glacial and interglacial periods, the consequent sediment influx from continents, and changes in bottom current intensity. These forces create a dynamic and continually changing environment. Therefore, understanding the evolution and active processes of EEZ seabed regimes and being able to reasonably predict their effect on the seabed are essential to seabed development activities.

Two broad categories of active seabed processes are particularly important to EEZ utilization because of their widespread effects: mass wasting and slope deformation, and sediment dynamics (erosion, transport, and deposition).

Sediment Mass Movements

Mass wasting is the downslope movement of sediment or rock, such as a submarine landslide. Typically, what occurs is catastrophic slumping or sliding along a well-defined failure surface within the sediment, which results in an upslope scar surface and fairly coherent but deformed sediment deposit on the downslope side. A full range of deformations occurs on submarine slopes; very gradual (creep) deformations may eventually lead to more catastrophic failures, fluid-like debris flows, and turbidity currents (Figure 2-4). These processes may encompass enormous masses of sediment and influence areas of more than 100 km^2 (half the area of Rhode Island) and are therefore important considerations in siting offshore facilities.

Because mass wasting can occur even on very low-angle slope inclinations (less than 1°), it constitutes an important geohazard to many submarine installations and operations. In addition to gravity, the primary causes of slope failure are earthquakes and associated faulting; changes in slope geometry resulting from oversteepening; or scour, wave loading, creep, loading by structures and construction, gassy sediments, and rapid sedimentation. Failure does not usually result from just one cause, but rather from a combination of factors. Thus a slope that is safe in normal conditions may fail under unique storm-loading conditions. Areas of potential slope instability are

- deltas, which continually build by rapid sediment input;
- areas subject to storm wave influence; and
- the continental slope and upper continental rise, where slope inclinations are relatively steep and sediments are weak.

Slope failures have been documented in many EEZ environments including the Mississippi River delta, Copper River (Alaska), the continental slopes off the Atlantic coast, in the Beaufort Sea, and off the west coast of the Bering Sea.

Much of the mass wasting on the Atlantic margin occurred during low sea level stands (50- to 100-m lower than present) when sediment was rapidly supplied to the shelf edge. The amount of mass wasting still occurring is uncertain; however, it is known that erosive processes are active on the continental slope, and mass wasting is occurring upslope as a result of undercutting. Mass wasting is also occurring in the Mississippi delta, offshore of fjords on the northwest coast, in many submarine canyons, and in localized areas of the Atlantic coast slope.

There are obvious implications of mass wasting for engineered installations on slopes. As oil and gas operations move to deeper water, the full range of downslope processes (Figure 2-4) will need to be better understood in order to avoid potentially hazardous areas or to design structures that can withstand the resulting forces. In addition, horizontal installations such as pipelines and cables are particularly vulnerable to mass wasting because they may traverse varied seabed conditions.

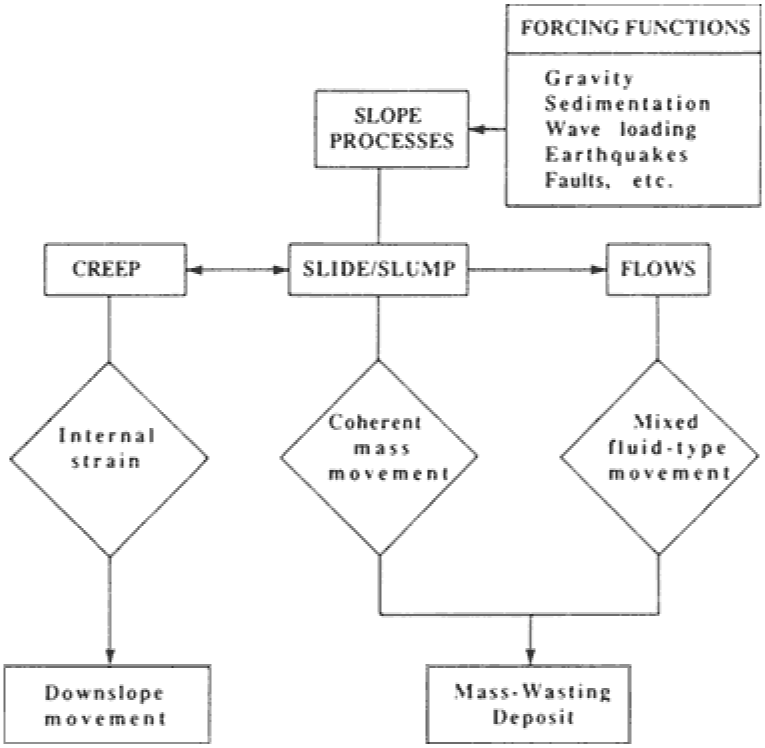

Figure 2-4
Interrelationships of slope deformation and failure processes. Slope processes can be viewed as a continuum ranging from very gradual downslope deformations (creep), submarine landslides that involve rapid movement of fairly coherent masses, and fluid-sediment where the mixture moves rapidly downslope as a viscous fluid. Any one type of process can lead to another depending on site conditions.

Sediment Dynamics

Sediment dynamics refers to the erosion, transport, and deposition resulting from interactions between the sediment and the moving waters directly above the sediment-water interface. In many areas, however, there is no clear interface, and in fact there is usually an active interchange between the water and sediment. In these areas, the definition of the seabed in this report includes the benthic boundary layer, the zone composed of approximately the lower 10 m or less of water (with suspended sediments) and the upper 1 m of sediment.

Sediment dynamics depend principally on near-bottom currents. Although the bulk of sediment transport is caused by episodic events caused by large benthic storms, persistent currents result in significant long-term erosion and deposition. Knowledge of these currents is crucial to understanding dispersal of pollutants; local scour around structures, buried pipelines, and cables; stability of moored arrays or other bottom-mounted installations; the fate of dredged materials; and the possibility that sediment suspended by bioturbation, mining, or excavation will be transported elsewhere.

The migration of sand waves on the Atlantic continental shelf in response to storm-driven currents has been documented by side-scan sonar. Sediment on most of the continental slope and rise off the Atlantic coast, if resuspended by seafloor uses, will travel tens of kilometers before settling to the bottom. Because of high turbulence in continental shelf regimes, any fine-grained suspended material tends to be well-mixed and dispersed rapidly.

As discussed in greater detail later in this chapter, benthic organisms also play an important role in sediment dynamics because they may enhance the erodibility of sediments by mixing and resuspending sediment or may undercut a slope by burrowing in steep canyon walls. Although recent research has shed light on the complex processes of sediment dynamics, the capability to quantitatively predict sediment erosion and its subsequent fate under a variety of environmental conditions still does not exist. For some applications, such as disposal of wastes, it will be necessary to enhance understanding of long-term sediment dynamics in order to reasonably predict their fate.

SEDIMENT PROPERTIES

Knowledge of physical, chemical, and biological properties of ocean sediments is important to potential uses of the seabed. Engineering behavior depends on all three. For example, the strength of fine-grained sediments is largely controlled by the geochemistry (mineralogy) of the constituents, which in turn is often closely linked to biological processes. Also, the properties of a given sediment deposit are not constant, but may change significantly over time. Some common properties of sediments are described in this section and elsewhere in this report as they pertain to particular uses.

Physical Properties

Physical properties are the geological and engineering properties of sediments that must be understood in order to make calculations related to seabed processes and uses. In general, physical properties of marine sediments (with the exception of carbonate and siliceous materials) are similar to those of water-saturated terrestrial soils (Chaney and Fang, 1986). Thus, with some important modifications, most geotechnical principles developed for land apply to engineering analysis of the seabed.

Physical properties of marine sediments are important to geotechnical engineering (Tables 2-1 and 2-2). Site-specific properties are important because within most regions properties vary vertically, from the seafloor down through the sediment column; and longitudinally, from the coast out across the shelf, slope, and rise. Special conditions that affect physical properties and seabed behavior are dynamic loading by waves, earthquakes, and sediment-structure interactions; high carbonate content; gas in sediments; high organic content; permafrost and freeze-thaw processes; ice-seabed interactions; and state of consolidation (compaction).

Compressibility and Permeability

Knowledge of compressibility and permeability (perviousness) of marine sediments is important in analysis and design of structures for seabed applications. For example, the loading imparted by a structure placed on the seabed causes compression and settlement of underlying sediments (Figure 2-5). The state of consolidation within the sediment column is also important in reconstructing the geological history of an area and assessing the suitability of a site for a given use. Permeability data are critical for evaluating the potential for pore fluid migration in sediments being considered for waste disposal.

TABLE 2-1 Site Data Requirements for Categories of Geotechnical Engineering Applications in Marine Sediments

	Topography			Sediment		
Application	Macro (>1 m)	Micro (<1 m)	Index properties	In situ strength	Laboratory strength	Dynamic response
Shallow foundations/ deadweight anchors	high[a]	high	high	low[b]	high	low
Deep foundations/ pile anchors	high	low	high	high	high	high
Direct-embedment anchors	low	0[c]	high	low	high	high
Drag anchors	high	low	high	low	low	low
Penetration	0	0	high	high	low	low
Breakout	low	low	high	low	high	high
Scour	high	high	high	low	low	0
Slope stability	high	high	high	high	high	high

NOTES: [a] High = mandatory, [b] low = can design without, [c] 0 = not needed
SOURCE: After Rocker, 1985.

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Drag anchors	high	low	high	low	low	low
Penetration	0	0	high	high	low	low
Breakout	low	low	high	low	high	high
Scour	high	high	high	low	low	0
Slope stability	high	high	high	high	high	high

NOTES: [a] High = mandatory, [b] low = can design without, [c] 0 = not needed
SOURCE: After Rocker, 1985.

Accurate determination of compressibility and permeability requires recovering good quality samples for laboratory testing, although some success has been achieved in measuring permeability characteristics in situ. In either case, it is usually difficult and costly to obtain detailed data on these properties.

Sediment strength and response to loading, called "stress-strain behavior," are important criteria for evaluating slope stability and designing seabed installations. Knowledge of undrained shear strength, based on short-term static loading, is adequate for some applications, but most engineering situations require determination of shear strengths for varied loading conditions. Loadings that result from complex interactions among environmental forces, the structure, and the seabed (Figure 2-5) are dynamic and cyclical. Thus, it is not usually possible to designate a single strength value to assess seabed stability; rather, it is necessary to determine the full range of stress-strain-time properties that apply to a given situation. This variability, especially the presence of weak layers, is important in analyzing slope stability and calculating the stability of bottom-supported structures.

Organic content can also influence the physical properties of sediments. The organic content may vary vertically in the sediment column due to a change from oxidizing to reducing conditions, and horizontally due to zones of high productivity or oxygenated areas. Hence, changes in consistency and strength within fine-grained sediments may be due to variations in organic content rather than changes in texture, mineralogy, pore water chemistry, or sedimentation (Keller, 1982; Bennett et al., 1985; Booth and Dahl, 1986).

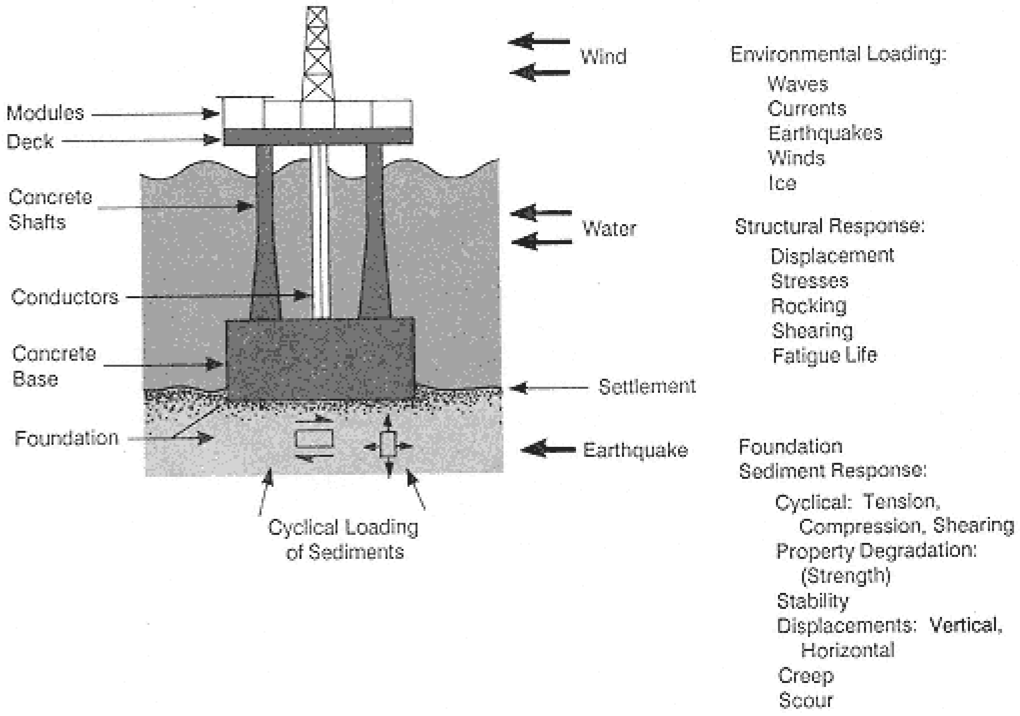


Figure 2-5
Interactions among environmental forcing effects, structural behavior, and foundation/sediment responses for a typical oil production gravity platform. The dynamic and static ocean structure-sediment interactions can lead to complex sediment behaviors, including degradation or enhancement of strength properties, depending on the nature of the sediment beneath and around the structure.

Chemical Properties

Most of the sediment varieties in the world's oceans can be found in the U.S. EEZ. For example, there are deposits rich in biogenic silica in the Bering Sea; organic-rich hemipelagic sediment along the Pacific coast; metal-bearing ferromanganese crusts and nodules off Hawaii, other Pacific islands, and the Blake Plateau; gas hydrate deposits in the Bering Sea and the Gulf of Mexico; and well-oxygenated abyssal lutites off Puerto Rico and the U.S. Pacific trust territories. This diversity makes it difficult to summarize the geochemical properties of EEZ sediments, so only the more important aspects are discussed here.

Gas Hydrates

Gas hydrates form when dissolved gas concentrations exceed thermodynamic solubility under local temperature and pressure. Much of the continental margin sediments could contain hydrates, although hydrates containing methane are less likely in depths less than 500 m and temperatures warmer than 7°C. Brooks et el. (1984) reported gas hydrates of thermogenic and biogenic origin in the Gulf of Mexico.

Thawing of hydrates that are near the sediment-water interface will adversely affect geotechnical properties and installation of facilities. Such effects are inferred, however, since little experience exists as to the effects of hydrates on engineering properties and behavior of sediments. Formation of gas hydrates may be associated with the supply of reduced gases (such as methane, CH_4, and hydrogen sulfide, H_2S) to sedimentary regimes in which microorganisms chemosynthesize the gases and form the basis for a food web. Therefore, extraction of hydrates could possibly adversely affect ecosystems that have evolved in these regions.

Ferromanganese Deposits

In many EEZ seabed regions, complex chemical interactions among the overlying water, interstitial (pore) fluids, and rocks lead to concentrations of mineral deposits. One important process involves precipitation of ferromanganese compounds on or in the sediment. Most of these deposits contain varying amounts of economically important or strategic metals (such as cobalt, platinum, manganese, and chromium) that could be in short supply during a natural or political crisis. Deep-sea ferromanganese nodules have 0.24 percent cobalt, equivalent to the cobalt content of ore from Zaire, which supplies the metal imported by the United States. Shallow-water ferromanganese crusts have two to three times more cobalt than deepwater nodules. Upper slopes of seamounts and ridges tend to have 2 to 4 cm of black ferromanganese oxide crusts containing high contents of cobalt as well as other metals, such as nickel, cerium, molybdenum, and vanadium.

Sediment Oxidation-Reduction Chemistry

The average oxidation state is perhaps the most critical parameter in predicting the chemical reactions in sediment. In general, shallow-water sediment near the coast is reducing, and deepwater sediment on the continental slopes is oxidizing, although there are exceptions. The amount of available oxygen affects the abundance and species composition of benthic organisms, which can strongly modify the biogeochemical processes that occur (Aller, 1982). Burrow abundance and geometry can considerably alter distribution of the principal oxidants within sediments, and the average size and distribution of burrows can strongly influence fluxes of solutes across the sediment-water interface.

Knowledge about redox processes and their possible effects on EEZ sediments is reasonably good, but on a gross scale, EEZ sediments along the Pacific coast are richer in organic carbon (up to 2 percent), and therefore more reducing than EEZ sediments along the Atlantic coast (0.25 to 0.5 percent).

Biological Properties

Biological processes can have important effects on the character and behavior of sediments. Physical and chemical alteration of sediments occur when benthic animals move about and feed, and in areas such as steep canyon walls burrowing animals can cause sediment instability. In most areas of the seabed, benthic organisms affect sediment stability and can alter erosion rates and resuspension.

Under what physical conditions the sediment in a given location will be eroded is important information for a number of ocean engineering applications. The water velocity needed to initiate sediment movement and transport is an especially critical engineering parameter, and much theoretical and experimental work has been directed at predicting this value for different sediments. Recent work has demonstrated that much of the discrepancy between these predictions and what we observe in the ocean is due to biological effects on sediment properties (Jumars and Nowell, 1984).

Bioturbation is the physical reworking and redistribution of sediment particles in the normal course of movement and feeding of benthic organisms. The rate of bioturbation varies with temperature, amount and input rate of organic matter in the seabed, type of benthic community, and abundance of organisms. Bioturbation rates decrease with sediment depth, due to decreased abundance of organisms, and generally are important only within the upper 1 m of sediment.

Knowledge of bioturbation processes is important to predicting sediment response to activities such as waste and dredge disposal, since bioturbation can reintroduce materials from sediments into the overlying water and possibly disperse them over large areas. By itself, bioturbation generally acts to increase erodibility of sediment by maintaining a high water content and physically moving material toward the sediment surface where it can be moved about by bottom currents. However, an important counteracting consequence of feeding of sediment-dwelling animals is the packaging of small sediment particles into large fecal pellets, which have different transport thresholds and hydrodynamic properties than the ambient sediments.

Adhesion of sediment particles due to mucous secretions of organisms can also alter sediment erodibility. Mucus is produced by many benthic animals as an aid in locomotion and feeding, as well as by sediment microalgae and bacteria as an anchorage or protective mechanism. Mucous secretions increase the shear stress required to erode sediment by promoting particle-to-particle contact. The resulting effect is strongest near the sediment surface, since most biological activity is concentrated there.

Once adhesive effects or other stabilizing biological factors are overcome by a strong enough current, the underlying sediments tend to be rapidly eroded since the overlying resistant 'cap' is gone. The effects of biological modification of erodibility may vary with time, given the strong coupling among seasonality, temperature, and biological activity. At continental shelf depths, this coupling is especially important since seasonal increases of bottom stress from winter storm waves is likely to coincide with the period of minimal biological activity.

SEABED RESEARCH

Research in the EEZ requires investigation—generally long-term and multidisciplinary—of complex interactive systems to acquire the quantity and quality of data necessary to test theories, develop a framework of knowledge, and verify predictive models of seabed processes; and the application of results to specific problems related to utilization of the seabed. Of the three major geomorphic subdivisions of the EEZ seabed—the shelf, slope, and rise, collectively called the "continental margin"—the shelf has been studied most extensively because it is the most accessible. Many research topics are being actively pursued within the U.S. EEZ by numerous applied and basic research organizations. A brief overview of these activities follows.

Surveying

Mapping of the EEZ is being conducted to assess nonliving resource potential under the auspices of a cooperative mapping agreement between the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) carried out by the Joint Office for Mapping and Research (JOMAR) (McGregor and Lockwood, 1985). The plan incorporates NOAA's Sea Beam swath mapping coupled with GLORIA side-scan surveys conducted by the USGS. The resultant products, high-resolution bathymetric maps and reconnaissance side-scan sonar maps, provide an excellent geologic framework for future research.

JOMAR's program is carrying out blanket coverage of the EEZ and providing high-quality sea floor maps to industry and local, state, and federal agencies for mineral exploration extraction, and resource assessment. Continued and expanded high-resolution surveying will follow, building on the data base provided by GLORIA (Lockwood and McGregor, 1988). These detailed surveys will lead to improved terrain evaluation procedures using survey data for quantitative classification of areas. Sound scientific questions and problems related to present and anticipated uses of the EEZ require information on resource potential and assessment of bottom conditions that may inhibit or constrain development. Water depth, bottom slopes, seafloor topography, sediment properties, and effects of various geologic processes must be known in order to design, install, and maintain engineering structures such as platforms, pipelines, and cables. Surveying and mapping of seafloor characteristics provide an important basis for development decisions. The needs will evolve as development proceeds and as knowledge of the EEZ sea floor improves. However, it is clear that each use of the seabed will require site-specific bathymetry, seafloor imagery, near-surface sediment profiles, and measurement of sediment properties. By comparison, reconnaissance information may provide useful background context, but in many cases is not appropriate for development of particular sites or uses.

Sampling

Near-surface sampling is used to primarily correlate sediment distribution characteristics with acoustic imagery analysis and process evaluation. Hindcasting of processes based on sedimentologic results and age dating to determine magnitude and frequency of recent geologic events is typically done from box and gravity cores.

In situ measurements of shear velocity and attenuation as a function of depth in unconsolidated shelf sediments have been made in a few isolated locations (Jacobson, 1987; Heacock, 1988). In conjunction with these tests, shallow-water, in situ sediment probes were recently developed and tested. In situ measurements of sediment porosity, permeability, and excess pore pressure fluctuations have been made, and these data are being compared to acoustic information (Yamamoto and Torii, 1986).

Three acoustic systems for use in EEZ shelf waters are being evaluated. The first is the shear sled receiver system, which can generate and receive shear sound waves to determine the rigidity modulus of sediments. A deep-tow, high-resolution, shallow-water, subbottom seismic system is also available that can be used for three-dimensional seismic mapping of shelf and upper slope geologic structures and sedimentary facies to better understand their geometry and development processes (Milliman et al., in press). Another high-resolution seismic system in shallow-water use is the Chirp Sonar, a broad-band system designed for high-resolution profiling and for ascertaining lateral and vertical variability in sound attenuation. This system is undergoing extensive field testing and is considered developmental (Schock et al., 1989).

Deep coring (e.g., Ocean Drilling Project) can be used to provide sediment data from the ancient rock record for correlation with acoustics to establish overall geologic development of sedimentary sequences and provinces. Although sampling techniques using bore holes are well developed, there is still no reliable and quick method for getting deep (tens of meters) cores in noncohesive sediments (sand).

Sediment Transport and Organism-Sediment Interaction

Studies of cohesive sediment transport processes influenced by bottom currents in the absence of waves on the continental rise off the northeastern United States show that most sediment particles are transported and deposited during short periods (days) by benthic storms that occur about ten times a year in this region (Nowell and Hollister, 1985).

The present level of understanding of the effects of benthic organisms on sediment transport is inadequate for predictive models. Only a few studies have considered the cumulative effects of organism communities on sediment erosion, deposition, and transport (Grant et al., 1982); most research has focused instead on single species maintained in laboratory flumes. Even under controlled laboratory conditions, the net effects of an organism on erosion and deposition are difficult to predict (Jumars and Nowell, 1984), particularly the point at which biological effects become unimportant relative to physical processes.

Outstanding questions on the effects of biological processes on chemical processes in sediments include how organisms' activities and biogenic structures alter the flow in the boundary layer, especially the viscous sublayer. Another important research area is the effect of sedimentary material passing through the guts of benthic organisms on remobilization of particle-bound materials, such as metals and organic pollutants. Feeding, irrigation, and burrowing activities of benthic animals are particularly important in shelf environments, where a substantial portion of organic matter remineralization takes place on the seabed, and nutrients are returned, with only minor time lags, to the photic zone.

Alterations of the benthic community during disturbances due to environmental or normal population variations can influence short-term transport of solutes and particles within the environment as well as long-term storage in the seabed. How such changes influence primary production, plankton species composition, or cycling of different bioactive elements through the food web and water column are largely unknown.

Recent advances in the understanding of nonlinear wave-current interaction theory has provided the breakthrough necessary to initiate research into the predictability of changes in the sediment regime and microscale topography of the continental shelf resulting from forcing functions active during major storms (Nowell et al., 1987).

Gas and Frost in Sediments

Studies of the distribution and geometry of gassy sediments in the Gulf of Mexico, California, and Alaska are being conducted, and models are being developed to explain their distribution (Anderson and Bryant, 1987). The geochemistry, stability, occurrence, and transformation of frozen gas hydrates, and their relation to deep source gas resources and geohazards (to drilling) are continuing concerns.

A subsea permafrost study is under way in Prudhoe Bay, Alaska, where physical and geotechnical measurements of thawed and permafrost layers will be interpreted in terms of heat and mass transport using existing theories and numerical calculations. Seismic methods have been used to detect and map discontinuous permafrost in the Beaufort Sea, but results are equivocal. A combination of acoustic soundings, measurements, and deep cores would be useful to delineate the extent of the permafrost.

Slope Stability

There is abundant evidence of deformations and failures on submarine slopes, including catastrophic movement of large masses of sediment in fairly coherent blocks or slumps, debris flows, and turbidity currents (Campbell et al., 1986). There is also evidence of some slope sediments gradually deforming downslope (creeping) and that accumulated creep strains may eventually lead to catastrophic failures (Booth et al., 1984; Silva and Booth, 1985; Silva et al., 1989). Regions subjected to these processes can encompass enormous masses of seabed over areas exceeding 100 km.

Quantitative analysis of undersea slopes has so far been largely restricted to crude estimates of slope stability using limit equilibrium procedures. There are no reliable techniques for predicting initiation of debris flows and turbidity currents or for modeling their behavior. At the other end of the spectrum, long-term creep deformation of slope sediments is just beginning to be understood.

Understanding of slope sediment dynamics is complicated by the effects of earthquakes and wave loadings (surface and internal waves), the morphology of subbottom stratification, and the pertinent stress-strain-time and theological properties of sediments. Improved analytical models to determine deformations and stability of complex submarine slope situations is needed, including long-term (creep) deformations of undersea slopes, prediction of creep-rupture mechanisms, stability of slopes for a variety of forcing conditions, and post-failure behavior of flows. Significantly more focus is required to develop a theoretical framework to describe and analyze seabed materials behavior, and to develop methods to predict seabed stability and dynamics (Nelson and Smith, 1989).

Physical and Biological Research

Physical oceanographic research will use the seafloor as a base for instrument packages for long-term monitoring of oceanographic phenomena. Bottom boundary layer studies relevant to erosion and sediment transport within canyons are examples of such research that can be envisaged to expand. The seafloor will also be used for deployment of sensors that measure processes and properties in the water column (Brink, 1987; Allen et al., 1987): for example, acoustic current meters and inverted echo sounders look at topographic control of currents, warm core ring degradation, and internal wave generation.

Long-term biological monitoring of specific sites is anticipated to examine population changes and ecosystem dynamics in response to different uses, such as oil and gas development, waste disposal, and mining. Biological research will expand its data base on benthic communities, such as infaunal and epifaunal zonations, structures, and controls. Considerable site-specific work can also be expected on new exotic communities, particularly at vents.

Remote Sensing

Satellite and aerogeophysical technology provide useful instrumentation for exploring and monitoring the EEZ. Geophysicists have developed a number of remote sensing techniques for gravity analysis that provide information on sediment loading and basin development, strength and age of the lithosphere, continental rifting, and location of faults, basins, sediment types, and other geological features (Hammer, 1983). Magnetic anomaly analysis of data from remote sensing technology indicates the distribution of ferromagnetism within the lithosphere and therefore is linked to the mineralogy of the crust. Magnetic basement techniques, which rely on the wavelength of the observed field, can be used to infer thickness of sediment cover. Magnetic analysis can be useful in determining the age of the oceanic crust, studying continental rifting mechanisms, and modeling the configuration of the continents and their margins prior to the formation of the bordering ocean (Webster et al., 1985).

Satellite and aircraft remote sensing can provide synoptic and repetitive information about environmental changes associated with development of seabed resources and other uses of the seabed, such as waste disposal. More intensive experimentation with these techniques is needed to optimize their use for acquiring information about the seafloor.

A system for airborne seismic surveying is in the experimental stage, based on elements of systems used by the U.S. Navy and researchers to map the acoustic properties of the oceans (LaBrecque et al., 1986). Surface and bottom arrays of expendable hydrophones are deployed by aircraft and monitored using the Global Positioning System (GPS). Explosive charges are used as sound sources. The advantage of this proposed technique would be its ability to cover large areas rapidly. It is unlikely that aeroseismics could ever achieve the resolution of three-dimensional multichannel surveying, but it would serve as a useful reconnaissance tool.

Research Activities

Many government agencies and private industries support research related to the benthic boundary layer, the seabed, and the subseabed. Research on seabed processes is conducted by the National Science Foundation (NSF), the Office of Naval Research (ONR) (Advisory Committee on Ocean Sciences [NSF], 1987; Jacobsen [ONR], 1987; and Heacock [ONR], 1988,), the USGS, and NOAA. An ongoing mapping and surveying program in the EEZ is underway through the USGS/NOAA Joint Office for Mapping and Research (Lockwood and McGregor, 1988; Lockwood, 1989). NOAA, through its Sea grant Program, supports research that includes offshore mineral resource evaluation (Sea Grant Abstracts, 1988). Research on particle flux across the EEZ has been supported by the Department of Energy (DOE) (McCammon, 1988). Summaries of engineering research activities on the EEZ can be found in Seymour and Webster (1987) and Yuen (1987).

3

Present and Potential Uses of the Seabed

The contribution of the ocean sector to the U.S. economy was about 2.6 percent of the total gross national product (GNP) in 1987 (Pontecorvo, 1989), an amount on the same scale as other components of GNP, such as mining, transportation, and communications. The role of the oceans as a resource base for future growth and development is likely to increase under the pressures of population growth and economic expansion (Corell, 1988).

This chapter identifies existing and potential uses of the seabed, assesses their current scope and future potential, estimates time frames required for development, and examines constraints to current and future development. Problems and issues associated with each resource or activity are analyzed, particularly existing or potential conflicts among different uses. Resources and uses examined include oil and gas exploration and development, mineral exploration and development, waste disposal, cables and military uses, biological resources, ocean energy resources, and cultural and recreational resources. The technology and information required to develop these resources or activities are examined in depth in Chapter 4.

OIL AND GAS EXPLORATION AND DEVELOPMENT AND OFFSHORE STRUCTURES

Background

Since the first oil and gas wells were drilled from piers offshore of Summerland, California, in 1896, the U.S. petroleum industry has been shifting a greater percentage of its activities from onshore to offshore. Today, offshore oil and gas production is an important source of the nation's energy supplies. In 1985, 11 percent of total crude production (1.07 million barrels) and 25 percent of total gas production (1,335 billion m^3) was produced offshore, and it is estimated that the percentage of U.S. oil and gas reserves from marine sources will continue to increase each year as land reserves decline (Bettenberg, 1987; OTA, 1985; Nehring, 1981; MMS, 1987). The USGS estimated in 1981 that 26 to 41 percent of the oil and 25 to 30 percent of the natural gas that will be discovered and recovered in U.S. controlled territory in the future will be found offshore within the EEZ. Offshore oil and gas production also began to move toward the Arctic—specifically the Beaufort, Chukchi, and Bering seas—when activities in the Beaufort Sea commenced in the mid 1970s.

The technology and operational expertise associated with hydrocarbon exploration is well developed for activities conducted from mobile structures, such as jack-up rigs or submersibles; floating vessels, drill ships, or semisubmersibles (Figure 3-1); and fixed structures for up to 300-m depths, such as template type platforms, tower platforms, or caisson platforms (over 4,100 of these platforms have been successfully installed offshore [Anon, 1988]). In addition, design and construction capabilities for new types of production structures for water deeper than 300 m—guyed towers, tension leg platforms, compliant towers, and subsea production systems (Figure 3-2)—have improved greatly over the last decade (OTA, 1985). Exxon installed the first guyed tower (*Lena*) in 300 m of water (LeBlanc, 1983) in 1983 and Conoco's installation of its tension-leg platform *Joliet* in 535 m of water was scheduled to be completed in August 1989 (Ocean Oil Weekly, 1989). Three other production systems have also been installed in deep waters: Shell's *Cognac* (312 m) and *Bullwinkle* structures (412 m), and Placid's *Penrod* 72 (465 m) (Ocean Oil Weekly, 1987 and 1988). Subsea production systems are an important alternative for deepwater field development. Although over 100 of these systems have been installed around the world in a variety of water depths, Placid oil's subsea system installed in the Gulf of Mexico at a site in 680 m of water is the maximum depth for the U.S. EEZ (Wickizer, 1988). This system is an attractive cost-saving option for well completions in water depths greater than 1,000 m, since the wells are drilled from a floating rig and completed on the seafloor. The majority of the subsea completions are a single well classified as a 'wet' system that relies on a flowline to transport the hydrocarbon to a nearby fixed or floating platform for processing before transporting the oil and gas to market. The 'dry' system places an atmospheric chamber around the wellhead on the seafloor, allowing flowline connection and maintenance to be performed by workers inside the chamber. In the future, subsea production systems of the dry type will be used more widely in water depths from 1,000 to 2,000 m, especially for satellite reservoirs. Improvements in deepwater flowline installation and artificial lift technology should allow the system to be economically attractive for water depths out to 3,000 m.

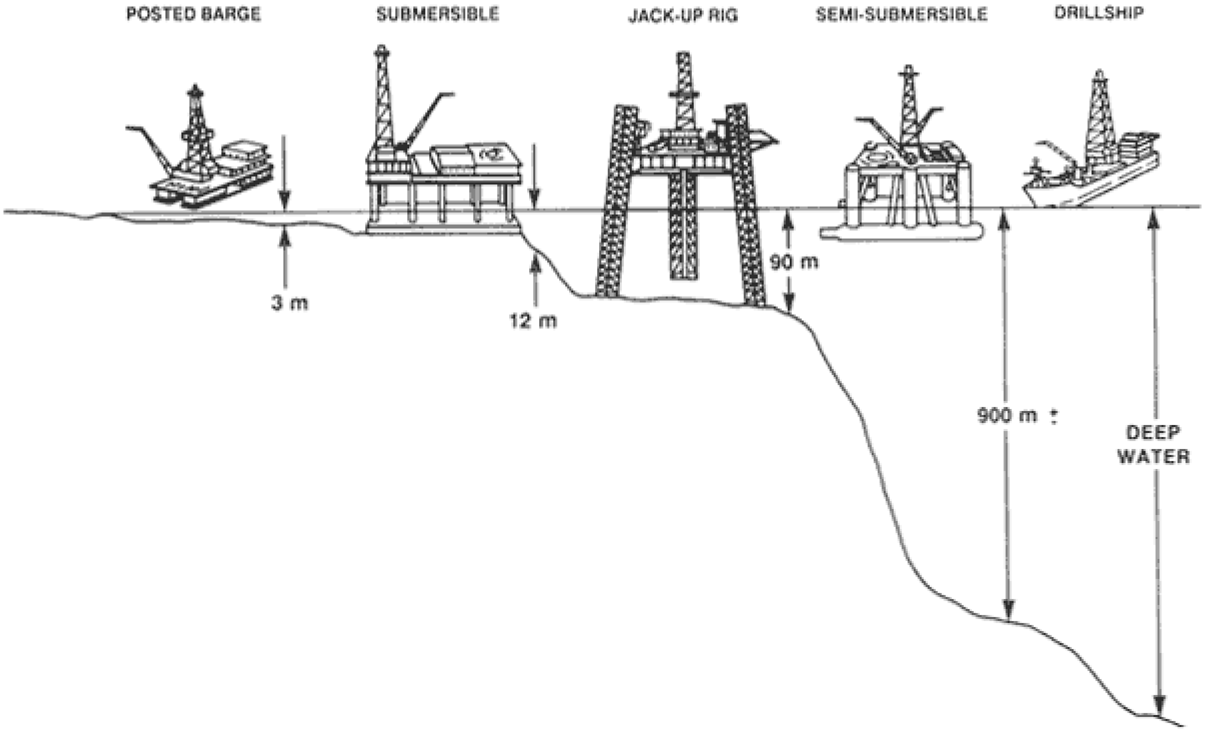


Figure 3-1
Family of offshore exploration drilling rigs

To date, arctic activities have primarily involved exploration wells drilled from artificial islands, although a few wells have been drilled from mobile steel caissons like the one shown in Figure 3-3 (Yokel and Bea, 1986). Improving the nation's capability to produce oil and gas from the EEZ will continue to depend on improving these technologies in order to move into the frontier areas like the Arctic and deep water (over 300 m).

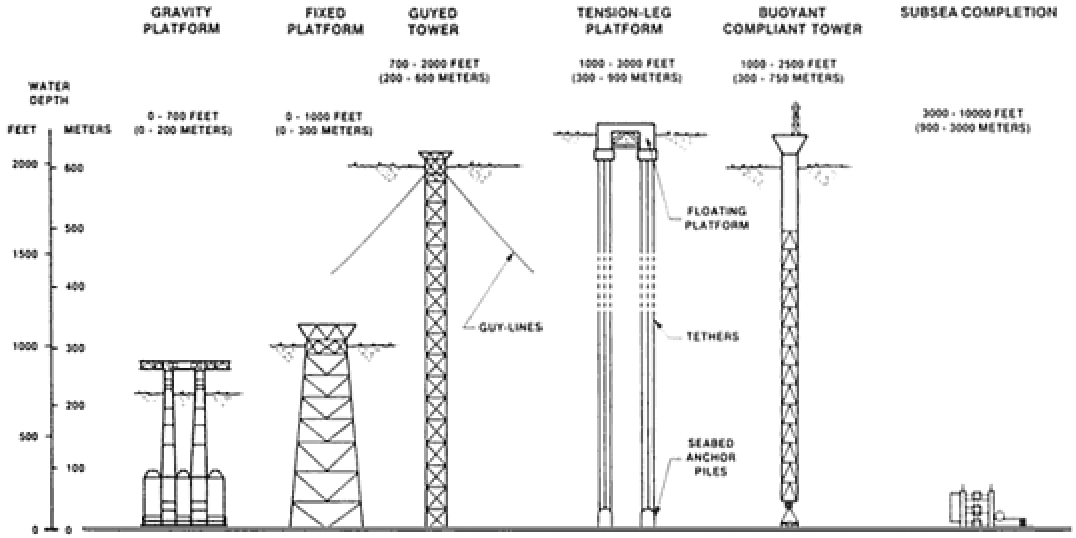


Figure 3-2
Range of water depths for various types of production platforms.

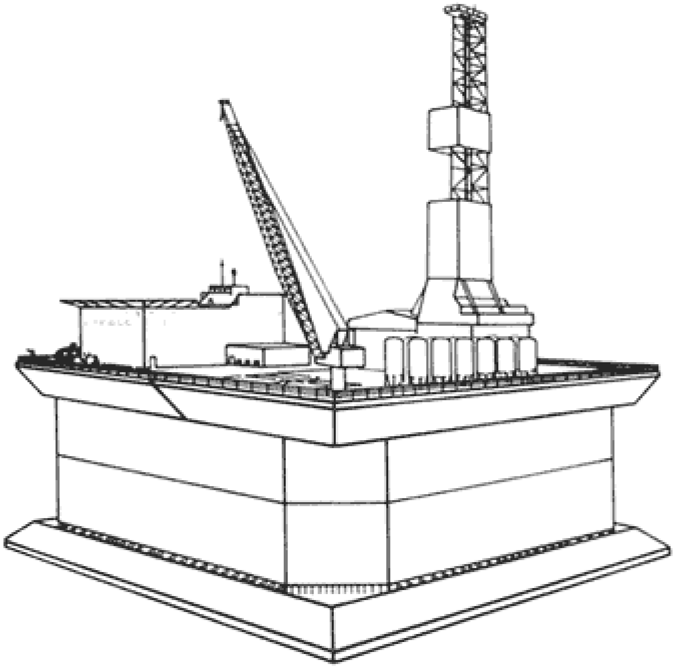


Figure 3-3
Mobile steel arctic caisson production platform.

Scope of Development

Future offshore oil and gas activities will include development of presently unleased areas of the outer continental shelf (OCS) where mature technology offers assurance of operationally safe, environmentally sound, and economically secure development (NRC, 1979 and 1977). Although oil and gas reserves in frontier areas of the EEZ cannot be forecast with absolute certainty, since 1975 the number and extent of exploration and recovery activities in water depths greater than 300 m has increased dramatically. For example, the number of deepwater wells drilled in the Gulf of Mexico increased fourfold since 1975 (Figure 3–4), and in 1988 Shell Oil set a new world depth record when it spudded a well in 2,273 m of water in the Mississippi Canyon area.

Most of the production of oil and gas has occurred to date in the shallow water of the Gulf of Mexico and offshore California. Some studies (OTA, 1985) suggest that most of the undiscovered oil and gas in the United States will exist offshore Alaska and California and in the deep water of the Gulf of Mexico. Trends suggest that actual production (including subsea completions) in water depths up to 2,000 m is likely by the end of this century. As EEZ oil and gas development expands farther in these deeper waters, construction and operating costs will increase due to the logistical requirements of operating farther from land. As a result, production configurations are likely to change to more wells per platform, more processing facilities, and fewer but larger platforms. As the capital investment and population per platform increases, the knowledge requirements for platform design and the operational environment will become even more exacting. To ensure that sound engineering design principles and practices are followed, industry groups, such as the American Petroleum Institute, will need to update their guidelines of recommended practices (API, 1987).

Uncertainties are inherent in predicting overall potential value to the nation of EEZ oil and gas resources. Uncertainty exists concerning the possible size, quality, and production costs of reservoirs that may exist, especially in the Arctic and deepwater areas of the continental slope. Ongoing development of an expanded and improved capability for resource forecasting in the entire EEZ is extremely important (USGS, 1986). The ramifications of this issue will require joint government and industry consideration of policies influencing developmental planning and economic strategy.

In addition to the size and quality of oil and gas reserves that may be located in deepwater and arctic environments, economic factors and technical constraints will affect future development of EEZ reserves. Among the important economic factors are world oil prices, availability of oil from dependable sources, and production costs. The primary technical constraints facing designers will be depth limits of current platform and pipeline technology; lack of knowledge about new seafloor sediment types; and lack of understanding of geological, biological, and oceanographic processes that control seafloor conditions that impact platform and pipeline design and operation.

Development Constraints

Many technical and economic constraints face the offshore oil and gas industry as it moves farther onto the continental slope and into unexplored arctic regions. The environmental hazards of operating in deep and ice-infested waters are considerably greater, and overcoming them will be far

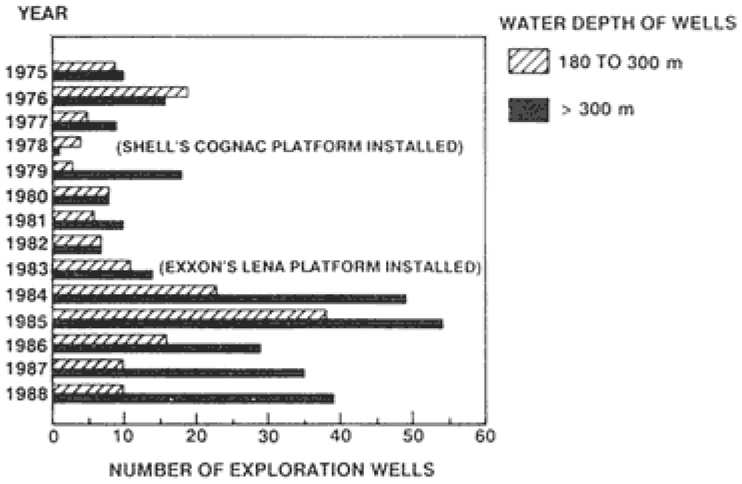


Figure 3–4
Number of deepwater exploration wells in the Gulf of Mexico in water deeper than 180 m.

more costly than previously experienced and will require innovative approaches to the design of drilling operations and structures (Wickizer, 1988). Despite these challenges, development of EEZ oil and gas resources is proceeding and can be enhanced by long-term planning and regulatory requirements that reflect sound understanding of the seabed environment. The sections that follow describe the information needed to improve the state of knowledge of this environment that will lead to such understanding.

Seafloor Gradients

Site-specific studies already completed for the oil and gas industry on the continental slope indicate that seafloor bathymetry, slopes, and local relief are considerably more complex than on the shelf. The severity and diversity of bottom relief may be important factors in development decisions, because areas with steep bottom slopes and rugged terrain may be too difficult to operate in and therefore uneconomical to develop. By comparison, bottom conditions on the shelf have never proven severe enough to be intractable to engineering solutions to detect and avoid problems.

A related problem is that existing bathymetric maps for EEZ continental slopes are not accurate enough to develop site-specific oil production systems. Considerably more detailed information on water depths and gradients is needed for potential development sites. It should be noted that multibeam swath bathymetry does not address the accuracy levels necessary for site-specific development. Sea Beam, for example, covers a swath of 0.8 times the water depth with a resolution of 5 percent of water depth. In 4,000 m of water, a swath width of more than 3 km results in a spatial resolution of about 200 m (Tyce and Pryor, 1988).

Seafloor Geologic Processes

Seafloor or near-seafloor processes—such as landslides, turbidity currents, erosion/scouring, faulting, creep diapirism, gas seeps, and sediment collapse—can impose considerable constraints on the development of engineered structures, depending on their magnitude and frequency. Many of these processes are present and active on the continental slope: for example, active faults, diapiric uplift, recent landslides, and subsidence all occur on the Gulf of Mexico slope (see Figure 2–4) (Campbell et al., 1986). Arctic frontier regions pose many different geologic hazards to development, including ice scour, freezing and thawing cycles of ice-bonded sediments, and gas hydrate stability (NRC, 1986).

An important constraint to EEZ development in deepwater and polar regions is the lack of knowledge and understanding of distribution and intensities of these processes. Moreover, they cannot be predicted from available regional geologic information. For example, a submarine landslide large enough to damage production facilities may be too small to show up in regional geologic data. Furthermore, even if a landslide is discerned, the data may not be sufficient to pinpoint its origin, so it wouldn't be useful in predicting future events. Thus, it is essential that regional data be interpreted in a way that provides a useful context for planning subsequent detailed, site-specific geophysical surveys, which are always required to evaluate the area's potential for exploration and production. Because of the complexity of deepwater and arctic frontier regions and associated higher operation costs, it is especially prudent to evaluate potential production constraints *before* beginning exploratory drilling.

Knowledge

If data from site-specific geophysical studies are combined with geotechnical information, it is possible to quantitatively predict the possible effects of seabed processes on seafloor installations over their lifetimes (Figure 3–5). However, such an integrated approach goes beyond routine geological surveying and measurement of geotechnical properties (Campbell et al., 1988).

Engineering Properties of Sediments

Knowledge of sediment properties, such as static and dynamic stress and strain behavior or compressibility and consolidation characteristics, is fundamental when evaluating geologic processes and designing piles, conductors, well heads, templates, anchors, and pipelines. A variety of techniques are used for offshore site investigations, such as laboratory testing of recovered samples combined with in situ measurements, which are now successfully used to depths of up to 1,000 m (McClelland and Ehlers, 1986). (More detailed discussion of engineering properties and problems of acquiring reliable data are presented in Chapters 2 and 4.)

Several important geotechnical problems arise when developing oil and gas production facilities for deep water and the Arctic. First, unique or exotic sediment types with fundamentally different properties and physical behavior are being encountered on the continental slope. For example, gas hydrates have been found in surface sediments in water as shallow as 450 m in the Gulf of Mexico and even in shallower water in the Arctic (Brooks et al., 1986). They are interspersed within the sediment matrix as small, contained ice pockets, or may have the form of large, conical shaped, ice-infested mounds that extend laterally hundreds of meters. The hydrates may pose design problems for foundations if they are heated by adjacent production well conductors and thereby become mobilized (Hooper and Young, 1989). Similarly, landslides and seafloor eruptions may be related to

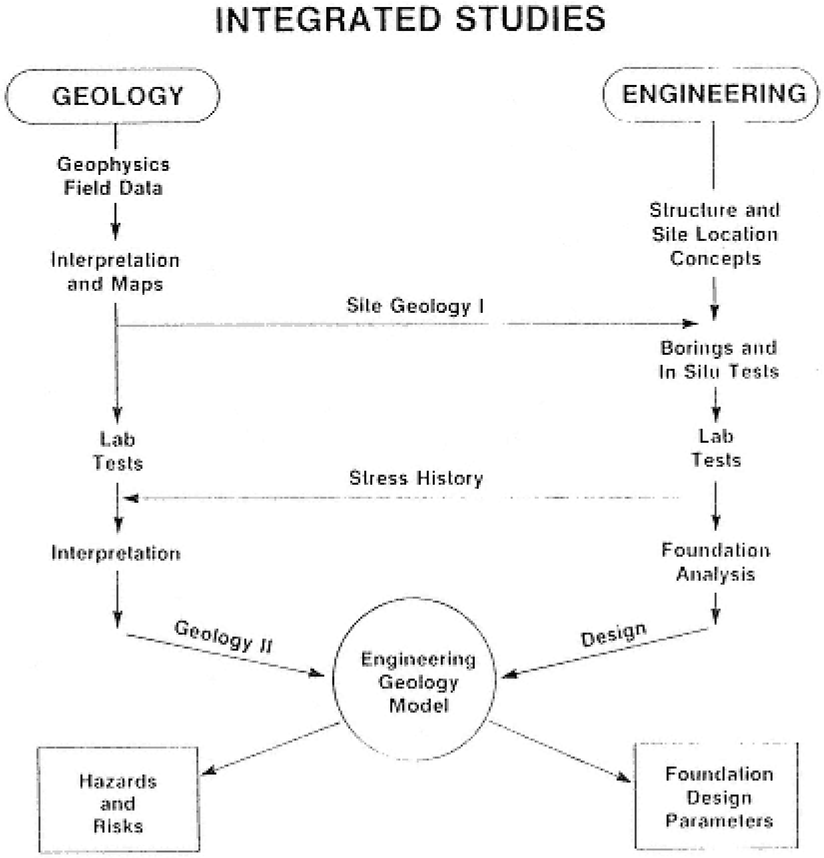


Figure 3–5
Interactive evaluation process for integrating geological and geotechnical information.
Source: Campbell et al., 1988.

expansion, contraction, or degeneration of hydrate materials (McIver, 1982; Prior et al., 1989). EEZ development will therefore require determining occurrence, stability, and likely future behavior of gas hydrates. Additional information, such as seafloor temperatures, will be required as a basic input for analysis of heat transfer from wells or pipelines in areas where gas hydrates occur.

In addition to gas hydrates, sediments are encountered in deepwater areas that exhibit the relatively high sensitivities (i.e., significantly reduced strength when disturbed) normally associated with bioturbation and high organic content. Such physical behavior can constrain foundation design because of the potential for slope failure, or loss of shear strength affecting foundation installations (Hooper and Dunlap, 1989). Improving knowledge about this type of sediment and determining related engineering constraints are important problems to resolve.

Gases in deepwater sediments are a greater concern than shelf sediment gases because the hydrostatic pressure is greater and there is a greater likelihood that gas expansion due to heating from oil and gas production will affect foundation sediments. All the various gas phases—dissolved, vapor, or solid—are detrimental and can adversely influence foundation conditions (Esrig and Kirby, 1977; Whelan et al., 1977).

A separate yet related set of geotechnical problems is the lack of technology available for sampling and testing deepwater areas (discussed in detail in Chapter 4). Cost-effective systems for geotechnical sampling and testing are presently not available for deployment from remotely operated vehicles (ROVs) or tethered-type seafloor platforms (Young et al., 1988).

Production Siting and Facilities

Considerable progress has been made in using geological and geotechnical data to conduct integrated risk analysis for the design of platforms and pipelines on the continental shelf. For example, in the Mississippi delta mudslide area, wave and sea bottom interaction models have been used successfully to determine foundation loading due to mudflows (Kraft and Ploessel, 1986). Deepwater areas of the EEZ will require correspondingly appropriate geological and geotechnical models for these and other complex processes. For example, diapiric or gas-induced slope failures are understood only qualitatively, and sediment and foundation interactions under earthquake loading—including stress propagation and modification of sediment properties—are poorly understood. Quantitative data for a wide range of deepwater sites that can be used to formulate analytical models and calibrate them to specific design conditions will be required for development of these areas to proceed (American Society of Civil Engineers, 1983).

There is considerable debate over the advantages and disadvantages of various deepwater structural systems, such as compliant towers, tension leg platforms, or subsea production systems (Figure 3–2). Design and emplacement of these new types of structures require site-specific geotechnical data and engineering and verification criteria that are presently based on single prototype designs. Hence, new innovative structures will require environmental data obtained by monitoring full-scale installations to assess the performance of foundation elements, including piles, mats, and anchors.

Seabed pipelines that transport oil and gas from offshore production platforms to refining or storage facilities are an important component of offshore development. At the end of 1985, there were 12,500 km of pipeline in the U.S. EEZ (NRC, 1985). Oil spills resulting from ruptures of these pipelines are a major concern because they can cause extensive local environmental damage. But, historically, pipeline ruptures have released far less petroleum into the marine environment than other transport systems, such as coastal tankers and barges (NRC, 1985). Any natural phenomenon that presents a potential hazard to a pipeline must be considered, however, and protective measures taken. Burial in the ocean bottom is the most effective way to protect them, but in some areas, such as potential sites of large mass wasting, the only solution may be to keep pipelines out of the region altogether. Deepwater and arctic areas pose new engineering challenges to pipeline routing, installation, monitoring, and repair similar to those associated with drilling and production. Problems that are unique to pipelines include design for an ice gouged seafloor, and leak detection and repair in ice-covered areas.

Summary

Over the last 40 years, offshore oil and gas technology has evolved that allowed the design and construction of facilities and equipment capable of extracting oil and gas from the continental shelf in a safe and pollution-free manner. If the industry is to move beyond its present capability to new areas of the EEZ, the difficulties of operating in more demanding and hostile environments must be solved. Developing equipment and platforms that can meet the challenge of these areas will be costlier, riskier, and more time consuming than previous offshore efforts, and will be affected not only by technical progress but also by nontechnical factors, such as fluctuating world oil prices, the impact of unstable political regimes in oil-producing countries, and a domestic regulatory climate subject to conflicting public pressures. Equally significant will be the extent to which government and industry cooperate to achieve a proper balance between meeting the nation's energy needs and environmental concerns and maintaining a competitive and technically innovative domestic oil and gas industry.

MINERAL EXPLORATION AND DEVELOPMENT

Background

During the late 1960s to mid 1970s, interest in seabed minerals was stimulated by exploration of extensive deposits of manganese nodules on the deep Pacific seabed. Amid this enthusiasm, recovery and processing prototype systems were developed and claims were staked in the deep ocean. This success also resulted in exploration for other potentially valuable marine mineral deposits in shallow water. By the late 1970s, however, falling minerals prices, combined with U.S. disagreement with Law of the Sea provisions over ocean mineral rights, caused the fledgling marine mining industry to shelve deep ocean mining exploration and systems development at a point where proof of concept and site reconnaissance were accomplished. In 1983, interest in offshore minerals was again stimulated by the EEZ proclamation, combined with the Reagan administration's expressed concern over dependence on foreign sources for strategic minerals. The impact of the EEZ proclamation was to reaffirm and clarify the jurisdiction of the Outer Continental Shelf Lands Act (OCSLA) of 1953, which established regulations for developing mineral resources on the outer continental shelf, and expand it to include U.S. territories as well.

EEZ marine minerals are conventionally classified into five groups—aggregate materials, placers, phosphorites, metalliferous oxides, and metalliferous sulfides. Occurrences of sulfur and miscellaneous mineral lodes, such as lead and zinc, are known to exist in the EEZ and comprise a sixth category in this report. These marine minerals are widely varied both with regard to type and location. Occurrences of marine minerals are widespread throughout the EEZ, with aggregates and placers off both coasts of the United States in mostly shallow waters. Sulfur, also a shallow-water mineral, is found in the Gulf of Mexico. Further offshore and in generally deeper waters off the southeast coast, phosphorites and manganese nodules have been discovered. In the deeper oceans, manganese crustal deposits are located on the slopes of Pacific seamounts and islands, and polymetallic sulfides are located at Pacific Ocean thermal vents or spreading centers. Principal characteristics and geographic locations of known EEZ mineral deposits discussed below are summarized in Table 3-1; additional information regarding extent, content, and location is given in DOI (1987), OTA (1987), and Broadus (1987).

1. *Aggregates*, siliceous sand and gravel and carbonate sands widely used for construction, beach replenishment, and concrete and ceramics manufacture, are widespread on the U.S.

TABLE 3-1 Principal Characteristics of U.S. Mineral Deposits in the U.S. EEZ

Deposit type	Geographic location	Water depth (typical)	Physiographic environment	Type and nature of deposit	Estimated quantities in place	Principal minerals/ elements
Aggregate materials (sand, gravel & shells)	Atlantic, Pacific, Alaskan, Puerto Rican, & Virgin Is. shelves	0-100 m	Surface and subsurface of shelf	Unconsolidated sediments (2- & 3-dimensional)[a]	Billions of m^3	Quartz carbonates
Placers	Atlantic, Pacific, Alaskan, Puerto Rican, & Hawaiian shelves	0-200 m	Surface and subsurface of shelf	Unconsolidated sediments (2- & 3-dimensional)[a]	Unknown but presumed large	Gold, Platinum, Titanium GRP, Chromite, Zircon, rare earths, Yttrium, abrasives
Phosphorites	Atlantic & California continental shelf	0-600 m (shelf & plateaus) Variable on seamounts	Surface and subsurface of shelf Tops of seamounts	Unconsolidated to indurated sediments (2- & 3-dimensional)[a]	Millions of m^3	Phosphate (some Mg & other metals)
Ferromanganese crusts (Cobalt rich)	Central Pacific Ocean, Hawaii & other U.S. islands	600-2,500 m	Flanks of islands and seamounts. Slopes 5°-20° Moderate to rough topography	Thin crusts (2-10 cm) on top of hard substrate (2-dimensional)[a]	Areas 10-100 km^2 Abundance 50-100 kg/m^2	Manganese Nickel Cobalt Platinum
Ferromanganese nodules	Atlantic shelf & Blake Plateau (also Pacific Ocean basins near islands)	600-900 m	Surface deposits in abyssal (or deep) ocean basins (occasionally on plateaus)	Nodules and pavement (2-dimensional)[a]	Areas 10-100 km^2 Abundance 10s of kg/m^2	Manganese Copper Nickel Cobalt
Polymetallic sulfides	Deep ocean (Oregon & California)	2,500-3,000 m	Spreading center ridges and crests	Massive: mounds & chimneys. Stratiform: bedded among sediment layers. (3-dimensional)	Areas–meters to kilometers Vertical extent unknown	Zinc, Iron Copper Cadmium Silver Gold
Sulfur	Gulf of Mexico	20-200 m	In caprock of salt domes	Embedded in subsurface formations	Probably present in most salt diapirs	Sulfur Salt
Miscellaneous mineral lodes	New England, Alaska	10-200 m	Surface and subsurface of shelf	Sediment bed formations & embedded in substrate	Areas–meters to kilometers Vertical extent unknown	Barite Lead Zinc Silver

[a] 2-dimensional – less than 100 cm in thickness

continental margins. Mining of these deposits, while dependent on local transport economics and market conditions, is presently done in shallow, nearshore waters and provides an alternative to onshore reserves (Katz, 1987).

2. *Placers*, heavy sands aggregated by oceanic hydraulic sorting, are the subject of accelerated mapping and exploration because they contain strategic and precious minerals and industrially useful refractory materials and abrasives, and because they are readily recoverable using available technology. Of special interest are the titanium group minerals on the Atlantic and Pacific shelves, chromite sands off Oregon, and gold and platinum on the Bering shelf. Gold placers have been mined nearshore and on beaches in Alaska, Oregon, and California since the early 1900s, and potentially valuable deposits exist farther offshore.
3. *Phosphorites* have been mapped from North Carolina to Florida out to the Blake Plateau. They contain trace quantities of platinum, uranium/thorium, and cadmium. Onshore phosphate deposits and low-cost overseas resources are adequate to meet near-term needs, but projected closings of Florida phosphate mines (due to soaring land values and environmental concerns) may eventually make EEZ phosphate mining economically viable.
4. *Metalliferous oxides* (ferromanganese deposits) consist of manganese nodules and crusts that contain strategic and industrially valuable metals, including copper, cobalt, nickel, manganese, and platinum group metals. The nodules occur mostly in the deep ocean outside the EEZ and to a lesser extent on the Blake Plateau. Manganese crust deposits are more abundant in the EEZ and are found on the flanks of Pacific seamounts and islands.
5. *Metalliferous sulfides* (also referred to as polymetallic sulfides) deposits contain zinc, copper, lead, gold, silver, trace amounts of barium and other metals, and large quantities of iron, which adds little to the deposits' economic value. Polymetallic sulfides are found along active spreading centers, such as the Gorda Ridge off Oregon.
6. *Sulfur and miscellaneous minerals* are found in shallow territorial waters along the continental shelf. Sulfur deposits are mined from nearshore caprock salt domes in the Gulf of Mexico, and a 1988 lease sale in the Gulf presages extension of sulfur mining into federal waters. In addition, barite was mined for ten years off southeast Alaska, and a lead-zinc-silver lode in the Gulf of Maine was mined in the early 1970s. Both operations successfully used conventional shallow-water dredging barges. Other shallow-water lodes with a greater diversity of metals are likely to be present in EEZ waters off Alaska and New England, and may eventually become commercially viable resources.

Commercial offshore mining is not a new phenomenon. It has been conducted since the mid 1800s, but these operations have been nearshore and in relatively shallow waters. The standard marine mining system has been the dredge, which has proven adequate for unconsolidated or weakly consolidated ore bodies in water depths to 60 m and in relatively calm seas. Major advances in methods and mining systems will be required to recover much of the EEZ deepwater deposits previously described. The present state of commercial recovery technology and needed advancements are described in OTA (1987) and Cruickshank (1987).

Scope of Development

Minerals markets are volatile, yielding to worldwide demand and socio-political forces. The U.S. minerals industry, squeezed by low international commodities prices and high domestic production costs, experienced a major recession from 1977 to 1987. Low demand and depressed prices continue to plague the industry, contributing to a worsening trade imbalance, poor international competitive position, and declining U.S. minerals production and industry employment (DOI, 1987). Except for isolated exploitation of shallow-water minerals, nearshore sand and gravel, and placers, this economic climate discourages offshore exploration or mining activities.

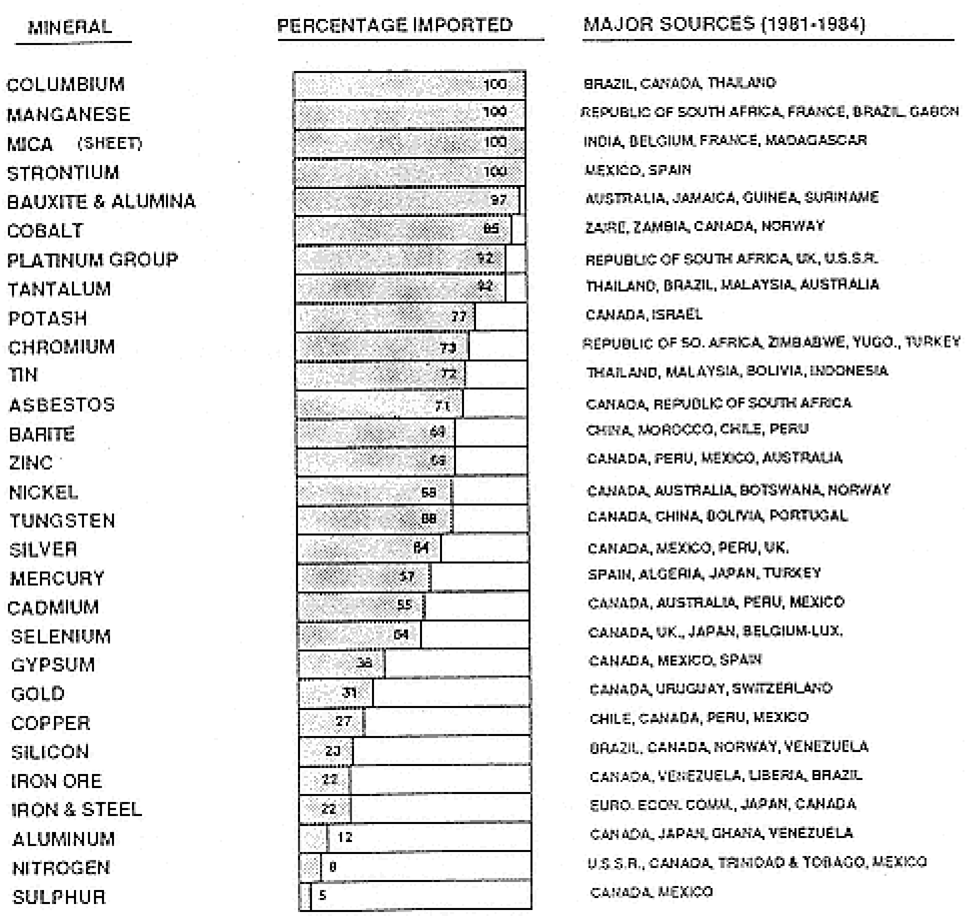
Although it is presently cheaper to import most hard minerals from abroad, U.S. market conditions are subject to fluctuations caused by such factors as unstable political regimes in Third

World countries, changing trade policies among U.S. economic allies, or increased labor and production costs in producing countries. The United States is nearing total dependence on foreign sources for some metals essential to national defense and industrial needs—e.g., cobalt, chromium, manganese, and the platinum group metals (Table 3-2). The need for secure supplies of these minerals, along with decreasing availability of economically mineable onshore deposits, provides an impetus to identify and quantify domestic mineral resources within the EEZ. This will require improved seabed mapping and exploration technologies, better quantification of extent of deposits, and continued advancements in offshore mineral recovery capabilities.

An assessment of EEZ mineral deposits that have potential for eventual economic recovery was made by a selected group of experts from government, academia, and industry at a workshop of this committee. Time frames estimated in Table 3-3 represent the group's collective opinion on probable time frames when normally evolving economic conditions may warrant initial commercial recovery. Each deposit was also evaluated for potential for accelerated development in the event that external influences create an improved economic climate or urgent national need.

One factor in predicting long-term development time frames for EEZ mining is that the U.S. marine mining industry is not competitive with nations such as Japan, France, the United Kingdom, and West Germany. The United States lags behind these countries in the ability to mine and market presently recoverable marine reserves and resources because of their lower labor rates, fewer regulatory and environmental constraints, and access to government assistance (e.g., joint industry-government development and exploration programs) (DOI, 1987). In fact, the lack of

Table 3-2



MINERAL	PERCENTAGE IMPORTED	MAJOR SOURCES (1981-1984)
COLUMBIUM	100	BRAZIL, CANADA, THAILAND
MANGANESE	100	REPUBLIC OF SOUTH AFRICA, FRANCE, BRAZIL, GABON
MICA (SHEET)	100	INDIA, BELGIUM, FRANCE, MADAGASCAR
STRONTIUM	100	MEXICO, SPAIN
BAUXITE & ALUMINA	97	AUSTRALIA, JAMAICA, GUINEA, SURINAME
COBALT	95	ZAIRE, ZAMBIA, CANADA, NORWAY
PLATINUM GROUP	92	REPUBLIC OF SOUTH AFRICA, UK, U.S.S.R.
TANTALUM	92	THAILAND, BRAZIL, MALAYSIA, AUSTRALIA
POTASH	77	CANADA, ISRAEL
CHROMIUM	73	REPUBLIC OF SO. AFRICA, ZIMBABWE, YUGO., TURKEY
TIN	72	THAILAND, MALAYSIA, BOLIVIA, INDONESIA
ASBESTOS	71	CANADA, REPUBLIC OF SOUTH AFRICA
BARITE	69	CHINA, MOROCCO, CHILE, PERU
ZINC	69	CANADA, PERU, MEXICO, AUSTRALIA
NICKEL	68	CANADA, AUSTRALIA, BOTSWANA, NORWAY
TUNGSTEN	68	CANADA, CHINA, BOLIVIA, PORTUGAL
SILVER	64	CANADA, MEXICO, PERU, UK.
MERCURY	57	SPAIN, ALGERIA, JAPAN, TURKEY
CADMIUM	55	CANADA, AUSTRALIA, PERU, MEXICO
SELENIUM	54	CANADA, UK., JAPAN, BELGIUM-LUX.
GYPSUM	38	CANADA, MEXICO, SPAIN
GOLD	31	CANADA, URUGUAY, SWITZERLAND
COPPER	27	CHILE, CANADA, PERU, MEXICO
SILICON	23	BRAZIL, CANADA, NORWAY, VENEZUELA
IRON ORE	22	CANADA, VENEZUELA, LIBERIA, BRAZIL
IRON & STEEL	22	EURO. ECON. COMM., JAPAN, CANADA
ALUMINUM	12	CANADA, JAPAN, GHANA, VENEZUELA
NITROGEN	8	U.S.S.R., CANADA, TRINIDAD & TOBAGO, MEXICO
SULPHUR	5	CANADA, MEXICO

U.S. Net Import Reliance On Selected Nonenergy Mineralsz competitiveness in the international minerals market plagues the U.S. mining industry in general, and will continue to hinder EEZ development and may extend the EEZ development time frames predicted in Table 3-3. If there is a perceived national need within the 10to 15-year time frame for critical minerals available from the seabed, it may be necessary for the federal government to intercede and assist the mining industry (e.g., protection measures and cooperative research and development programs).

Development Constraints

Information and technology needs for various phases of marine mineral development are summarized in Table 3-4, and the key constraints related to the needs listed in the table are briefly discussed in the sections that follow.

Resource Estimation

Regional research and mapping provide the foundation for investigating potential mineral deposits and gathering data to formulate geological models of deposit genesis, a key step toward prospecting and exploration. Appropriate models minimize random searching for minerals, and geostatistical techniques building on those models can be useful in estimating tonnage and grade. Continued and accelerated development of these techniques and tools is important to developing deepwater EEZ deposits. Estimating techniques are needed for various offshore deposit types and geologic settings to estimate grade and tonnage of recoverable but unproven deposits. Geological models for ore genesis also need to be developed for various EEZ ore bodies since present knowledge of how mineral deposits form is derived largely from the study of onshore deposits.

TABLE 3-3 Predicted Time Frames For Economic Recovery

Deposit type	Earliest market-favorable development	Potential for acceleration	
Sand and gravel	1-3 years	Medium/high	Primarily near large urban areas
Placers	2-5 years	Medium	For strategic and precious minerals
Phosphorites	5-15 years	Low	
Manganese nodules	10-15 years	Low	Resource assessments and technologies are in place.
Manganese crusts	15-30 years	Low	
Polymetallic sulfides	Undefined	Low	
Sulfur	1-2 years[a]	Low	
Miscellaneous lode deposits	2-5 years	Low	In isolated cases where favorable economics occur

[a] Sulfur lease sales planned for 1989 demonstrate a near-term market for this commodity.

TABLE 3-4 Information and Technology Needs for EEZ Mineral Development

Mineral deposit types	Reconnaissance phase	Research/survey phase	Prospecting phase	Development phase
Construction materials (sand and gravel)	Single channel seismics; vibracoring; chemical analysis of samples.	Sediment texture maps; shallow stratigraphy; organic content determination; bathymetric maps; geotechnical measurements on cores.	Wave/current monitoring; bathymetric maps; GPS positioning; ecosystem studies; overburden/deposit delineation; sediment physical properties.	Wave climate; weather forecasts; bathymetric maps; GPS positioning; bottom fauna monitoring.
Placers	Seabed morphology (sonar); sediment textures (coring); shallow stratigraphy (high resolution seismics); chemical analysis of samples.	Pleistocene sea-level curve; concentration models; deep coring capability; bathymetric maps; IP-method development; gravity/magnetics.	Improved coring/sampling; geotechnical surveys; shipboard separation/mineral analyses; resource appraisal models; wave/wind climate info; GPS positioning; bathymetric maps; grade & tonnage determinations; dense seismic grid; overburden determination.	Subsurface excavation; on-site heavy mineral separation; weather forecasts; current monitoring capability; tailings monitoring capability; GPS positioning; bathymetric maps.
Phosphorites	Testing models of occurrence; mass balance/geochemical models; shallow straitigraphy; sediment/mineral analyses.	Age determination; organic material studies; diagenetic studies; geochemical analyses; seismic response of phosphorites; bathymetric maps/microtopography; pavement thickness measurements; physical properties.	Rotary drill/large grabs; detailed seismic surveys; geochemical analyses; ROV acoustics; chemical/radioactive detection (gamma ray); geostatistical/ resource evaluation; geotechnical tests on indurated deposits; bathymetric maps; ecosystem studies; grade/tonnage determinations.	New mining methods (e.g., thermic lances, directional explosives); weather forecasts; current monitoring; suspended sediment monitoring; GPS positioning; economic evaluations; beneficiation of auxilliary minerals; waste isolation; bathymetric maps.
Manganese nodules and crusts	Sonar surveys; photographic and video; sampling; chemical/ composition tests; bathymetry/ geomorphology.	Crust/seawater interactions; paleoceanography of older crusts; sampling advanced techniques; geochem/evolution models; crust thickness measurements; nodule variability and abundance statistics; bathymetric maps; crust phosphorite studies.	Variability/grade determinations; metallurgy/beneficiation; acoustic imaging techniques; statistical evaluations; mining concept development; geomechanical properties of crusts and substrate; bathymetry; resource assessment methodology.	Weather forecasts; wave/ current statistics; GPS positioning; ecosystem monitoring; detailed bathymetry; mine site descriptions.
Metalliferous sulfides	Seismic reflection surveys; multibeam bathymetry; sonar surveys; deep-towed cameras; submersible diving; gravity/ magnetics; chemical analysis of samples.	Comparative studies with ophiolites; aqueous geochemistry; tectonic framework studies; sampling hydrothermal effluents; EM, MT-method development; ODP-drilling into ridge crests; OBS-microseismic monitoring; He-halo detection; physical chemistry of alteration; heat-loss determination at vents; large-sample recovery; downhole measurements (thermal gradient/ fluid chemistry).	Swath bathymetry; rock drilling capability; electrical detection methods; logging drill holes; rock/soil mechanics data; high-resolution seismic profiling systems; microtopography info; in situ metallurgy; environmental data.	Fragmentation techniques; continuous "ore" recovery systems; in situ leaching methods; observation and work vehicles.
Sulphur	Seismic reflection surveys; chemical analysis of samples.	Drilling sample recovery	Drilling logging; sampling; resource assessment; overburden/deposit delineation; indirect means of differ-entiating between shale & salt diapirs.	Economic evaluation; shallow hazards; ecosystem monitoring; mine site description.

NOTE:
GPS = global positioning system
EM = electromagnetic
ODP = Ocean Drilling Program
OBS = ocean bottom seismometers
He = Helium
MT = magneto telluric
IP = induced polarization

Reconnaissance and Exploration

Locating and characterizing ore bodies are fundamental to developing mining strategy. Geological ore genesis models and large-area reconnaissance mapping are helpful in defining the regional context of potential ore deposits and guide exploration efforts, but this must be followed by site-specific mapping and in situ sampling to evaluate and verify the deposit's economic value. Site-specific mapping is done with towed high-resolution sensors, including side-looking sonar and bottom and subbottom. profilers. Improved multisensor, high-resolution survey systems are required to advance the efficiency and accuracy of such ore assessments, especially in deep water. The use of remotely operated vehicles (ROVs) and antonomously operated vehicles (AOVs), as sensor platforms will also improve the effectiveness of site-specific ore assessments (see Chapter 4).

Nonacoustic remote sensing technologies successfully used on land—such as induced polarization, bulk resistivity, electromagnetism, gravity, chemical, and temperature—would be useful underwater, but have not yet been adapted to this environment due to development costs and the limited market in the marine mining industry (Francis, 1987). Electromagnetic techniques, for example, are useful in defining land locations and deposit thickness of heavy mineral placers (due to their magnetic content), but their offshore application is only in its infancy.

Optical techniques, including photographic and television imagery of the seafloor, are limited due to turbidity and low or nonexistent light levels in deep water. Improved optics, optical imaging techniques, and more sensitive films are needed. In addition, laser-induced fluorescence or mineral identification through optical spectrometry has not been explored due to technology development costs.

Present methods of shipboard resource assessment by drilling and coring are very costly. Development of riserless and seafloor drilling systems tethered to the ship by umbilicals could provide more economic systems to support deepwater EEZ ore body assessment (OTA, 1987).

Recovery Technology

A new class of deepwater mining systems will be required to recover deepwater EEZ minerals in commercial quantities. Extraction of EEZ seabed minerals will require advanced mining technologies and systems, especially platforms capable of prolonged operations in virtually all weather conditions equipped with motion-compensated handling and possible onboard beneficiation systems. Future mining systems also will need to be capable of reemplacement offloading of tailings and spoils. These requirements may be met by using large, stable, semisubmersible platforms similar to those developed for the offshore oil industry (OTA, 1987).

It may not be desirable to process all minerals at an offshore mining site, but some beneficiation may be necessary to reduce transportation costs and onshore disposal problems. In the case of precious metals (gold, silver, and platinum) and diamonds, complete onboard processing is proven, practical, and cost effective (OTA, 1987). Deepwater technologies for fracturing and ripping consolidated deposits will be required along with pneumatic and hydraulic lift systems to transport minerals to the surface. In some cases, preprocessing of bulk materials at the seabed will be needed to concentrate minerals before they are lifted to the surface. Numerous other specific engineering and technology problems will have to be solved by the mining industry to achieve commercial EEZ mining. It is generally conceded that a minimum lead time of 5 to 15 years is necessary to develop fully operational systems.

Even though impressive advances were made in developing prototype mining equipment during the 1960s and 1970s to recover deep ocean manganese nodules, present market conditions, the limited financial strength of the U.S. offshore mining industry and its poor competitive position internationally suggest that it will be many years before the U.S. marine mining industry will start to develop advanced commercial mining systems. A concern is that mining of the U.S. EEZ may be done by foreign offshore industries that are more robust, aggressive, and able to undertake the necessary development costs and risks.

Environmental Impact Assessment

For most of the EEZ deposits considered in this report, the existing background information is inadequate to support suitable environmental impact assessments due to lack of marine mining experience and inadequate environmental data bases for the specific ore bodies of interest. Impact predictions for marine mining are further complicated by uncertain operating conditions and production levels estimated from poorly defined deposit sites. On the other hand, believable and accurate impact predictions are required during prospecting and leasing before commercial mining operations will be allowed to begin. This situation presents industry with a "catch 22" in which early economic assessments must account for unforeseen environmental costs, yet under present regulations must be included in their upfront bonus bidding strategies. For most EEZ mineral deposits, this presents industry with an unacceptably high development risk (see discussion on leasing policy and regulation below). Further discussion of environmental impact assessment and monitoring is presented in Chapter 4.

Leasing Policy and Regulation

The present U.S. marine hard minerals regulatory situation is at best controversial and at worst inadequate to encourage development of EEZ mineral resources and deposits. The federal policy, administered by the Department of the Interior (DOI) through the Minerals Management Service (MMS), is based on the OCSLA as amended in 1978. Authority for hard minerals mining is derived from Section 8(k), which addresses mineral resources in the OCS "except for oil, gas and sulfur." To fill the regulatory void and encourage development of OCS mineral resources, MMS has promulgated rules, based on the OCSLA, establishing a three-phased regulatory regime for marine minerals development—prospecting (MMS, 1987), leasing (MMS, 1988a), and operating (MMS, 1988b).

Although these proposed regulations have a clearly derived authority, many segments of industry and government argue that the OCSLA has serious shortcomings as a legislative basis for hard minerals regulations. From this view, the OCSLA does not treat the EEZ equally with the OCS in terms of its jurisdictional province, i.e., U.S. territories are not part of the OCS but are within the 200-mile EEZ. Of greater concern to the mining industry is that the OCSLA, while adequate and proven for oil and gas operations, does not allow sufficient flexibility for hard minerals leasing and mining. The main issues include the mandatory up-front bonus bidding system, lack of preference rights for companies conducting early prospecting and exploration, the need for a more equitable federal, state, and local revenue sharing and consultation process, and more flexible environmental provisions (U.S. Congress, 1989).

Recommended remedies to the existing regulatory situation range from no action (Pendley, 1989) to various OCSLA amendments (OTA, 1987) to new legislation (Curtis, 1989). This report takes no position other than to note that the issue has been recognized and recommendations have been made for some years without resolution (NRC, 1975), and the continued lack of a predictable regulatory framework impedes exploration and development of some EEZ resources that have near-term potential for development. In all fairness, the economic situation is a larger deterrent to progress than the lack of policy. However, industry activity in the EEZ will be negligible until the regulatory problems are resolved.

Alternative legislation was proposed but not passed in the 100th Congress (H.R. 1260). During the 101st Congress, a bill establishing a program for the exploration and commercial recovery of hard mineral resources from the U.S. seabed has been introduced in the U.S. House of

Representatives out of the Committee on Merchant Marine and Fisheries (H.R. 2424). The House Committee on Interior and Insular Affairs, Subcommittee on Mining and Natural Resources, may also consider legislation authorizing a self-initiated access system for the rights to explore and develop offshore hard minerals (Brad Laubach, MMS, personal communication). It is hoped that with the emergence of regulations and the ongoing Congressional oversight hearings, a comprehensive and predictable legislative and regulatory framework will emerge to support timely and effective development of EEZ minerals.

Use Conficts

EEZ mining will inevitably conflict with other potential seafloor uses, such as commmercial pipeline and cable routes, marine traffic lanes, military/defense activities, oil and gas activities, and fishing. Most conflicts can be anticipated and resolved by regulation and negotiation during the long lead times required for exploration, leasing, and development. However, conflicts with fishing and military interests have already caused some concern and may require particular attention by decision makers. If mineral development activity expands in the future, methods for arbitrating conflicts will be required. Discussion of use conflicts is presented in Chapter 6.

Summary

Although extensive hard mineral resources exist in the EEZ, their extent, value, and commercial recoverability is not well known or adequately quantified. Present offshore mining activity is limited to shallow-water resources, such as sand and gravel, heavy mineral placers, and sulfur. The time and investment required to develop a competitive, economically viable EEZ mining industry—especially for consolidated sediment or hard rock minerals—are beyond the present capability of a domestic industry weakened by ten years of a depressed worldwide minerals market and technologically outpaced by foreign competitors operating with the support of their governments. As a result, most companies involved in offshore mining operations and development have reduced their activities or closed, and experienced marine mining personnel have retired or left the industry (DOI, 1987).

The technologies and capital investment required to map and evaluate many EEZ minerals (especially in deep water) are beyond the industry's present capabilities. Thus, present reconnaissance and assessment efforts are primarily federally sponsored efforts. Basic engineering development of new recovery, at-sea beneficiation, and processing technologies presently rests with industry. The present slow pace of deepwater EEZ mineral exploration and development is unlikely to accelerate without improved market conditions and revisions in policy and programmatic incentives in federal leasing programs.

WASTE DISPOSAL

Background

The seafloor and coastal ocean waters surrounding the United States have been used for disposing of dredged material and municipal and industrial wastes for many years. Two arguments have been used for ocean waste disposal. One is that some areas of the marine environment have a lower value relative to alternative onshore sites. The other is that natural cycles in the marine environment can assimilate certain types of wastes without detrimental effects. In the first instance, the decision is to sacrifice a portion of the marine environment (for example, a specific dumpsite) for waste disposal based on the assumption that ocean disposal is more cost effective than other alternatives and that impacts will be confined to the disposal site. The second approach evaluates quantities and types of wastes for marine disposal based on their compatibility with marine biological and geochemical processes. Both approaches are the basis for past and present ocean waste disposal practices.

Disposal schemes tend to follow two strategies: dispersing waste in order to dilute it to concentrations low enough to be considered harmless, or depositing it within confined areas of the seabed or in containers to isolate it from the surrounding environment. Dispersed wastes—generally dumped directly from a vessel at sea—are transported by currents, ingested and excreted by organisms, and incorporated into particles that settle through the water column before eventually becoming incorporated into seabed sediments. Wastes discharged from pipelines tend to result in more localized accumulation of contaminants because the point of release is fixed and generally near the seabed.

This report considers the principal types of solid wastes disposed beyond coastal waters—dredged material, sewage sludge, and industrial wastes—and potential new sources of wastes that might be considered for ocean disposal in the future. The types of waste disposal that are not discussed are nonpoint and municipal point-source discharges into coastal and estuarine waters and plastics.

• *Dredged materials* are the single greatest source of solid wastes disposed of in U.S. waters. They range from sands and gravels to fine-grained silts and clays, some of which contain petroleum hydrocarbons, synthetic organic chemicals, toxic metals, and other hazardous substances. Figure 3-6 illustrates the locations of dredged materials disposal sites around the U.S. coastline. Disposal of

Figure 3–6
Location of waste dumpsites in U.S. coastal waters. Sources: I. W. Duedall, Florida Institute of Technology (unpublished).

dredged materials on the EEZ seafloor is likely to be broadly distributed around the U.S. coast, with the greatest need associated with major ports and harbors. Most dredge disposal sites are within three miles of the coast, but there are disposal sites in the EEZ, and the tendency to locate sites farther from land is increasing.

- *Sewage wastes* are introduced into the ocean in the vicinity of major coastal cities. Sewage sludge has been discharged from pipelines and dumped in the ocean off the mid-Atlantic states for years. Sludge is still being discharged from pipelines into the Southern California Bight and off Hawaii. New York City and municipalities in northern New Jersey and western Long Island dump sludge at the Deepwater Municipal Sludge Dumpsite (DMSD) 120 nautical miles southeast of New York City. Sludge is a major source of DDT and PCBs, and contaminants have become incorporated into the sediments near previously used disposal sites off New York and Delaware Bay (Lear and O'Malley, 1983; Sawyer and Bodammer, 1983; Stanford et al., 1981). Organic contaminants in New York Bight sediments attributed to sludge dumping are summarized in Table 3-5.

TABLE 3-5 Distribution and Sources of Organic Contaminants in New York Bight Sediments

A. Concentrations[a] ($\mu g/g^{-1}$) of four organic substances at four locations and in sewage sludge

Material	Dieldrin	Total DDT	Total PCBs	Total PAH
Sediment				
Christiaensen Basin	7	160	0.7	6,000
Dredged material dumpsite	N.S.	9	0.4	N.S.
Sewage sludge dumpsite	N.S.	120	2	1,100
Outer bight	N.D.	N.D.	0.0004	22
Sewage sludge	N.D.	1.094	9	20,400

B. Annual input (kg y^{-1}) of organic compounds from dredged material and sewage sludge

Source	DDT	PCB	PAH
Dredged material	65	3,500	176,000
Sewage sludge	106,231	600–2,000	4,100

[a] Concentrations are on a dry weight basis. N.D. = not detected; N.S. = not sampled/analyzed.

[b] The New York Bight is the region of the continental shelf off Long Island and New Jersey.

SOURCE: O'Connor et al., 1982

- *Industrial wastes* have been disposed of principally in the New York Bight, and have included primarily acid-iron wastes dumped at the Acid Waste Site in the New York Bight and the Deepwater Industrial Waste Site just west of the DMSD, and drilling muds from offshore oil platforms. Overall, marine dumping of industrial wastes has decreased dramatically since the early 1970s. Particulate loading from drilling muds varies widely, depending on the extent of activity over a geographic area (see Duedall et al. [1985] for studies of drilling mud discharges in marine waters).

From 1946 to 1970, containers of low-level radioactive waste (LLW) and other hazardous substances, including obsolete nerve gas and munitions were disposed of in the ocean. During that time, 107,000 containers comprising 4.3×10^{15} Bq (Bq = Becquerel: flux of radiation across a unit area per unit time) of radioactivity were disposed of at 24 sites, with four sites receiving 90 percent of the waste: two off the mid-Atlantic region, one in Massachusetts Bay, and one near the Farallon Islands off San Francisco. Future candidates for ocean disposal include incineration ash from burned municipal refuse, fly ash, scrubber sludge, and coal ash.

Scope of Development

The need to use the ocean for dumping could increase in the future as volumes of waste increase, as concerns for maintaining or improving the water quality of estuarine and coastal waters restrict dumping nearshore, and as land-based options become more expensive and restrictive. In addition to increased or continued dumping of those wastes already being disposed of in the open ocean, some new options for ocean waste disposal are being studied and will be discussed in this section as possible future strategies.

Finding suitable disposal sites for dredged material is becoming more difficult as land sites become more expensive and as estuarine disposal faces a more restrictive regulatory climate. Although only one-sixth of all dredged material is currently dumped beyond three miles, that volume is expected to increase in the future as ports and harbors increase maintenance dredging to accommodate deeper draft and larger vessels, and as U.S. Navy homeport projects generate dredged material (NRC, 1985). For contaminated material, this dumping will depend on improved methods for separating it from uncontaminated material and containing or isolating it. Over the long term, the volumes of contaminated material may be minimized as source reduction practices lessen the industrial and municipal waste input into coastal waters.

Land application and incineration of sewage sludge face increasing public opposition and limitations caused by contaminant levels. Further, while the open ocean is considered to be healthy and capable of assimilating some wastes, estuarine and coastal waters that have borne the primary burden of societal wastes have deteriorated. Arguments will be made to maintain an ocean dumping option for sewage sludge in the future. Future ocean dumping will depend on a variety of factors, such as whether the regulatory climate becomes more or less restrictive, economic tradeoffs between transportation costs over greater distances (to the DMSD) versus increased land-based costs, reduction of toxic pollutants in sludge that would make land disposal more attractive, and granting of waivers from secondary treatment requirements to coastal municipalities.

Several large coastal municipalities (Baltimore, Boston, Washington, D.C., Jacksonville, Philadelphia, San Diego, San Francisco, and Seattle) want to maintain dumping or pipeline discharges as a potential option; and Orange County, California has proposed discharging of sludge from a pipeline eight miles offshore into deep ocean waters on an experimental basis (OTA, 1987).

The solid waste byproducts of incineration of municipal solid wastes (incineration ash) and electric power plant combustion (fly ash and flue-gas desulfurization sludge) have been proposed as possible candidates for ocean disposal (Duedall et al., 1985). Combustion ash is not presently dumped in the marine environment, but anticipated increasing quantities will require disposal either on land or at sea in the next decade. Ashes from different combustion sources have different chemical compositions and disposal considerations, and the impact of such substances on marine organisms and the food web will require examination. Leaching experiments on municipal incinerator ash showed quantities of 14 elements leached from the ash (Francis, 1994). Although many of the leached chemicals are abundant in seawater and would not be toxic to marine organisms, highly toxic organic components, including dioxin and lead, have been found (Benefenati et al., 1986; Benestad et al., 1987).

Although statutory restrictions preclude near-term consideration of ocean disposal of certain hazardous wastes, such as radioactive material, future pressures on land-based repositories may give rise to incentives to explore the use of submarine geologic formations as permanent repositories for some low-volume, highly toxic, and radioactive wastes. One strategy that has already been investigated is engineered placement of containerized high-level radioactive waste (HLW) within soft ocean clay formations in the EEZ (Heath et al., 1983). Technical and nontechnical constraints for HLW disposal are likely to prevent such an option for many years, but some LLW disposal may prove less restrictive: for example, disposal of defueled, decommissioned submarine reactor vessels and soils containing naturally occurring radioactivity.

Development Constraints

Understanding Fates and Effects

There is considerable knowledge of physical processes in the marine environment, such as the dilution of wastes resulting from near-field dispersion and the general circulation associated with ocean currents. Also known are many of the chemical cycling processes that occur in the ocean. However, understanding of marine organisms, their life cycles, and population variability is only rudimentary. One main deficiency for developing sound EEZ waste disposal practices is real-time and time-series information about oceanic processes. Time-series data on the cycles and variability in the marine environment and the effects of anthropogenic perturbations are limited, because most technical investigations have been designed to answer specific questions. Yet, whenever it has been available, the accumulation of one or two decades of systematic data in the ocean or the atmosphere is extremely valuable. The following are information needs for managing waste disposal practices in the EEZ:

- Sedimentation rates and types of materials responsible for sediment accumulation on the seabed need to be gathered and mapped. For example, suspended sediments from rivers play a major role in some areas; in others, sedimentation is primarily biologically driven.
- Erosion mechanisms need to be determined.
- Biogeochemical behavior of specific organic hazardous wastes that may become incorporated has not been investigated.
- Diffusion and/or advection rates of wastes through the geological medium need to be modeled and validated.
- Better understanding of the life cycles and variability of marine organisms is needed.
- Understanding is needed of vertical transport and food web interactions from pelagic to benthic organisms.

Isolating Contaminated Materials

Identifying and isolating contaminated from uncontaminated material is a major constraint for ocean dumping of materials such as dredged sediments. One of the first issues to address is the extent and nature of contaminants present. Uncontaminated dredged material can be a resource rather than a waste for disposal. Placed on the seabed, this sediment may be colonized by different communities of organisms than normally occur at the dumpsite. This localized effect may be helpful or detrimental. If dredged material contains substances harmful to the marine ecosystem, the material must be isolated either on land, in coastal waters, or on the EEZ seabed.

During the past two decades, there has been an evolution in procedural and regulatory approaches to identifying contaminated dredged material (Kester et al., 1983). Table 3-6 summarizes four procedures used to establish the presence of contaminants, ranging from relatively simple chemical tests (the Jensen criteria and elutriate procedure) to complex bioassays required by the 1976 Ocean Dumping Criteria (EPA, 1976).

Bioassay procedures to evaluate sediment contamination (EPA and COE procedures are summarized in Peddicord and Hansen, 1983) generally result in a statistical statement of the effects of dredged material on organisms different from or similar to those produced by some reference sediment. The test outcome can depend on how it is performed; in some cases it may be difficult to find a valid reference sediment (Kamlet, 1983). There are problems associated with pooling and averaging bioassay results for performing statistical tests of the experimental data. The bioassays do not identify which contaminants are responsible for toxicity. If the toxicity is caused by a substance, such as cadmium or mercury, that is prohibited by the London Dumping Convention, other disposal methods would have to be used.

The state of Connecticut procedure (Table 3-6) attempts to establish degree of contamination and types of disposal procedures to be used. This approach has advantages over present federal procedures. If a procedure similar to the Connecticut system were to be developed on the federal level, it should extend the chemical criteria to include such substances as petroleum hydrocarbons, PCBs, pesticides, and organic carbon.

Methods for isolating contaminated dredged material include using containment structures on land or in coastal regions, and placing contaminated material in a mound on the seafloor and capping it with clean sediments (Morton, 1983). A mound capped with sand in Long Island Sound remained intact for six months, but after a hurricane the silt cap showed slumping, flattening, and removal of about 2 m of sediment. In some areas, previously excavated borrow pits or natural seafloor depressions are possible containment sites (Bokuniewicz, 1983). Many contaminants in harbor sediments are bound to reduced sediment phases that include sulfides and organic matter. If these sediments are moved to an oxidizing environment, the sulfide can oxidize to sulfuric acid and potentially toxic metals can be mobilized. These anoxic sediments should be contained below sea level using a method such as a pit capped with clean material (Kester et al., 1983). The possibility of seafloor erosion must be considered at such disposal sites.

Over the long term, environmental problems associated with contaminated dredged material can be minimized by source reduction practices. Recycling wastes, reduction of sediment transport and erosion into harbors, and reduction of industrial and municipal waste input into coastal regions will result in less contaminated dredged material being generated for disposal in future decades.

A major technical constraint to EEZ seabed disposal of dredged material includes needed improvements in methodology used to distinguish contaminated from clean sediments. Contaminated sediment could be handled according to one set of disposal procedures, and uncontaminated sediment can be used as a resource or disposed of separately and at lower cost than contaminated material. Isolation methods within the marine environment, such as mound capping, borrow pit capping, or engineered structures should be used for contaminated material. Improved understanding leading to prediction of erosional processes on the EEZ seabed is needed for long-term prediction of the suitability of such disposal sites.

A number of technical questions need to be addressed before subseabed disposal of contained wastes will be feasible. For example, packaging methods for reliable placement need to be devised (one proposed system uses a fleschette, an arrow type penetrator that is robust, heavy, streamlined, and cheap) and models need to be devised and verified that address rates of canister dissolution. Reliable penetration within the seabed will also require knowledge of the geological medium, especially hole closure, the dynamic response to penetration. Research about hole closure behind the penetrator needs to be done for a variety of penetration shapes and insertion speeds. The U.S. Department of Energy Subseabed Program has studied mid-plate, mid-gyre regions in the deep ocean basins (Heath et al., 1983); however, these are not representative of most U.S. EEZ regions.

TABLE 3-6 Characteristics Used to Clarify Contaminated Dredged Material

Procedure	Description	Year
Jensen criteria	A sediment is contaminated if one or more of its properties exceeds a permissible limit (see limits below).	1971
Elutriate test	A sediment is contaminated if resuspending one part of sediment into four test parts of water (both by volume), increases a pollutant concentration in the aqueous phase by more than 50 percent.	1973
Bioassay test	A sediment is contaminated if its liquid phase, resuspended particles, or solid test phases are lethal or result in pollutant bioaccumulation when tested with appropriate organisms.	1977
State of Connecticut designation	Class I: nondegrading to water quality and nontoxic to organisms. Class II: moderately polluted, but suitable for island or marsh habitat development and for open-ocean disposal. Class III: contaminated and potentially hazardous. If bioassays show these to be toxic they cannot be ocean dumped; they must be disposed on land or contained at onshore locations. (See classification criteria below)	1979

Jensen Criteria Limits

Parameter	Limit
Chemical oxygen demand	< 50 mg g^{-1}
Total Kjeldanl nitrogen	< 1 mg g^{-1}
Volatile solids	< 60 mg g^{-1}
Oil and grease	< 1.5 mg g^{-1}
Mercury	< 1 µg^{-1}
Lead	< 50 µg^{-1}
Zinc	< 50 µg^{-1}

State of Connecticut Classification

Parameter	Class I	Class II	Class III
Silt and clay (%)	< 60	60–90	> 90
Water content (%)	< 40	40–60	> 60
Volatile solids (%)	< 5	5–10	> 10
Oil and grease (%)	< 0.3	0.3–1.0	> 1.0
Mercury (µg/g^{-1})	< 0.5	0.5–2.5	> 1.5
Lead (µg/g^{-1})	< 100	100-200	>200
Zinc (µg/g^{-1})	< 200	200–400	> 400
Arsenic (µg/g^{-1})	< 10	10–20	> 20
Cadmium (µg/g^{-1})	< 5	5–10	> 10
Chromium (µg/g^{-1})	< 100	100–300	> 300
Copper (µg/g^{-1})	< 200	200–400	> 400
Nickel (µg/g^{-1})	< 50	50–100	> 100
Vanadium (µg/g^{-1})	< 75	75–125	> 125

SOURCE: Kester et al., 1983

If the United States is to consider using the EEZ seafloor for disposal of containerized wastes in the future, further follow-up studies at historic radioactive waste dumpsites would be highly informative. The waste drums presently on the seafloor can be viewed as "experiments in progress." Colombo et at. (1983) provided evidence of container and substrate degradation based on in situ rates. The decadal effects of episodic events at the seafloor—current scouring, sediment slumping, and sedimentation—can also be examined. Although the evidence to date is limited, it does not show statistically significant radioactive contamination of sediments from the waste drums.

Regulation

Waste disposal in the ocean (beyond state waters) is regulated by both federal statutes and by U.S. agreement to international treaties and conventions. The following are the principal laws and treaties governing ocean disposal.

U.S. Regulations

- The Marine Protection, Research and Sanctuaries Act of 1972 (the Ocean Dumping Act as amended) regulates ocean dumping of dredged material, barged sewage sludge, and industrial waste, and prohibits disposal of HLW and radiological warfare agents in the ocean.
- The Clean Water Act, National Pollutant Discharge Elimination Systems (NPDES), and the OCSLA cover drilling discharges, under the purview of the MMS and regulation by the EPA.
- The Surface Transportation Assistance Act outlines requirements for LLW disposal, however, the United States has not permitted LLW disposal in the ocean for more than ten years.

International Agreements

- The London Dumping Convention (LDC) prohibits dumping of organohalogen compounds, mercury, cadmium, persistent plastics, petroleum hydrocarbons, HLW, and biological or chemical warfare agents. Many LDC countries believe that subseabed burial of HLW is illegal, and there is a consensus that any such disposal (even if environmentally safe) would need to be regulated under the LDC.
- The International Atomic Energy Agency (IAEA) revised the definition of HLW prohibited from ocean disposal in 1986 and developed guidelines and ocean disposal practices for all other radioactive materials. A signator to the convention, the United States is bound by the IAEA's definition of HLW.

Recent events have created a regulatory climate that favors protection of the marine environment. During 1988, commercial and sport fishermen in the north-eastern United States attributed declines in the health and abundance of some shellfish species to sewage sludge disposal at the DMSD, and incidents of hospital medical wastes washing up on beaches from New Jersey to Massachusetts led to beach closures. These events generated considerable political attention, and Congress subsequently passed legislation (Ocean Dumping Ban Act of 1988) designed to prevent continued ocean dumping of sewage from the New York-New Jersey metropolitan region beyond 1991.

With the increasing realization that pollutant impacts are regional in scale, rather than local, legislation has been written that addresses marine pollution and research on a regional basis. The March 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska, further heightened public concern about the fragility of marine ecosystems and the economic impacts of contaminants in the ocean.

It is likely that the ocean will continue to be used for dredged material disposal. However, in the near future, resistance to marine disposal of other types of waste (such as sewage, incineration ash, industrial, and radioactive) is expected to grow. There is a clear need for a national policy on waste disposal that emphasizes methods that minimize impacts to the total environment—the air, land, rivers, groundwater, estuaries, and oceans. It is possible that such a policy could result in increased use of the ocean for waste disposal within 10 to 15 years. Improved technical understanding and sound regulatory controls could enhance public confidence that some types of waste can be disposed of in the marine environment without degrading it.

Siting

More resources and technical expertise will be needed if dredged material dumpsites are to be designated and monitored on a more timely basis during the 1990s than they were in the 1980s. While progress is being made to systematically review and designate dredged material dumpsites, there are large areas of the country where established sites are not available, and only 14 percent of the sites being designated by the EPA have received final designations after more than 10 years of work (Table 3-7). A systematic EEZ data base and improved understanding of long-term predictability of seafloor erosion processes may contribute to speeding up the designation process.

TABLE 3-7 Summary of Dredged Material Dumpsite Designation Status as of 1987 Located in EPA Regions and Associated with Various Coastal States

State	EPA Region	Pending	Proposed	Final
Maine	1	2	0	0
New Hampshire	I	1	0	0
Massachusetts	I	2	0	0
Rhode Island	I	0	0	0
Connecticut	I	0	0	0
New York	II	4	0	1
New Jersey	II	4	0	0
Puerto Rico	II	6	0	0
Delaware	III	0	0	0
Maryland	III	0	0	0
Virginia	III	2	0	0
North Carolina	IV	2	0	0
South Carolina	IV	2	0	0
Georgia	IV	2	1	0
Florida	IV	16	9	2
Alabama	IV	1	0	0
Mississippi	IV	3	0	0
Louisiana	VI	23	0	0
Texas	VI	5	0	1
California	IX	11	0	2
Hawaii	IX	3	0	0
Pacific Islands	IX	3	0	0
Oregon	X	9	0	3
Washington	X	3	0	4
Alaska	X	3	0	0
Total Number of Sites		107	10	19

SOURCE: U.S.EPA

The EPA has conducted a number of efforts to evaluate disposal siting for sewage sludge and industrial wastes (Reed and Bierman, 1989). Consideration has been given to an ocean incineration site off the east coast (OTA, 1986). Most presently used ocean dumping and pipeline discharge sites have been located based on historical practice and proximity to the waste source.

Public Perception

Public perception has developed into a major category of nontechnical constraint on using the marine environment as a waste disposal medium. The socioeconomic tradeoffs of disposing of waste on land—where it poses a serious hazard to groundwater, freshwater lakes and rivers, and the rich nearshore environment of bays and estuaries—have been given far too little attention in risk assessments of marine waste disposal.

Summary

Over the past ten years many waste disposal practices in the ocean have been phased out, and while seafloor disposal of dredged materials will continue, public and political opposition is likely to uphold restrictions of ocean dumping of sewage and industrial wastes. Future use of the EEZ seabed for waste disposal will hinge on socioeconomic pressures, innovative engineered approaches to ocean waste disposal and better understanding of the mobility of contaminants.

CABLES AND MILITARY USES

Background

The ocean environment and the information needed to install and implement protective measures for submarine cables in the EEZ are common to many military uses. For this reason, these two uses are addressed in the same section.

Cables

Communication cables carrying voice and data transmissions constitute the majority of ocean cable installations—approximately half of all overseas communications are transmitted through ocean cables installed on the seabed (Federal Communications Commission [FCC], 1988). They can be transoceanic or intraoceanic and perform diverse functions. There are toll systems constructed by communications common carriers; private systems, such as those used in the offshore oil and gas industry; or dedicated cables for transmission of military information.

With the rapid development of fiber optic technology in the 1980s, the medium of choice shifted from satellites to cable (Table 3-8). The introduction of digital services by Intelsat International Business Service in 1986 led to a soaring demand for digital and higher quality service, as users dealt with "rain fade" and 0.25-second propagation delay inherent in satellite transmissions. One implication of the rapidly increasing capacity of these facilities is that the revenue per minute lost due to a cable fault is also increasing and true economic cost of interruption to the user must be considered.

The greatest potential hazards to these cables are bottom fishing trawlers and natural downslope processes, such as slumping and sediment flaws. Armoring of cables has helped somewhat in combatting cable faulting by trawl gear, although fisherman often cut away lightly armored cables to free their gear. For example, in one such incident, the TAT-8 cable suffered major disruptions in service due to fishing activity in early 1989 (Anon., 1989). Burying the cable in the ocean bottom has been an effective countermeasure against trawling damage. Current burial methods include plowing and trenching of cables as they are being installed, or jetting-in of previously installed cables. In addition, directional boring has been utilized to minimize environmental damage where cables cross beaches, dunes, and barrier islands. This technique also reduces the probability of anchor fouling by placing the cable in a steel pipe, meters under the seafloor.

TABLE 3-8 Transatlantic Cables and Capacity

Facility type	Year in	Capacity (voice circuits)
Dual coax cable	1956	50 (3kHz)
Dual coax cable	1959	48 (3kHz)
Single coax cable	1961	80 (3kHz)
Single coax cable	1963	138 (3kHz)
Single coax cable	1965	138 (3kHz)
Single coax cable	1970	845 (3kHz)
Single coax cable	1974	1,840 (3kHz)
Single coax cable	1976	4,000 (3kHz)
Single coax cable	1983	4,200 (3kHz)
2 × 280 Mbit/s[a] fiber	1988	7,560 (64 kbps[b])
3 × 420 Mbit/s[a] fiber	1989	18,144 (64 kbps[b])
2 × 560 Mbit/s[a] fiber	1991	15,120 (64 kbps[b])

[a] Mbit = Megabits per second
[b] kbps = Kilobits per second
SOURCE: National Telecommunications Information Agency, 1984.

Military Uses

The military utilizes the EEZ as an operational arena, as a laboratory for researching, developing, testing, and evaluating operational systems and techniques, and to train personnel. Military missions take pre-eminence in the ocean in times of conflict, but this position is less readily accepted in peacetime and is subject to more careful review to balance military, commercial, and ecological considerations. Typically, when a planned commercial venture within the EEZ potentially conflicts with military objectives, the matter is negotiated between the Department of Defense and the federal agency that has regulatory oversight for that commercial undertaking. For example, oil leases are selectively awarded to minimize interference with military operations in or near the lease field. Conversely, the military may seek alternative means of obtaining their objectives if existing commercial operations conflict with the development of military operations. Co-existence of military and commercial ventures relies on sharing knowledge about planned or existing activities to anticipate potential conflicts. The degree to which such sharing is possible, however, may be restricted by national security and commercial proprietary interests.

Because military interests in the EEZ cover a broad range of activities—from cable and sensor installations to supporting research and development concerned with physical, mechanical, and acoustical properties of sediments—this section will identify activities that have technical elements in common with commercial developments or pose potential conflict. In addition to seafloor uses, naval operations on the surface—such as firing ranges, transit lanes, and test ranges—can also interfere with the availability of the proximate seafloor for other uses. The following are widespread military uses that can be expected to continue into the future:

1. *Submarine cable systems* are used for voice and/or data transmission among shore-based facilities and between sensors and shore-based processing facilities, and to transmit power and control signals.
2. *Sensors and transducer systems* of various types are deployed on and above the seafloor to support research and development activities; to test and evaluate ships, submarines, aircraft, and weapons systems; and as integral parts of tactical and strategic monitoring systems.
3. *Mooring systems* are required for surface and midwater devices, such as ships, surface instrumentation buoys, and subsurface to near-bottom instrumentation pressure vessels.
4. *Remotely operated (ROVs) and autonomous underwater vehicles (AUVs)* , used for research and development and tactical operations, are normally used within the water column, but may include deployments of bottom crawlers as well. The military has become a major user of ROVs and AUVs.
5. *Asset disposal* includes dumping of surplus, outdated, and hazardous defense materials and equipment on the seabed. Although ordnance (explosives) is no longer dumped on the seabed, previous sites may still contain dangerous materials. Naval vessels are disposed of at sea in a variety of forms and for different reasons, including bombing or artillery practice, formation of artificial reefs, or nuclear-powered vessel disposal.
6. *Mine warfare* in times of conflict can benefit from highly detailed bathymetric charts used to fingerprint areas of significance. Navy efforts to provide such fingerprint data are closely related technically to commercial and research requirements for detailed bathymetry.
7. *High-powered, low-frequency active sonar systems* for antisubmarine warfare (ASW) and mine hunting applications must contend with the seafloor as an acoustic reflector. Acoustic reflectivity mapping and research aimed at improving the predictive capability of reflectivity models provide an important data source for enhancing ASW operations.
8. *Firing ranges* are remote areas reserved for use as firing and bombing practice, and are excluded from either research use or commercial development.
9. *Acoustic test ranges* are instrumented test ranges covering many square kilometers of ocean set aside for a variety of acoustic tests. Other seafloor uses in these ranges are extremely limited.
10. *Submarine transit lanes* along the seafloor exclude commercial exploitation of oil, gas, and mineral resources.

Scope of Development

Cables

Despite communications satellite development, economics and security have provided the impetus for the continued use and planned extension of ocean cable systems (Figure 3-7). In addition, because of the relative vulnerability of satellites, the military is reassessing its position of substantial dependence on satellite communications for land-based facilities.

In the next 10 years, the development of fiber optic cables with wider transmission bandwidth will reduce the number of active cables in use for a particular link. However, over the next 25 years, the number of cables is likely to increase as links to other continents and islands become more cost effective, due to improved economy per unit length of fiber optic cables.

An additional advantage of fiber systems is that they can have multiple landings; each pair of fibers in a transoceanic fiber cable can have a separate landing point. For example, an existing fiber optic cable has only one U.S. landing, but it branches 200 km offshore for a 1,200-km spur running to Bermuda.

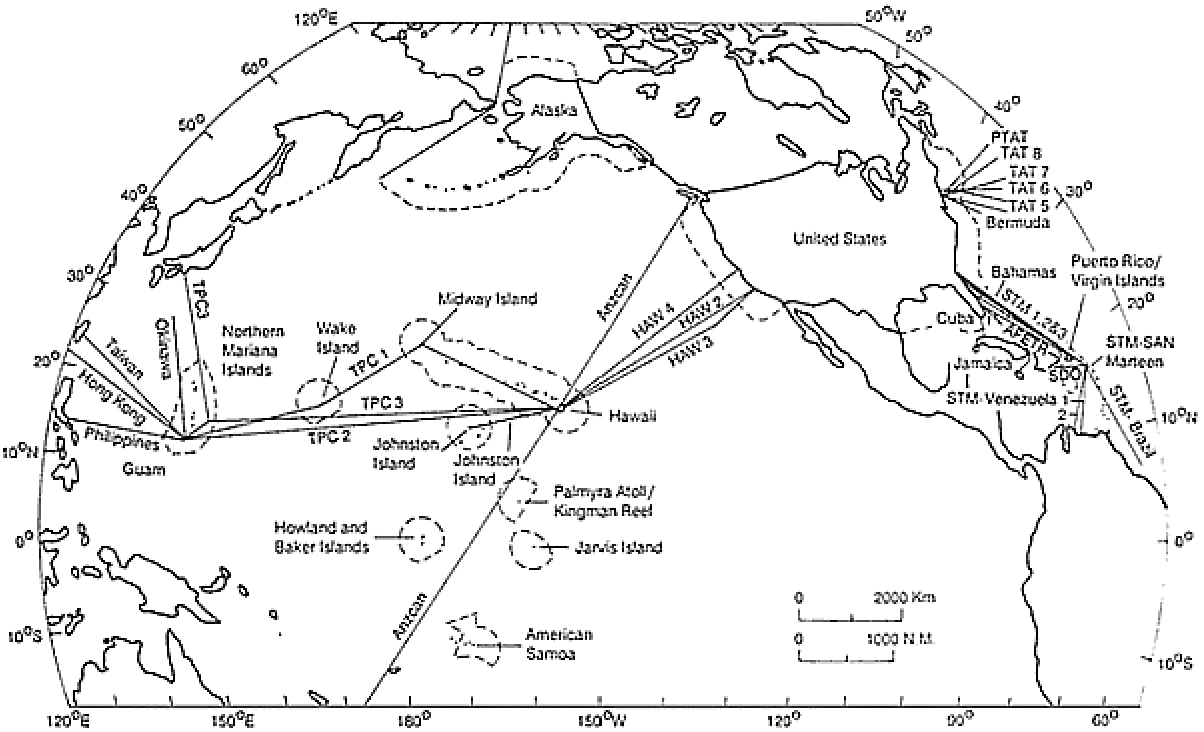


Figure 3-7
Major commercial communications submarine cables passing through the EEZ.

Another major shift in commercial communications is the introduction of facilities competition. Transoceanic facilities are no longer the sole province of existing telecommunication monopolies. Private companies are building facilities on the assumption that traditional forecasting methods have resulted in a shortfall in capacity over the next five years. Recently installed cables in the Atlantic and Pacific oceans are examples of this new facilities provider.

In the immediate future, fiber optic cable systems will cause coax cables to become obsolete on high traffic density routes, resulting in fewer active cables. However, rapid growth in digital traffic means that more fiber cables are being planned. Therefore, the number of very high-capacity, high-revenue fiber cables will grow. Table 3-9 shows the capacity of existing and planned submarine fiber optic cables, and likely developments based on other recently announced cable systems.

Ongoing development in halide fiber technology presents an enticing vision of repeaterless, transoceanic fiber optic systems. (Fluorine- or chlorine-based glass, if pure, has an extremely low attenuation curve in the infrared frequencies.) Researchers at the Naval Research Laboratory estimate that this will be possible in 15 to 25 years.

To protect cables against trawl gear damage, approximately a dozen commercial and several military cables have been buried on the U.S. continental shelf to a depth of a third to half a meter. Future cable system plans include protective burial, where possible, from the beach landing to the point of entry to deep water (relative to trawling hazards to cables, this is usually defined as 900 m, and is extended to 1,300 m in some cases). As more powerful trawl rigs are developed, the range and depth of bottom trawling will expand.

TABLE 3-9 Submarine Fiber Cables

Facility type	Year in service	Capacity (voice circuits-64 Kbps)
2 × 280 Mbit/s fiber	1988	7,560
2 × 280 Mbit/s fiber	1988	7,560
2 × 280 Mbit/s fiber	1989	7,560
3 × 420 Mbit/s fiber	1989	18,144
3 × 420 Mbit/s fiber	1990	18,144
2 × 560 Mbit/s fiber	1991	15,120
2 × 560 Mbit/s fiber	1991	15,120
2 × 1,800 Mbit/s fiber	1991	36,000

Military Uses

Since the EEZ waters are central to U.S. defense, a significant military role in the following areas will continue and grow as technology advances.

- *Ocean cables:* Because ocean cables provide an economical and secure means of transferring data over long distances, installation of cables will grow in the future. Fiber optic technology will enhance ocean cable application, and cable connectivity, especially for remote areas, will be more complex.
- *Sensors and transducer systems:* Scientific applications of sensors and transducers by the military have increased, and as the technology upon which they are based has advanced, their reduced cost and greater capabilities stimulate use of a greater range and number of sensors. Improved characteristics and capabilities of naval platforms result in increasingly greater numbers of tactical and strategic sensor systems. Anticipated ten- to twenty-fold expansion of military ranges in the EEZ in a few years will also increase the number of sensors used.
- *Mooring systems:* Advancing technology is making a wider range of moored devices possible and more affordable, thus increasing the need for mooring systems. Although the moorings in many cases are small, the number and spatial range in any undertaking tends to grow with advancing technology.
- *Remotely operated vehicles and autonomous underwater vehicles:* The application of ROVs and AUVs to military tasks is in its infancy relative to the potential of these vehicles for solving many problems associated with accomplishing underwater tasks, and military investigation of this potential will yield vehicles capable of performing increasingly complex tasks, some of which will use the seabed as a working surface. Military development of these vehicles for installation and support of complex mechanical structures in deeper water will well outstrip corresponding commercial development.
- *Asset disposal:* Although disposal of ordnance at sea has ceased, disposal of defueled, decommissioned nuclear-powered submarines is an increasing concern. The disposal of nuclear-powered submarines presents a challenge to achieve safe disposal through conventional reclamation procedures. Therefore, the submarine is usually disposed of by sinking the defueled, decommissioned boat to the seabed at a position deemed as having minimum impact on the environment.

Constraints to Development

Geophysical Constraints

Geological processes and the composition of the substrate are the most dominant physical constraints on emplacement and maintenance of ocean cables and military uses. Some of these considerations are summarized below.

- *Seismic tectonic activity:* Special design criteria and considerations are necessary where seismic activity causes ground motion that can damage cables or other bottom-mounted structures.
- *Seafloor instability:* Routing of cables and placement of structures are affected by downslope mass wasting processes (debris flows, turbidity currents, and slumps and slides), which cause movement and eventual failure of cables and other structures on the seabed. Rerouting of cables and selective placement of structures to avoid these hazardous areas are often required.
- *Sediment transport dynamics:* Where sediment transport and scour processes are active, cables may need to be buried or rerouted. Bedload movement and the development of bedforms can expose previously buried cables, resulting in strumming (vibrations set up by hydrodynamic forces), reduction in support, and ultimate failure. Additional research and field data are needed to more accurately model interactions between currents, the seabed, and the cable.
- *Ice gouging:* In high-latitude regions cables must be buried deep enough to protect them from gouging by sea-ice keels.
- *Subsea permafrost and gas hydrates:* Not only is burial difficult in permafrost, it provides a thermally unstable environment that can result in differential collapse of the substrate and eventual failure of cables.
- *Bottom topography:* Submarine cable routes are directly determined by ocean bottom topography. Extreme rates of change in depth may require detouring to avoid excessively long segments of suspended cable, where currents cause the cable to strum. For extreme lengths, suspended cables can break under their own weight. Seafloor structures and acoustical performance of sensor systems are all affected by bottom topography. Excessive variances can create azimuthal blockage of acoustical transmissions.
- *Acoustical properties of the ocean bottom:* These are directly affected by substrate composition and are important in developing sensor systems.
- *Trafficability of the seabed:* As ROVs and AUVs become more common for underwater tasks, trafficability of the sea bottom will become an important factor as "bottom crawlers," which depend on the seabed for support and traction as they maneuver, are introduced to military applications.

Use Conflicts

A major issue in the development of military uses of the seabed is the conflict between military applications and commercial, recreational, and environmental interests. The most intrusive situation by the military, as viewed by civilian interests, is the exclusion of civilian uses from military areas for safety, interference, and security reasons.

Fishing activity, dumping, and historic sites also preclude certain activities. Figure 3-8 illustrates various uses of the sea and how they impact the installation of a cable. Avoiding existing hazards is the responsibility of the cable system developer. Managing relations with fishermen to avoid deploying systems in areas with significant fishing activity is a key factor. Since commercial fishing activity moves from one area to another over time, cable operators must also work with fishermen to reduce the probability of a trawl striking the cable.

The bottom trawling fishing industry uses gear that are often incompatible with the protection of ocean cables and sensor/transducer systems. Although ocean cables can be buried, some sensor and transducer systems cannot be buried, either because of their mechanical configuration or mission performance criteria. Fishing gear can also tangle with moored devices, resulting in damage to gear or mooring or both. Restricting areas around moored devices is a protective alternative.

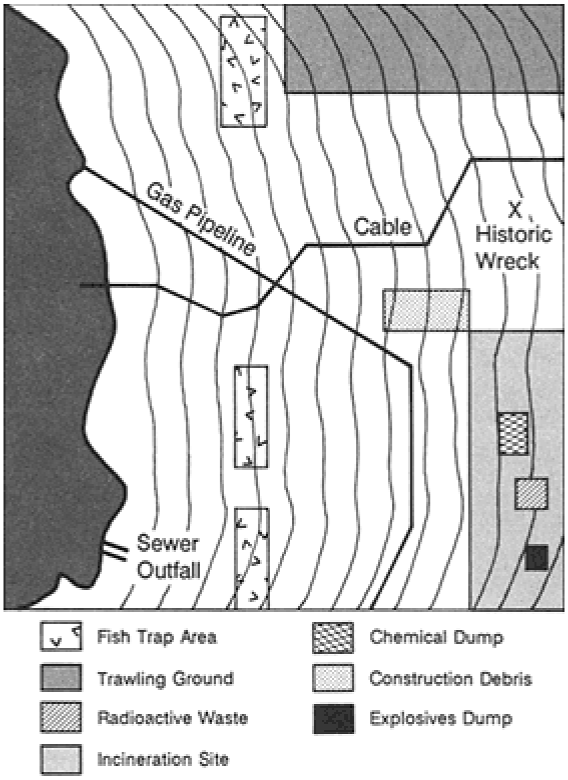


Figure 3-8
Hypothetical use conflicts for underwater cables.

Areas designated for mineral extraction may exclude the routing of cables, or, conversely, mining may not be feasible in heavily impacted areas of cable installations. Oil exploration activities may directly conflict with the effective performance of some tactical sensor systems. For example, seismic profiling for resource exploration represents an extreme form of acoustic pollution to an acoustic surveillance system. Countering these noise sources requires equipment with greater dynamic ranges and a substantial data processing investment. This interference with sensor systems produced by oil exploration seismic profiling and any other noise generators will constrain further development of these sensor systems. The U.S. Navy has recently explored these issues with the Western Oil and Gas Association.

Summary

Future growth in the number and value of ocean cables is assured by the soaring demand for digital transmission using fiber optics, which have produced more reliable, economical, and secure telecommunications. There is also every reason to believe there will be an increased military presence in the EEZ because the nation's defense depends on military activities carried out in these waters. Continued advances in technology that enhance defense capabilities will find application in the EEZ. But submarine cable systems will continue to face serious risk of interruption presented by geophysical processes and conflicting uses or restricted access. Additional research and field data are needed to more accurately model the interactions between currents, the seabed, and cables for more effective protection (burial), and to prevent strumming of exposed cables. Technology is needed for more effective geotechnical survey and data interpretation and more cost-effective and reliable burying systems during and after installation.

BIOLOGICAL RESOURCES

Background

Living resources associated with the benthic boundary layer fall into one of two categories in this report: commercially important fishery resources and organisms of special scientific interest or of potential importance as biotechnological or genetic resources. A third category of organisms (discussed in Chapter 2) are those of little or no direct economic importance, but whose roles in seabed processes must be considered in the context of other existing or potential seabed uses.

The United States is one of the world's largest consumers of seafood products: 1987 per capita consumption was 15.4 pounds (edible weight), a record high (O'Bannon, 1988). Commercial imports reached a record $8.8 billion in 1987, a 16 percent increase over 1986, and exports were a record $1.7 billion, a 22 percent increase. A large portion of the $6.1 billion trade imbalance in fishery products is attributed to aquaculture products, which are being produced in greater numbers in foreign countries. Domestic aquaculture operations are generally restricted to coastal waters and significant expansion beyond three miles into the EEZ seabed is unlikely and is therefore not discussed in this report.

U.S. EEZ commercial fish and shellfish catches from 1982–1987 are summarized in Table 3-10. Foreign vessel catches have declined dramatically: the 1987 total foreign catch was 150,000 metric tons, only 13 percent of the average for the preceding five years. Only 8,400 metric tons (6 percent) were seabed finfish and shellfish species. U.S. vessel landings increased gradually over this period, and joint-venture catches (U.S. flag catches transferred to foreign vessels) increased sharply. The total EEZ catch has not changed markedly over this six-year period, mirroring the overall world catch (O'Bannon, 1988). The 1987 catches of seabed-associated species (Table 3-11) are combined landings by U.S. vessels and joint venture catches. Excluding species that include aquaculture products (clams, oysters, scallops), the catches of bottom species (shrimp, crabs, lobsters, and flounders) rank second through fifth in value of all species caught in the U.S. EEZ in 1987, exceeded only by salmon.

TABLE 3-10 Commercial Catches (Metric Tons) in the U.S. EEZ

Year	Foreign vessels	Landings by U.S. vessels	Joint venture catches	Total
1982	1,410,000	820,000	230,000	2,460,000
1983	1,320,000	730,000	430,000	2,480,000
1984	1,340,000	680,000	680,000	2,700,000
1985	1,140,000	770,000	910,000	2,820,000
1986	590,000	1,140,000	1,320,000	3,050,000
1987	150,000	1,180,000	1,590,000	2,920,000

SOURCE: O'Bannon, 1988.

TABLE 3-11 Catches of Seabed-Associated Species by U.S. Flag Vessels in 1987

	0–3 mile offshore zone		3–200 mile offshore zone	
	weight (metric ton)	value ($million)	weight (metric tons)	value (million)
Shrimp	79,500	$ 264.9	85,300	$ 313.2
Crabs	106,500	123.3	68,700	198.5
Lobsters	17,900	112.9	5,300	41.6
Flounders	27,600	24.9	284,000	148.0
Halibut	12,300	30.7	22,200	57.5
Clams, oysters, scallops[a]	35,500	197.2	62,000	172.4
Total	279,300	$ 753.9	572,500	$ 931.2

[a] Includes aquaculture
SOURCE: O'Bannon, 1988

Within the last ten years, new species of marine organisms have been discovered in the EEZ seabed where geological and chemical processes result in zones in which chemically reduced compounds mix with oxygenated bottom waters. For example:

- the subduction zone off Oregon, where pore waters enriched in natural gas (methane) and probably hydrogen sulfide are squeezed out of the accretionary wedge;
- oil-and gas-producing regions on the Louisiana continental slope, where methane and hydrogen sulfide are released from the sediment;
- the Florida Escarpment, where thermochemical reactions at depth appear to be responsible for producing hydrogen sulfide-rich hypersaline brines; and
- the Gorda Ridge off northern California and Oregon, where active hydrothermal vents occur.

In these locations, unique animals have been found living symbiotically with bacteria that utilize the chemical energy in hydrogen sulfide. These characteristics suggest that such organisms may have important potential applications for biotechnological or genetic engineering.

Scope of Development

Although most fisheries experts believe that traditional fisheries are at or near maturity, there are opportunities to develop nontraditional seabed resources. Some resources of the continental slope can be harvested by extending existing technology into deeper water. Deepwater crab and ocean perch fisheries, for example, will require only minor technological modifications.

Bacteria capable of using chemical energy for growth have been known for many years (for example, bacteria that grow on simple, one-carbon compounds such as methane have been the subject of research on the production of single-cell protein), but previous research has concentrated on terrestrial-based free-living bacteria. Only recently has the symbiotic association of such bacteria with higher organisms been elucidated (Cavanaugh, 1983). The consequences of these discoveries for genetic engineering and biotechnology may be substantial, insofar as these animal-bacterial symbiotic pairs have solved the problem of passing bacterially produced carbon compounds directly to the cells of the host animal.

These findings take on added importance in light of the toxicity of hydrogen sulfide and hydrocarbons to most organisms. Animals living in these locations have evolved biochemical mechanisms to avoid toxicity, thus their study is of considerable physiological significance and warrants investigation (Felbeck and Somero, 1982). Additionally, many bacterial species found in chemically unusual marine environments are logical candidates to study for their ability to degrade toxic chemicals (Jannasch, 1989). Discoveries of microorganisms with the ability to metabolize chemical compounds previously thought to be resistant to biodegradation have stimulated the search for additional microbes with such desirable abilities (Roberts, 1987).

The use of natural products as pharmaceutical agents in the treatment of cancer, AIDS, and other diseases is receiving renewed interest from the National Cancer Institute (Booth, 1987). Many marine benthic invertebrates are potential sources of such drugs. Although it is impossible to predict which organisms are likely to produce substances of medical value, organisms that have adapted to unusual conditions, such as those discussed above, are worthwhile candidates.

Given the rapid pace of advances in isolating and cloning genes, it is difficult to estimate time frames for biotechnical development of genetic resources. In the past, screening organisms for the presence of compounds of possible pharmaceutical or commercial activity was haphazard. However, the Natural Products Branch of the National Cancer Institute has initiated a five-year program to search more systematically for drug candidates derived from various organisms, including marine invertebrates and blue-green algae (Booth, 1987). An example of a potentially valuable natural product is didemnin B, an extract from a benthic tunicate that is being tested in clinical trials against a variety of human cancers.

Development Constraints

Increased utilization of wild stocks from the new regions of the EEZ will require confronting the longstanding problem of assessing population sizes. The abundance of fishes and invertebrates in topographically complex regions, such as banks, escarpments, and seamounts, are difficult to assess because these environments inhibit conventional sampling techniques, preventing accurate estimates of population size. Newer techniques based on ROVs, better sensors, acoustics, and improved data interpretation may alleviate present assessment problems. High-frequency acoustical profiling techniques, for example, have detected high abundances of krill (euphausiids) in the benthic boundary layers of submarine canyons off Georges Bank that may be important food sources for commercial fisheries (Greene et al., 1988).

Use conflicts between defense operations, cables, and fishing gear may also inhibit fishing development. One such conflict arises over the need to provide safe navigation lanes for submarines. These lanes are well established, but fishing vessels tend to ignore them and enforcement efforts have been ineffective. Another conflict exists between bottom trawl gear and Navy underwater surveillance installations. Although the Navy has buried cables in trawling areas in the past, planned expansion of undersea surveillance installations could exacerbate this use conflict, potentially leading to the prohibition of bottom trawling in certain areas. Commercial transoceanic telecommunications installations pose a similar conflict. A number of seabed trawlers have reported fouling of underwater cables and fishing gear resulting in damage or loss to both cables and trawls. Underwater cable routes are marked clearly on the navigation charts, but general compliance does not exist and enforcement has been ineffective. Other seabed uses—oil and gas development, mineral extraction, and waste disposal—pose additional potential conflicts in the absence of established use priorities.

Development of nonfishery living resources will require characterization of benthic communities throughout the EEZ before potentially invaluable species are lost due to habitat alteration by other uses. The National Cancer Institute's program for identifying and collecting organisms with promise for supplying pharmaceutically active compounds (Booth, 1987), is primarily focused on tropical plants and coral reef invertebrates because these environments are rapidly disappearing or being altered. Benthic organisms that occur in seafloor areas with commercial utility (i.e., hydrocarbon seeps on the Louisiana continental shelf) or with potential economic value (i.e., polymetallic: sulfides on the Gorda Ridge) are not presently included in this screening. So far, only a few species have been screened, and increased extinction rates of many rare species caused by habitat disruption could deprive the medical and scientific community of valuable sources of natural products.

Summary

EEZ biological resources are extensive and represent important sources of food and potentially valuable medical products. Information on their diversity, abundance, and occurrence is limited, however. The yield from traditional fisheries, using present technology, is at or near its upper limit and improving fisheries yields will depend on improved forecasting and stock assessments in topographically complex and deepwater regions to assess the potential for expanded fisheries. The potential for establishing the value of exotic organisms will hinge on the pace and extent of inventorying these resources and maintaining biodiversity in the oceans.

OCEAN ENERGY RESOURCES

Background

Ocean energy resources—thermal energy, waves, tides, currents, salinity gradients, biomass, winds, and seafloor geothermal—and related technologies are in very early stages of development, and the extent to which they will make significant demands on the EEZ seafloor is difficult to estimate. Nevertheless, it is possible to consider possible effects and tentative information needs associated with ocean energy development.

Not all potential ocean energy resources exist at all locations around the U.S. Shoreline.

- *Ocean Thermal Energy Conversion (OTEC)* requires a substantial temperature difference between warm surface water and cold deeper water and a nearshore steeply sloping seafloor, conditions that are found off Puerto Rico, the Virgin Islands, and Pacific islands (Figure 3-9).
- *Waves* exist in all coastal locations but appear most suitable along the eastern seaboard.
- *The ocean current* most accessible to the United States that appears to be the best candidate for power generation is the Florida current off Miami.
- *Tidal power* is most efficiently produced where the tidal range exceeds 5 m, either off eastern Maine or in Cook Inlet, Alaska.
- *Salinity gradients* exist principally at the mouths of large rivers.
- *Biomass production* requires a good nutrient supply, cold water temperatures, and adequate sunlight—conditions met off the south and central California coast.
- *Ocean winds* exist all along the U.S. coast but are most persistent off the northeast coast.

With the exception of OTEC and possibly wave energy, it is unlikely that these technologies will have a significant impact on U.S. energy supplies or require placement in the EEZ. Tidal power installations, given their need for embayments, enclosures, or ponds, will not involve the EEZ or its seabed. Salinity gradient power, and most other ocean energy sources generally will require relatively shallow coastal waters and, probably would be located within the territorial sea.

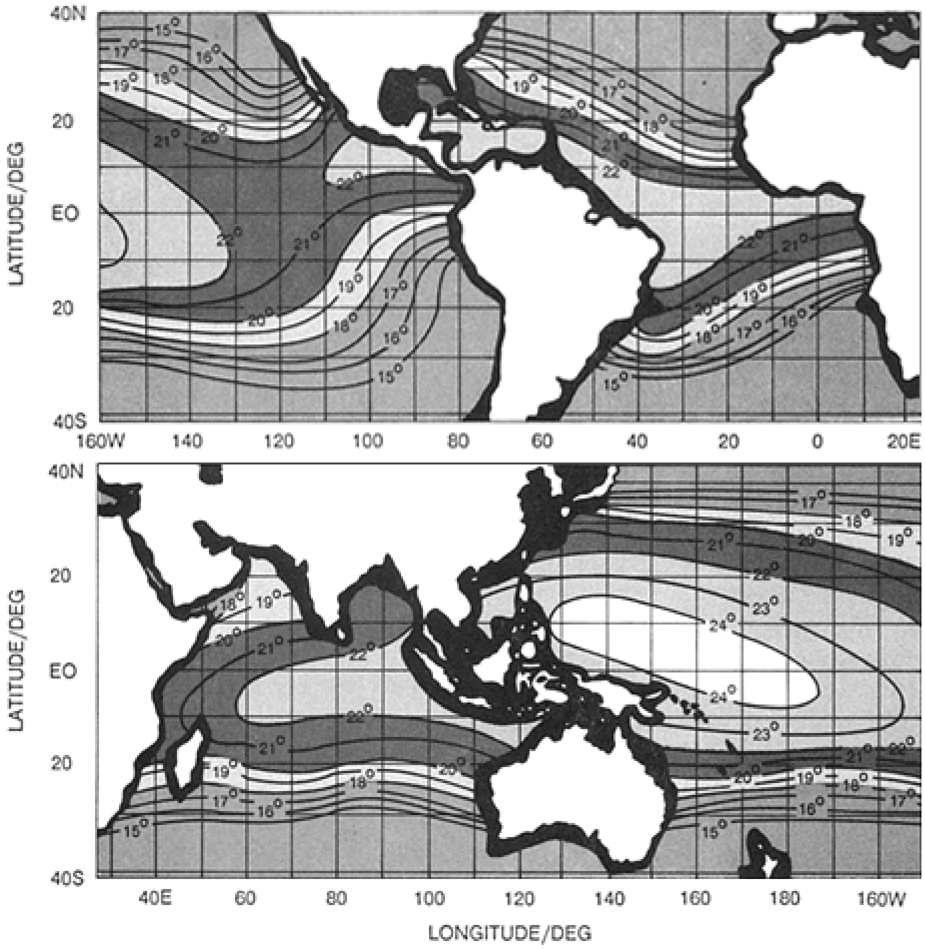


Figure 3-9
Worldwide distribution of the ocean thermal resource. Contours are for the annual averages of monthly temperature differences (in degrees Celsius) between the ocean surface and depths of 1,000 m: (top) the Western Hemisphere, (bottom) the Eastern Hemisphere. The black areas in coastal regions indicate water depths less than 1,000 m. Source: Cohen, 1982

Scope of Development

OTEC involves harnessing the temperature differences between surface and deeper waters and converting them to energy. A closed system version vaporizes a working fluid using warm surface water, which expands under high pressure to run a turbine, and is then recondensed by deep cold water. The open-cycle system uses sea water as the working fluid and produces fresh water as a byproduct.

OTEC requires a 20° C or greater temperature differential between surface and deep water. In a shore- or shelf-based system, the deep cold water must be relatively close to the beach. An OTEC system with potential EEZ applications is an at-sea floating facility with a pipe suspended to the deep coldwater supply. Because of engineering problems associated with the suspended coldwater pipe, electrical power riser cables, and deepwater mooring, attention has been focused on onshore or nearshore bottom-mounted facilities with a coldwater intake pipe resting on the sloping ocean floor. Floating systems could still become feasible in the future (beyond 10 to 15 years), however. In 1979, a small-scale, barge-mounted OTEC plant model moored off Hawaii (mini-OTEC) produced a small amount of power for a few weeks, thus confirming the validity of the principle (Cohen, 1982).

U.S. OTEC interest has focused on Hawaii, Guam, the Virgin Islands, and Puerto Rico, with the work in Hawaii being the most advanced. The state of Hawaii, the U.S. Department of Energy, and the Pacific International Center for High Technology Research have combined resources to build a pilot OTEC plant at Hawaii's Natural Energy Laboratory (NELH) at Keahole Point. The system includes the production of nutrient-rich, pathogen-free cold water for aquaculture and an open-cycle OTEC system for generating electricity. The NELH project consists of five, 40-inch-diameter coldwater pipes in a 1,800-m system that can pump fluid from a depth of 660 m at a rate of 13,000 gallons per minute. The coldwater pipe represents a significant technical challenge. It must be sufficiently long for its intake to reach the cold depths of the ocean, and it must have a diameter large enough to accommodate the flow of massive quantities of water (Rogers et al., 1988).

Extracting energy from ocean waves has been discussed for years by the British, Japanese, and Norwegian governments, and many wave energy devices have been proposed (McCormick, 1981). A consensus has developed around the oscillating water column approach, in which the motion of water within the wave energy conversion device acts as a piston, compressing the air and forcing it through an air-driven turbine connected to a generator. Such devices can also serve as breakwaters, reducing costs to a very competitive figure, as low as 4 cents per kilowatt hour.

This concept is reportedly being tested in a five-megawatt prototype system under construction in the Scottish Hebrides Islands (Baggott and Morris, 1985). Although more wave energy is available in the deeper offshore waters, the system is being built in only 21-m depth because its designers have not found a way to permanently anchor a structure big enough to provide commercially useful energy supplies, while at the same time it is able to withstand maximum interaction with incoming waves. In late 1988, agreement on a wave energy project was reported between the kingdom of Tonga and the Norwegian government, who agreed to build and install a three-megawatt wave-generating facility in Tonga.

Based on such recent developments, it is reasonable to predict that a number of wave energy projects will be built within the next 10 to 20 years. However, it is impossible to predict if and when wave energy conversion systems will be operated in the deeper waters of the EEZ. Higher wave energies make offshore operations attractive, but the problems of mooring and energy transmission to the mainland will undoubtedly retard such developments.

Development Constraints

OTEC could place technically significant demands on the EEZ seafloor. A commercial-scale shore-based facility would require a very large pipe (or tunnel) to supply cold water that will need to follow a sloping seafloor down to a depth of as much as 1,000 m to find seawater 20° C colder than surface water. The fixing of such a pipe (which could be as large as 9 m in diameter and 5,000 m long for very large-scale applications) to a steeply sloping seafloor will be technically demanding, and will require a wide range of seafloor information (Rogers et al., 1988). The most important information will pertain to properties of the upper continental slope: strength and stress-strain time parameters, compressibility and stress history, permeability, effects of slope deformation and failure, landslides, turbidity currents, debris flows, faulting, erosion, and scour. Site-specific information will be needed on nearshore properties to successfully "fasten" large coldwater pipes to a sharply sloping seafloor (Lockwood and McGregor, 1988).

Floating and moored OTEC facilities and wave energy facilities will require information on the seafloor properties needed to construct safe and reliable mooring or anchoring systems. In some configurations, the electrical energy would have to be transmitted to shore by seafloor cable, creating a need for detailed seafloor information along the cable route.

Summary

The development of ocean energy systems in the U.S. EEZ during the next 10 to 20 years depends on the potential economic advantage in specific areas where it is feasible. The most promising technology—OTEC—is limited to subtropical and tropical areas where there is an adequate temperature differential and accessible deep ocean water. Higher oil prices will be the crucial factor driving the development of these technologies.

Although wave evergy systems are being developed in Norway, Japan, and the United Kingdom, there is little interest in these systems in the United States. It is likely that islands with appropriate wave climates and high existing energy costs (Pacific islands qualify on both counts) will be the first places considered for wave energy systems, if they become commercially viable. Of the two technologies, OTEC will have more demand for EEZ seafloor information since wave energy systems will almost certainly be located on or near the shore.

CULTURAL AND RECREATIONAL RESOURCES

Background

Cultural and recreational resources of the EEZ include marine archaeology, treasure seeking, and commercial salvage; recreation; and marine sanctuaries.

- *Marine archaeology, treasure seeking, and commercial salvage:* Marine archaeology is a very small and relatively stable activity (perhaps no more than 100 individuals in the United States), but treasure seeking and commercial salvage are substantially larger and more visible. Commercial salvors, excluding treasure seekers, seek to retrieve hulls or cargo of recently sunk vessels. Their activities are regulated under maritime law, which asserts that abandoned shipwrecks and other items on the seafloor become the property of the "finders."
- *Recreation:* Seafloor habitats are becoming underwater attractions in some coastal locations with large tourist populations. This trend will probably accelerate as the popularity of coastal and ocean recreation grows.
- *Marine sanctuaries:* Ocean areas of special interest, uniqueness, value, and importance are the wet counterparts of national parks and forests, wildlife preserves, and historical monuments. They are set aside to protect unique recreational amenities (coral reefs), cultural sites (historic shipwrecks), habitats or wildlife areas, or valuable research sites. Most of them remain to he discovered, so a probable growing activity in the EEZ will be identifying and designating such areas for long-term protection. The approach usually employed is designation as a marine santuary under the Marine Protection, Research, and Sanctuaries Act (MPRSA). Eight marine sanctuaries have been designated so far: the U.S.S. *Monitor* off North Carolina, Key Largo and Looe Key off Florida, the Channel Islands, the Farallon Islands and Cordell Bank off California, Gray's Reef off Georgia, and Fagatele Bay in American Samoa. Six are located in the territorial sea and two in the EEZ: the U.S.S. *Monitor* and Gray's Reef (Figure 3-10).

Scope of Development

In light of recent advances in deep sea and exploration technologies, such as the ARGO/JASON program at Woods Hole Oceanographic Institution (Ryan, 1986), shipwrecks and historical objects will probably be discovered in increasing numbers. Some discoveries will be of considerable archaeological, cultural, and historical value. In the EEZ, establishment of marine sanctuaries has been used to designate and protect such sites (for example, the U.S.S. *Monitor*), but beyond national jurisdiction there is no legal framework for this purpose. In the case of H.M.S. *Titanic*, the Congress created a "memorial," but its restrictions are legally enforceable only against U.S. citizens. In the future, it is likely that professional and amateur treasure seekers will increase in numbers and interest in marine archaeology will also grow, but at a smaller rate. The availability of small submersibles in the coming decade or two will further stimulate treasure hunting. It is reasonable to predict that information demands will accompany the growth in these activities.

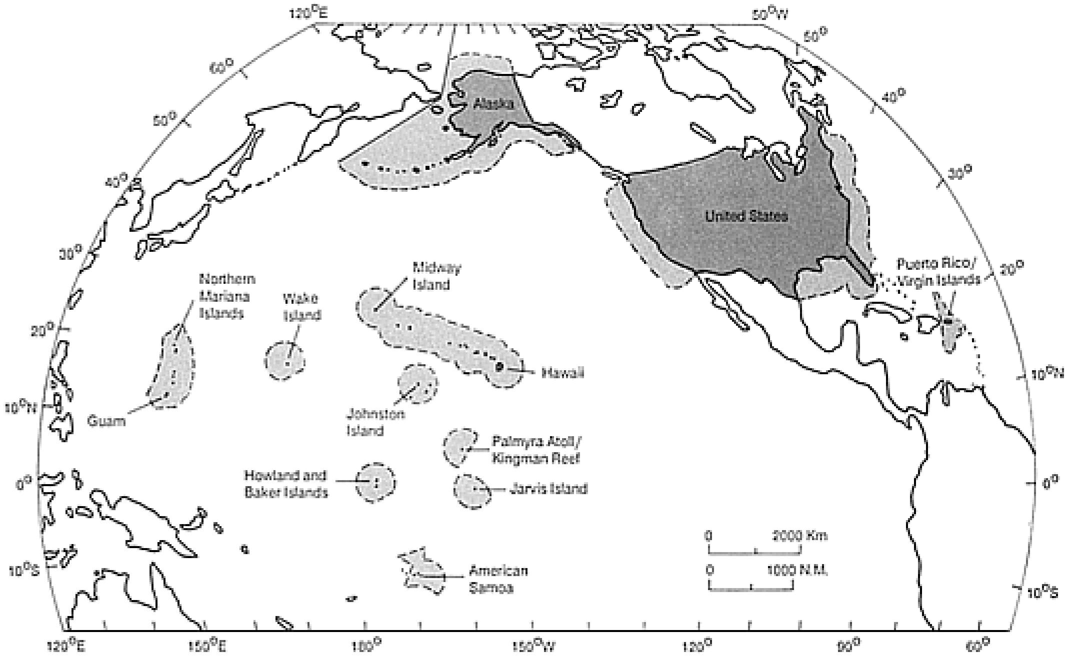


Figure 3-10
The seven U.S. National Marine Sanctuaries, and the U.S. EEZ. Source: After Foster and Archer, 1988.

With the continued popularity of snorkeling and scuba diving, more individuals will seek access to the seafloor in scenic underwater areas. The recent availability of relatively inexpensive submersibles for recreation could also create the need for more underwater destinations. Despite unrealized earlier predictions, underwater hotels are also likely to be constructed in a few especially interesting settings. Tourist submersibles are already operating; several vessels carrying over 40 passengers and crew are operating in U.S. nearshore waters (U.S. Virgin Islands, Guam, and Hawaii), but not yet in the U.S. EEZ. While these activities will create new demands for more detailed seafloor information in selected locations in the foreseeable future, these will fall within the territorial sea.

With increased exploration of the EEZ, many new ocean areas deserving protection as marine sanctuaries will be identified. After formal national designation, management plans are formulated to protect the resource for which the sanctuary was created, yet allow other uses that do not impact the protected resource.

Development Constraints

Recreational and cultural ocean activities—especially treasure hunting, salvage, and marine archaeology—will benefit from better information on the nature of the bottom load-bearing characteristics and bottom topography, bottom stability; potential for sediment erosion, transport, and deposition; thickness of unconsolidated sediments; strength of bottom currents; and visibility.

For marine sanctuaries, specific criteria need to be developed in advance that spell out the properties of various ocean areas deemed appropriate for sanctuary designation. Such early identification of candidate areas would ensure that legitimate sanctuaries are established before inconsistent competing activities are approved. The identification and designation process will require detailed site-specific information on physical and biological characteristics.

Summary

Increasing utilization of ocean-related cultural and recreational resources will stimulate demand for better and more detailed seafloor information. Because many marine areas contain rare and endangered species, uniquely valuable habitats, scenic coral resources, unusual geological formations, archaeological or cultural resources, or represent sites having exceptional research or recreational values, sanctuary designation is an important federal responsibility. Yet, to date, it has been a relatively low-level effort with only eight sanctuaries designated thus far. A waiting list for consideration now includes more than 30 candidate sites (Foster and Archer, 1988).

4

Technology and Data Acquisition

A large body of information is needed for planning efficient use and management of the EEZ seabed. Many data needs cut across individual uses. For example:

- oceanographic and meteorological data for real-time forecasts to improve operations and public safety;
- data on sediment characteristics, including shear strength and permeability, compressibility, and geochemistry;
- information and knowledge of seafloor geologic processes, including landsliding, turbidity currents, faulting, erosion and scour, volcanism, and sediment transport and deposition; and
- information related to specific and multiple uses of the seafloor, including the need for improved environmental quality monitoring of seafloor uses and their effects.

Obtaining this data in a marine environment frequently requires complex and expensive technologies and techniques specially designed for ocean use. This chapter presents assessments of the current status and future requirements of technologies and techniques used to gather information about the EEZ, including surveying and mapping technologies, geotechnical data collection activities, and environmental monitoring. A final section of this chapter discusses approaches to managing the large amounts of data that are likely to result from increased research and development efforts. In addition to present and emerging technologies and techniques, technical and nontechnical constraints that may limit technology development and deployment are examined.

SURVEYING AND MAPPING

There are four basic types of surveying and bottom mapping required to support development and protection of the EEZ seabed; these are water depth (bathymetry), seafloor imagery (mostly acoustic, some photographic), subbottom profiling, and direct sampling of seafloor surface and subsurface sediment characteristics. This section presents assessments of the current status and future requirements of seabed mapping and surveying technologies, including navigation technologies to correctly position seafloor mapping data. Included are a description of ongoing government, industry, and academic mapping programs; a discussion of mapping strategies; and an investigation of technical and nontechnical constraints that may limit technology development and optimal mapping programs.

Background

Surveying and mapping of seafloor characteristics provide fundamental and essential data and information for resource development and environmental protection. The seafloor can be mapped using a wide variety of tools and techniques, at different scales and accuracies and for different purposes.

Reconnaissance surveys provide a broad overview of regional geology, large-scale variations in seafloor morphology, rock or sediment type, and features resulting from long-term evolution of continental and island margins. Higher resolution mapping (with higher positioning accuracy) is required for task-specific or site-specific surveys. These are useful for precise resource assessment (type, location, quality, and volume of seabed commodities); quantitative measurements of bottom conditions (sediment properties and geologic processes) for engineering design, construction, or installation of seafloor structures; and seafloor process mapping (movements of the seafloor and its overlying sediments) for environmental monitoring and research purposes.

The state of knowledge and map coverage of EEZ regions on the continental shelf reflect the extent to which existing techniques have been applied in response to the needs of shallow-water users. However, most of the EEZ is beyond the continental shelf, in water deeper than 300 m, on the continental slope and rise. Use of these areas for resource extraction (particularly oil and gas) and activities such as telecommunications or military installations is increasing, and these areas are likely to become the principal location of development in the near future. This frontier region poses considerable challenges to survey methodology and practice. Although regional reconnaissance surveys are in progress, resource distribution and bottom conditions of the deepwater EEZ areas are generally poorly documented.

Mapping Technologies

Most seabed mapping is done by acoustic techniques, essentially by underwater remote sensing. Sound beams are bounced off the seafloor, or through the seafloor sediments, and their return time or return phase angle is measured. The resolution (fineness of detail) of different seabed mapping systems depends on many things. Range is increased as sound frequency is decreased. Lower frequencies, 3.5 kHz or lower, are required to penetrate sediments (subbottom profilers); medium frequencies, 12 kHz or higher, are required to avoid sediment penetration, thus accurately measuring the water depth (bathymetry) to the seafloor, or water/sediment boundary. In simple terms, the resolution of acoustic mapping data is generally increased by widening the frequency band width of the sound source, narrowing the width of the sound beam(s), reducing the width of the sound swath, reducing the survey ship speed, or reducing the system's altitude above the seafloor. The survey resolution is increased by reducing the distance between tracklines, or by improving the accuracy of the navigation/positioning system.

Seabed mapping technologies described below include bathymetric survey systems, side-scan sonar systems, swath imaging and bathymetric (combined) systems, subbottom profiling systems, and direct sampling technologies. Because accurate positions of all mapping data are necessary for the data to be useful, navigation/positioning systems are also discussed in this section. Capabilities of some commonly used acoustic mapping tools are described in more detail in McQuillin and Ardus, 1977; McClelland Engineers, 1982; Trabant, 1982; Kosalos, 1984; Prior and Doyle, 1984; Tyce, 1986; Davis et al., 1986; and Prior et al., 1988.

Bathymetry, the measure of ocean water depth, was the first bottom mapping technique to be developed. Originally, a lead weight was lowered on a line to give depths at individual locations. The development of sonar during World War I led to a new technique for measuring water depth. Single sonars mounted on a ship's hull measure travel time for sound to bounce off the seafloor and return to the ship. Depths are measured along a trackline directly under the ship, parallel tracklines are surveyed, and the area between tracks is interpolated and contoured into a low-resolution bathymetric map.

Higher-resolution bathymetric data are derived from "multibeam" or "swath" bathymetry systems. An array of transducers on the ship's hull forms multiple acoustic beams, which completely ensonify a wide swath on either side of the ship (Figure 4-1). Parallel tracklines provide 100 percent coverage of a survey area, so all areas between tracks are measured rather than interpolated. An additional increase in accuracy is provided because adjacent measurements within each swath are keyed to the same ship position. The first multibeam system was developed for the U.S. Navy in the mid 1960s. The first commercial multibeam (Sea Beam) was marketed in 1975; almost 20 are now operating worldwide. Bathymetric systems provide accurate water depth, and an accurate map of seafloor topography, but do not provide data on sediment type or thickness or show very small geologic features or objects on the bottom.

Side-looking (or side-scan) sonars provide acoustic images of a swath of the seafloor, showing morphology (bottom topography), sediment type and distribution, and small geologic features showing geologic processes. Figure 4-1 shows comparative swath widths of some typical kinds of swath mapping systems. A low-resolution side-scan sonar currently being used for reconnaissance surveys of the U.S. EEZ is GLORIA (Geologic Long-range Inclined ASDIC), developed in the United Kingdom. GLORIA is towed near the ocean surface at 10 knots with a swath width of 60 km.

There are many high-resolution side-scan sonar systems; operating characteristics of a number of them are shown in Table 4-1. These systems typically use a side-scan sonar frequency of 30 to 100 kHz, are deep-towed from 30 to 150 m above the seafloor (some "fly" automatically at a certain height; others are controlled manually by cable length and tow speed), provide a swath of various widths up to 5 km, and are towed across the bottom at 2 knots.

With an accuracy specification of 1 percent of water depth, SeaMARC II provides a high-resolution system for both bathymetry and imagery. Potential additional advantages are its ability to be towed below the water surface and moved from ship to ship.

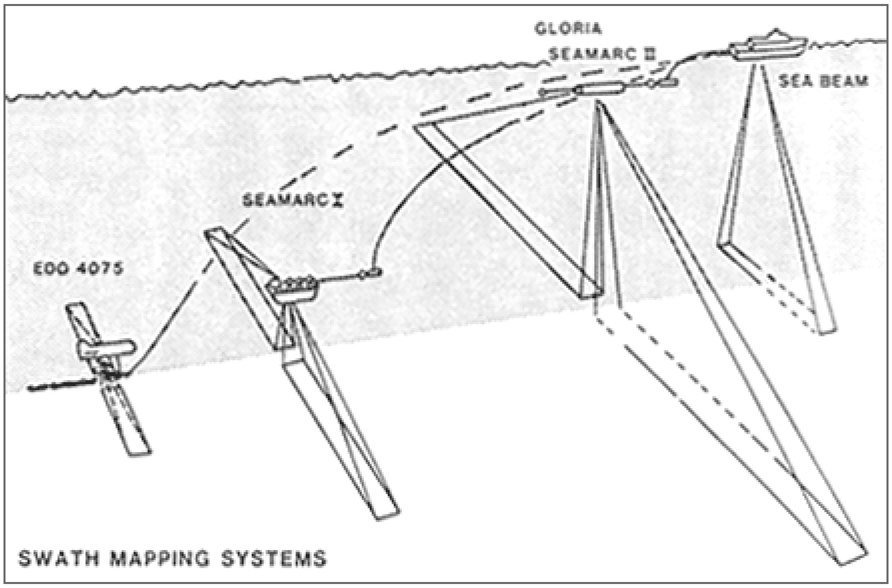


Figure 4-1
Comparative swath widths of some typical swath mapping systems. Source: After Davis et al., 1986.

Table 4-1 Bottom Mapping Systems

	Multibeam bathymetry	Side-scan sonars		Side-scan sonars & subbottom profilers				Side-scan sonars & bathymetry
System	Sea Beam	GLORIA II	ARGO/Klein	SeaMARC I	EDO 4075	Deep Tow	EG&G 990	SeaMARC II
Introduction	1975	1977	1985	1990	1980	1962	1980	1982
Number in use	18	2	1/6[a]	1	4	1	25	1
Frequency	12.150	6.2/6.8	100	27/30	100	110	59	11/12
(kHz)	(CW)	(FM)	(PULSE)	(CW)	(CW)	(CW)	(CW)	(CW)
Pulse length	7 ms	2, 4 sec	0.1 ms	0.15–3.2 ms	0.1 ms	0.1–0.4 ms	0.1–0.5 ms	0.25–10 ms
Pulse rep. (sec)	1–22	20–40	0.3	0.5–4	0.1–1	0.1–1	0.2–1	1–16
Bandwidth (kHz)	0.14	0.1	10	0.31–6.7	10	2.5–10	2–10	0.1–4
Beamwidth (deg)	2.7 x 2.7	2.5 x 30	1 x 40	1.7 x 50	1 x 25	0.75 x 60	1.2 x 40	2 x 40
Data type	Digital	Digital	Analog	Digital	Analog	Analog	Digital	Digital
Cameras			TV & still			TV & still		
Other sensors			Navigation	Subbot+mag[b]	Subbottom	Many[c]	Subbot+temp	
Tow depth	Hull mount	30–60 m	to 6 km	to 7 km	to 5 km	to 7.5 km	to 6 km	50–100 m
Water depths	>> 10 km	>> 10 km	6 km	7 km	5 km	7.5 km	6 km	>> 10 km
Tow altitude			10–50 m	25–1250 m	10–100 m	10–150 m	10–200 m	
Cross-track resolution	14–233 m	30 m	0.1–0.4 m	0.5–2.5 m	0.1–0.4 m	0.1–0.3 m	0.3–13.3 m	5 m
Along-track resolution	233 m	218 m	0.2–0.9 m	0.7–37 m	0.2–1.7 m	0.1–2.0 m	0.2–4.2 m	175 m
Bathymetric accuracy	10–50 m							150 m (3%)
Swath width	0.8 depth	14–60 km	0.1–0.7 km	1–5 km	0.1–0.8 km	0.1–1.5 km	0.2–1 km	1–10 km
Survey speed	15 knots	10 knots	1 knot	2 knots	2 knots	1–2 knots	2 knots	8 knots
Coverage @ 5 km depth	2,669	26,685	31	444	71	133	89	3,558/3,558
(sq km/day)	Bathymetry	Imagery	Imagery	Imagery	Imagery	Imagery	Imagery	Image/bathy
Coverage @ 0.5 km depth	(BSSS) 834	2,224	31	444	71	133	89	2,224/756
(sq km/day)	Bathymetry	Imagery	Imagery	Imagery	Imagery	Imagery	Imagery	Image/bathy

[a] Argo = 1; Klein = 6

[b] mag = magnetometer

[c] subbottom, magnetometer, navigation, conductivity, temperature, and depth, water sampler, precision pressure sensor, obstacle avoidance

SOURCE: From Tyce, 1986.

Many deep-tow side-scan sonar systems also carry shallow-penetration subbottom profilers. These downward-looking sonars are typically 3.5 to 7 kHz in frequency and penetrate 20 to 100 m of sediment, depending upon sediment type. These profilers provide detailed geometry, stratigraphy, and structure in the upper sediment layers; they may show individual sediment beds as thin as < 1 m. Sound attenuation and beam spreading in deep water will degrade data from surface ship profilers.

These different underwater remote-sensing tools employ various sensors to detect seabed characteristics, such as variations in acoustic reflectance and backscatter, gravity, and magnetic properties. The differences inherent in such methods are a consequence of relationships between range and resolution, which depend on the sensing system's properties. In common with other forms of remote sensing, ground-truth information (from bottom samples or cores) is essential for definitive interpretation of remotely acquired data. However, characteristics such as sediment texture, or "hard" and "soft" bottoms, can also be inferred by correlating different types of remote data. Complementary sets of remotely acquired data from different systems conbined with direct sampling can lead to elegant three-dimensional perspectives of seafloor phenomena. In particular, sideways-looking (side-scan) sonar provides images of seafloor morphology, sediment distribution, and signatures of geologic processes. Subbottom seismic profilers at various frequencies give near-surface sediment geometries, stratigraphy, and structure. Data from these systems is combined with bathymetry and in situ ground-truth data. Table 4-1 reviews the principal bathymetric and seafloor imaging sonar systems.

This area of technology development is dynamic; experimental new systems and advances in existing ones occur with regularity. The following review is not exhaustive, but presents state-of-the-art technology.

- *Sea Beam*: This multibeam bathymetry system uses sensors in the hull of the survey vessel and has depth resolution of 1 m and accuracy between 10 m and 50 m in deep water (Tyce, 1986). Swath widths are 0.8 times the water depth over a depth range of 100 to 11,000 m. SeaMARC II and Sea Beam bathymetry for the same area are depicted in Figure 4-2.
- *GLORIA*: This sideways-looking sonar is towed close to the survey vessel at a speed of 10 knots and has a 60-km swath. For most EEZ water depths, the actual range is 10 times the depth. The seafloor imagery has a pixel size of 50 m. The GLORIA II system is capable of rapid, large-area, regional coverage of large-scale features (Figure 4-3).
- *Argo Argo/Klein and SAR*: Argo is a deeply towed camera system that incorporates a side-scan sonar for high-resolution bottom images (similar to Edo 4075) over a 200-m swath at 1 knot (Tyce, 1986). SAR is a high-frequency, high-resolution, side-scan sonar that can obtain 1.5-km swath widths at 2 knots, but has seen only limited operational application.
- *SeaMARC I*: This is a deeply towed imaging system for site-specific surveys with both side-scan (27/30 kHz) and subbottom profiler (4.5 kHz). Transmitters and sensors are contained in a "fish" deployed 100 to 700 m above the seafloor at 2 knots. Swath widths are 1 to 5 km, and image pixels are typically 1 x 5 m, with cross-track resolution of 0.5 to 2.5 m (Davis et al., 1986). SeaMARC I can simultaneously record seafloor features and subbottom sediment geometries.
- *Edo 4075*: This is a sideways-looking, deeply towed sonar system incorporating a 3.5- to 7.0-kHz subbottom profiler. The towfish automatically traverses bottom irregularities with the positively buoyant vehicle held at a constant altitude of 30 to 50 m above the seafloor by a ballast weight. Range is 200 to 400 m at 2 knots. Its high-quality images of seafloor and subbottom topography, sediment texture, and geometry are suitable for site-specific engineering (Prior and Doyle, 1984; Prior et al., 1988). GLORIA II, SeaMARC I, and Edo 4075 data for the same area are compared in Figures 4-4, 4-5, and 4-6. Although the Edo 4075 swath widths are narrow (maximum 800 m), this system provides superior resolution.
- *Scripps Deep Tow*: A side-scan survey system capable of a wide variety of geologic, oceanographic, and biologic missions, this system has a typical swath width of 1.5 km, tow altitude of 150 m, and speed of 2 knots.

- *EG&G 990*: This is a high-resolution, deeply towed, 1-km swath system with cross-track resolution of 1.3 m and alongtrack of 2 m, at 100 m above the seafloor. Maximum operational depth is 6 km; tow speed is 2 knots. Operational effectiveness in deepwater high-relief areas is reduced by the need to tow the sensor close to the seafloor, with towfish altitude controlled only by cable length and ship's speed.
- *SeaMARC II*: This sideways-looking sonar is towed close to a survey vessel and simultaneously records seafloor imagery and swath bathymetry (Figure 4-3). It is capable of ranges of 1 to 10 km at tow speeds of 8 to 10 knots. Its imagery is composed of 1,024 equidimensional pixels over a range of 5 km per side, with a horizontal resolution of about 5 m. The swath bathymetry has a depth resolution of 20 to 50 m. SeaMARC II is capable of large-area regional surveys with higher spatial resolution and sensitivity to bottom roughness than the GLORIA system (Davis et al., 1986); however, relative to GLORIA, it has a significantly reduced swath width.

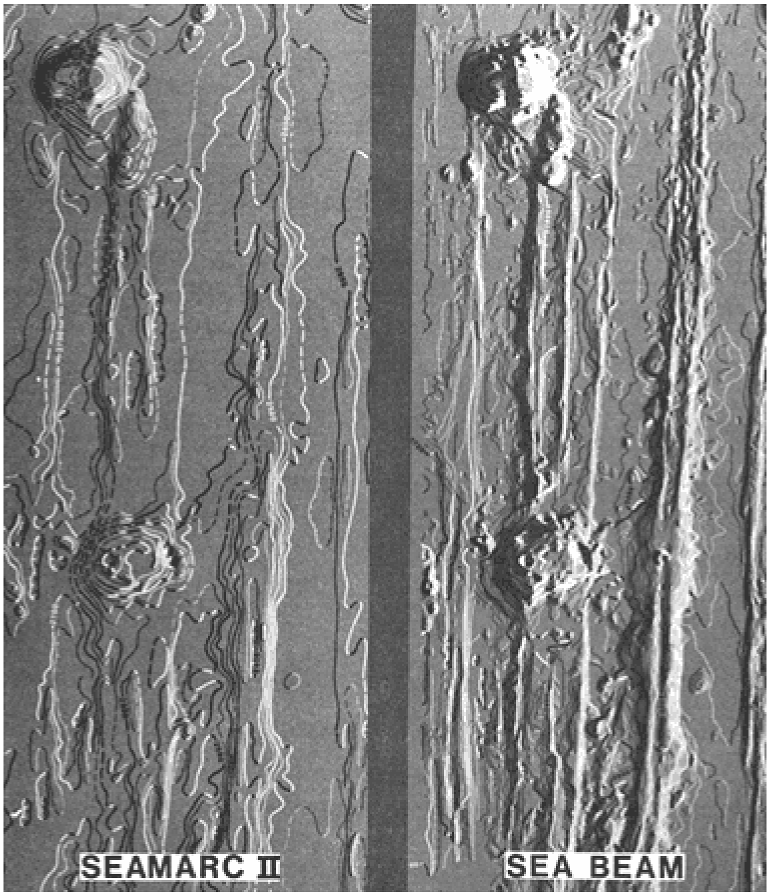


Figure 4-2
SeaMARC II bathymetry (50-m contour interval) and Sea Beam bathymetry (20-m contour interval) for the same area are compared. Source: Davis et al., 1986.

Profiling Systems

Profiling systems used to acquire information on water depth, seafloor profiles, and subsurface sediment, geometry and stratigraphy are listed in Table 4-2.

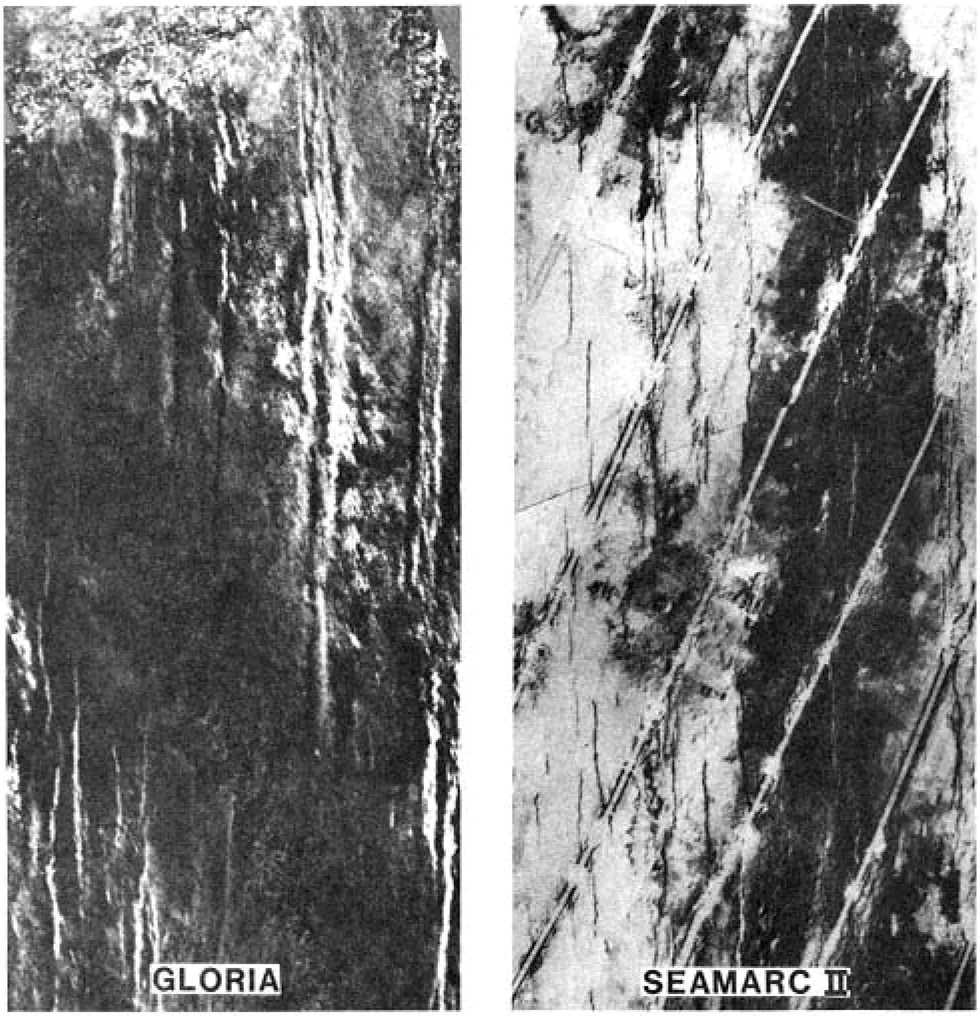


Figure 4-3
GLORIA imagery and SeaMARC II imagery for the same area. The images have reversed polarity (the SeaMARC II image shows steeper areas as dark, the GLORIA image shows them as light). Tracklines in the SeaMARC II imagery are approximately 10 km apart.

- *Water-Depth Echosounders*: For deepwater surveys, narrow-beam systems are required to minimize off-line echoes, and calibration for actual water column velocity variations is necessary to determine absolute depth (e.g., Prior et al., 1988).
- *Subbottom Profilers*: Profiling systems operating between 3.5 and 7.0 kHz can penetrate up to 30 to 50 m in soft sediments. However, penetration and resolution depend on geologic conditions and are highly variable. They are usually much less in sandy, cemented, or gassy sediments. Resolution of individual beds and strata may be less than 1 m. In deep water, beam spreading and attenuation from surface sensors reduce penetration and resolution. Figure 4-7 compares a surface-towed, 3.5-kHz profile with data from a deeply towed system 30 m above the seafloor (Prior et al.,. 1988).
- *Medium-Penetration Profilers*: Various medium-penetration, medium-resolution systems are used to provide details of sediment stratigraphy to 900 to 1,000 m below the seafloor (e.g., Minisparker, water gun, or minisleeve exploder). Actual penetration and resolution are affected by geologic conditions and the type, frequency, and power of the sound source. Data recording may be

single-or multichannel; the latter allows post-cruise processing to enhance usefulness of the profile data. Figure 4-8 illustrates information acquired by both 3.5-kHz subbottom profiling and multichannel data for the same area. Because of the apparent differences in penetration and resolution of the two types of data, both types of data are usually acquired simultaneously. Interpretation of near-surface geologic conditions is based on both 3.5-kHz and medium-penetration profiles.

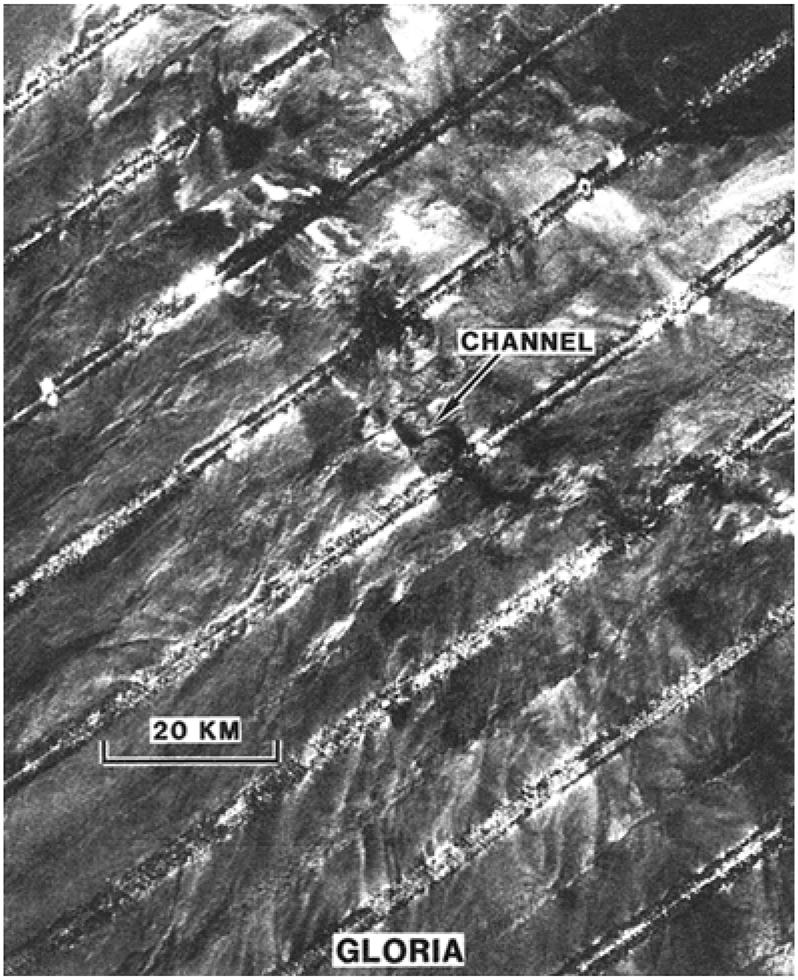


Figure 4-4
GLORIA imagery of part of the Gulf of Mexico. The same channel feature is further illustrated in Figures 4-3 and 4-6.

Direct Sampling

Seabed sediments and rocks can be retrieved using sediment grabs and dredges for surface materials, and boring, coring, probing, or drilling for subsurface samples. Characteristics of the retrieved materials and data from in situ measurements can then be mapped. Spatial integrity of the maps is directly related to sampling density, because of seafloor and subsurface variability between sampling sites. Sediment types, mineral deposits, and geotechnical properties inferred through other types of survey data are typically confirmed using direct sampling. Complementary sets of remotely acquired data from different systems combined with direct sampling can lead to elegant three-dimensional perspectives of seafloor phenomena.

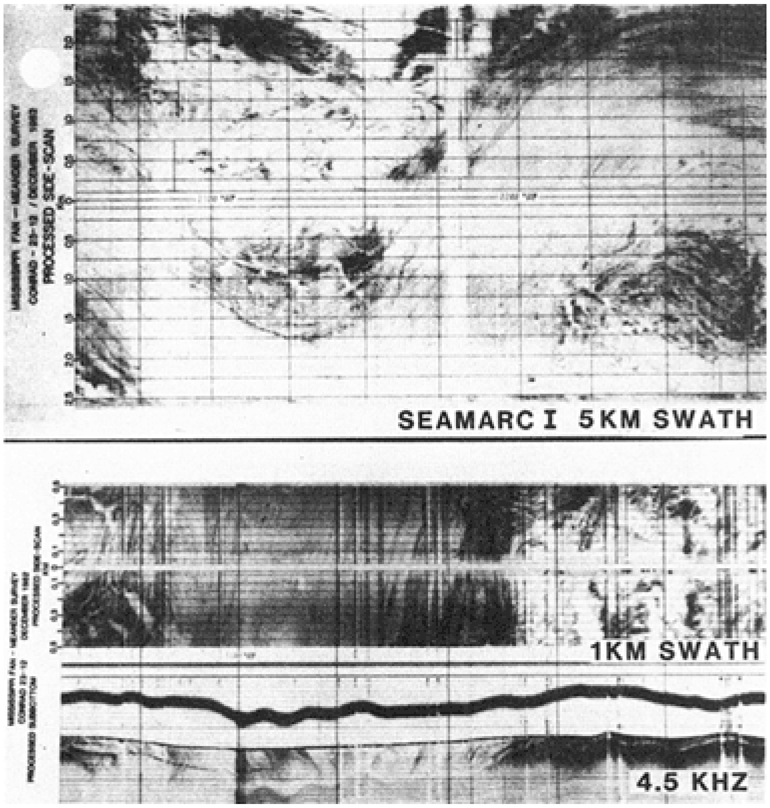


Figure 4-5
SeaMARC I imagery of the same channel showed by GLORIA data in Figure 4-2. Contrasting scales and resolutions (5-km swath, 1-km swath) are given. The 4.5-kHz subbottom profile accompanies the 1-km swath) Source: Kastens and Shor, 1985.

Navigation/Positioning Systems

The principal linkage between all survey and sampling measurements is navigation or position accuracy of the data collected. Historically, the accuracy of navigation systems has lagged the accuracy of survey and sampling systems, which has served as motivation for development of better navigation capabilities. Navigation systems can be characterized by the location of the reference systems:

- land-based systems,
- ship-based systems,
- seafloor-based systems, and
- satellite-based systems.

Land-based navigation systems have long been standard for survey operations conducted within range of shore stations. The permanent coastal navigation system, Loran C, has excellent repeatibility (return to same spot, but not necessarily know where it is) of 15 m, and sufficient range (300 nm) for EEZ surveys, but has insufficient accuracy (0.25 nm) to support many survey needs. A global land-based system, OMEGA, has been used to support open-ocean navigation, but has insufficient accuracy (1 to 4 nm) to support most EEZ surveys. Differential OMEGA (setting up a well-located, shore-based reference/retransmitting station) can reduce errors to 0.5 nm at 200-nm range, still insufficient for many survey purposes. For accurate nearshore surveys, temporary installations are generally used. These employ user-passive hyperbolic radio transmission systems (Argo, Sylidis), or user-active radar transponder ranging systems (Falcon, Miniranger, Hi-Fix). These systems have accuracies on the order of 1 m, but require careful surveying of the base station locations, and have ranges of only 50 to 100 nm.

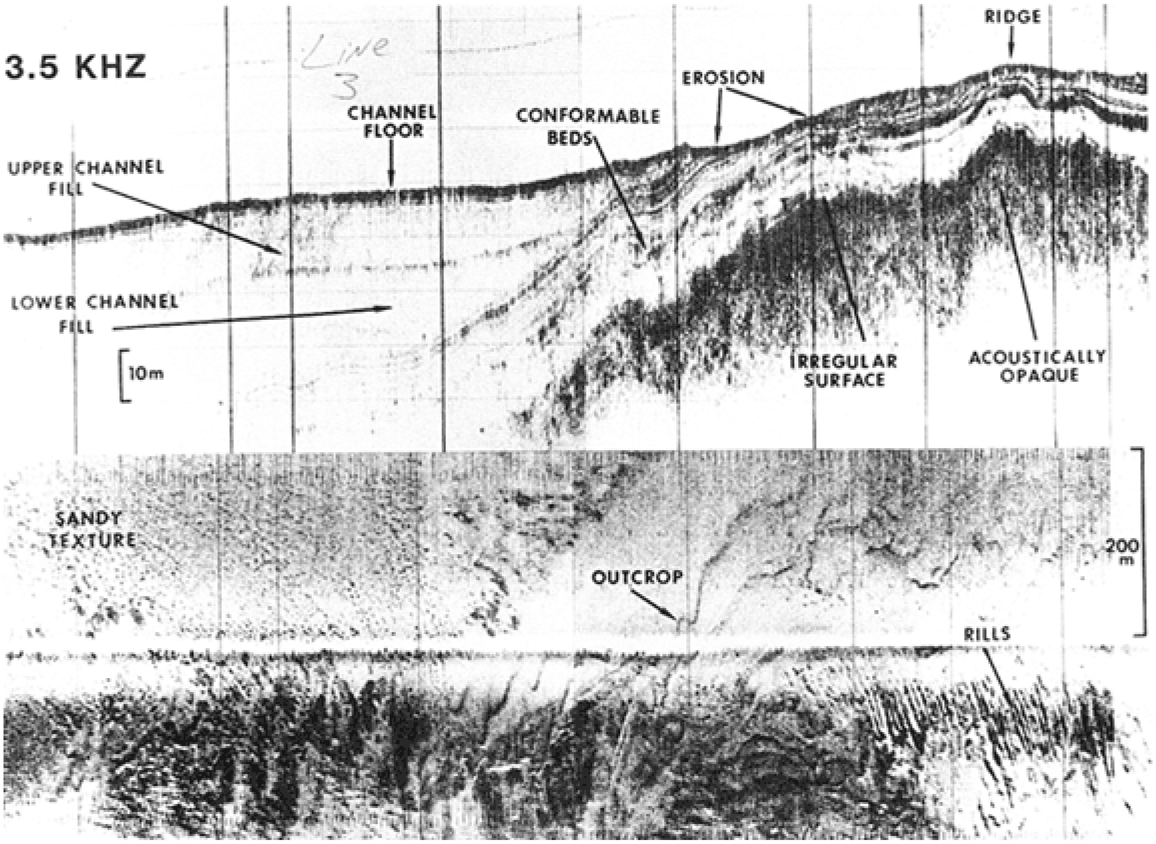


Figure 4-6
Edo 4075 imagery (3.5-kHz subbottom profile and 100-kHz side scan) for a portion of the channel shown in Figures 4-4 and 4-5. Source: Prior et al., 1988.

Ship-based systems generally determine range and bearing to stationary acoustic beacons, benchmarks or structures on the seafloor, or aboard moving vehicles. Ship position is the reference point from which all other positions are measured. These systems are called "short baseline" if they use the time of arrival of the beacon's signal at sensors widely spaced over the ship's hull for positioning. They are called "ultra-short baseline" if they use the phase difference of the beacon's signal at a closely spaced array of sensors. The accuracy of these systems is a function of both the accuracy of the underwater acoustic transmission and reception, and of the ship's position determined through other means.

Seafloor-based navigation systems generally consist of acoustic transponders, either on the seafloor or tethered some distance above. While limited in range by acoustic propagation to tens of kilometers, triangulation in range from bottom transponders produces navigation accuracy ranging from 1 m for near-bottom receivers to 50 m for surface receivers (such as ships). Systems are being

TABLE 4-2 Subbottom Profiling Systems

Acoustic System	Application	Frequency of Output Pulse	Maximum Operational Resolution	Type of Acoustic Source	Typical Energy Output
Water depth	1. Determine water depth echosounder	12 kHz to 200 kHz	< 1 m	Piezoelectric transducer	Much less than 1 Joule
Subbottom profiler	1. Provide very shallow sub-sea floor 2. Determine water depth 7 kHz 1 m 3. Detect gas bubbles in water column	3.5 kHz 7 kHz	Variable; typically 1 m	Piezoelectric transducer	About 2 Joules
Minisparker	1. Provide sub-seafloor profiles to intermediate depths (to about 200 m maximum)	Broadband 200 Hz to about 1500 Hz	About 2 m	Electric spark	Variable to 1,200 Joules
Sparker	1. Provide sub-seafloor profiles to intermediate depths (to about 900 m maximum)	Broadband 10 Hz to 500 Hz	Variable; 9 m to 25 m	Electric spark	4 kilojoules to 24 kilojoules
Water Gun	1. Provide sub-seafloor profiles to intermediate depths (to about 900 m)	Broadband 10 Hz to about 1500 Hz	Variable; typically 9 m but depends on frequently recorded	Hydraulic implosive	Variable; roughly equivalent to sparker
Minisleeve	1. Provide sub-seafloor profiles to intermediate depths (to about 900 m)	Broadband 60 Hz to about 1,000 Hz	Variable; typically 9 m but depends on frequency recorded	Contained explosion	Variable; roughly equivalent to sparker

SOURCE: McClelland Engineers, 1982.

developed for geodetic purposes with relative accuracies on the order of 1 to 10 cm, after careful calibration of water column acoustics, but such accuracy is not generally needed for survey and sampling operations. Careful surveying of the transponder locations is required to achieve any of these accuracies, along with processing to remove variations due to sound propagation effects.

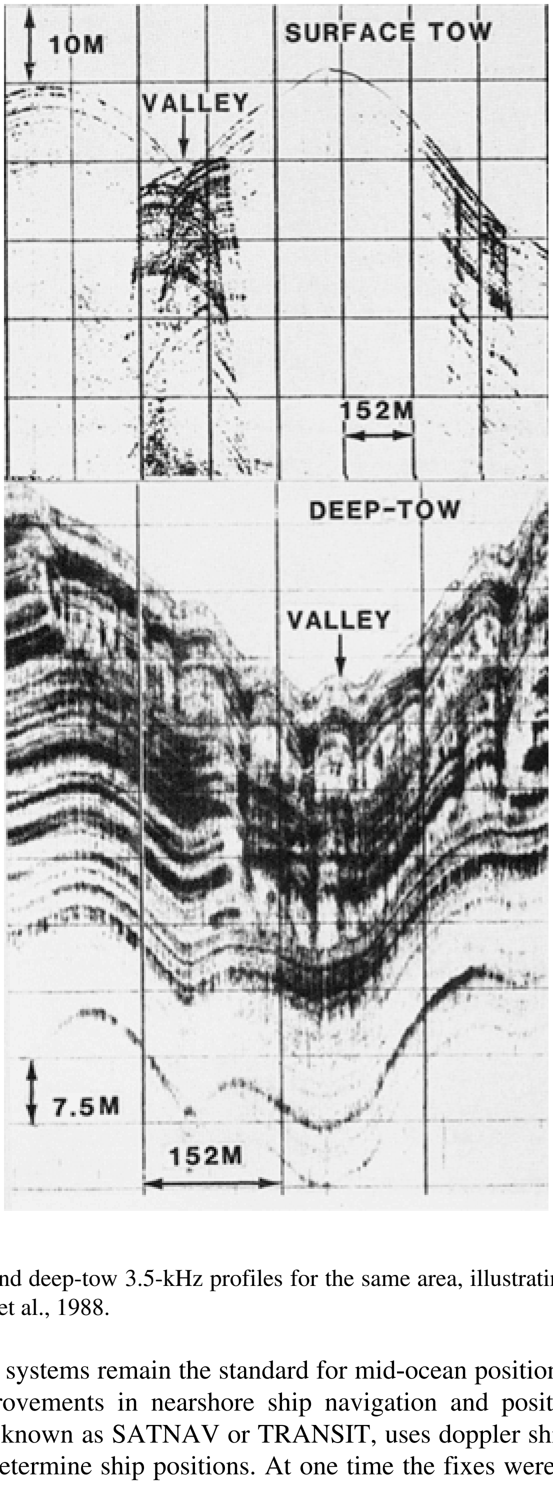


Figure 4-7
Comparison of surface-tow and deep-tow 3.5-kHz profiles for the same area, illustrating contrasts in resolution and penetration. SOURCE: Prior et al., 1988.

Satellite-based navigation systems remain the standard for mid-ocean positioning of ships, and also hold the most promise for future improvements in nearshore ship navigation and positioning. The Navy Navigation Satellite System (NNSS), also known as SATNAV or TRANSIT, uses doppler shift measurements from a series of polar orbiting satellites to determine ship positions. At one time the fixes were available about once an hour, with an accuracy of half a kilometer, but a declining number of satellites has increased time between fixes to 3 to 6 hours in mid-to equatorial latitudes. SATNAV positioning is generally inadequate both in accuracy and time interval for modern survey and sampling systems with resolutions of 10 to 200 m. The new satellite-based Global Positioning System (GPS), also know as NAVSTAR, uses range and time determinations from several of a series of polar orbiting satellites to establish position. When the entire "constellation" of GPS satellites is in orbit (after 1990), fixes will be available at least once a second with accuracies on the order of 1 to 10 m. GPS navigation is adequate for nearly all present EEZ survey applications. In 1990, however, its accuracy may be intentionally degraded to 100 m for national security reasons. If this happens, GPS will not replace some of the temporary-installation, nearshore systems described above.

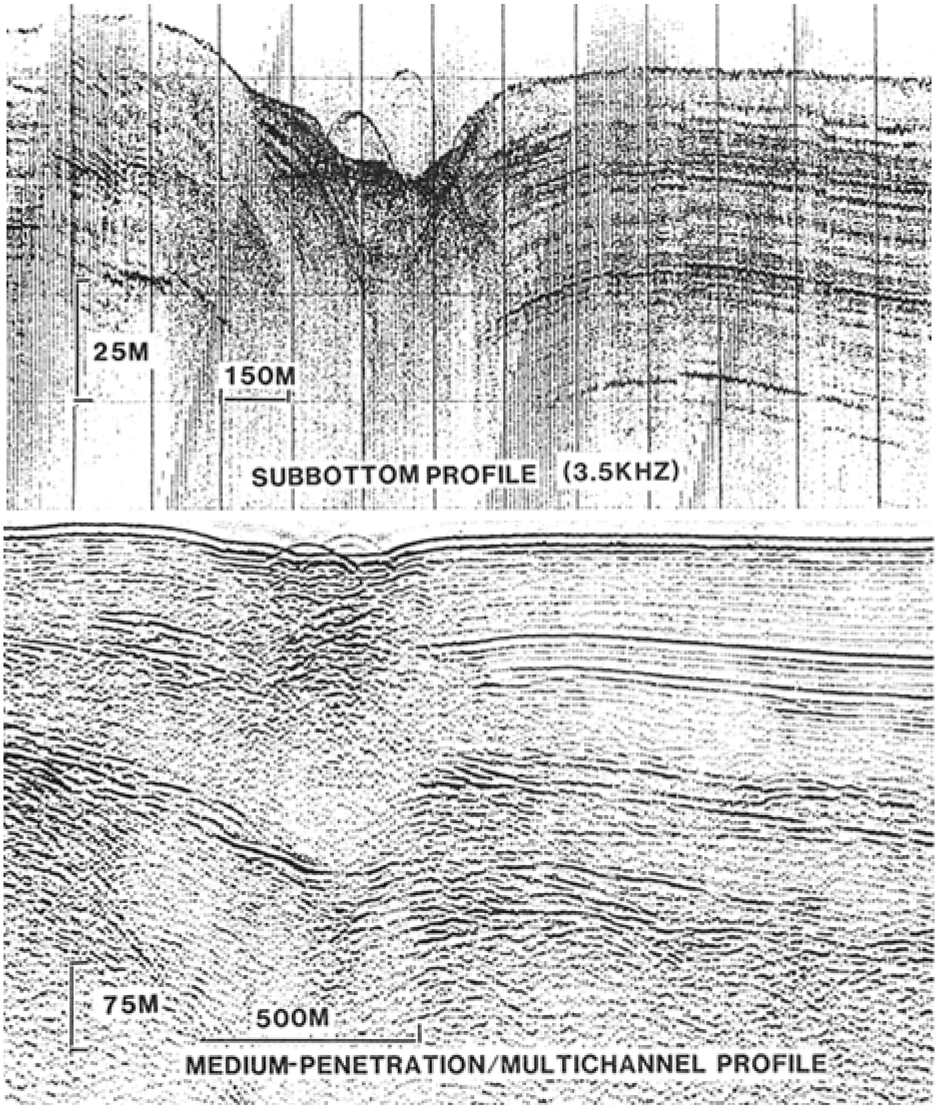


Figure 4-8
A 3.5-kHz subbottom profile and a medium-penetration seismic profile over the same area are compared. The 3.5-kHz record shows greater resolution in the near-surface sediments; the lower frequency seismic record shows greater penetration into the sediment layers.

Mapping Programs

Mapping within the EEZ is currently under way by government agencies, industry, and academia, each with different objectives and priorities.

Government Agencies

The USGS, NOAA, the Navy, the Army Corps of Engineers, and the Minerals Management Service (MMS) all carry out reconnaissance surveys, basic research, and task-specific activities, but their priorities and emphases differ. The USGS is conducting an ambitious EEZ-wide reconnaissance survey of bottom morphology using GLORIA. Surveys have been completed off the Pacific, Atlantic, Gulf of Mexico, Puerto Rico and Virgin Islands coasts, and in the North Pacific off Alaska; regional atlases of GLORIA side-scan mosaics have been published for the west coast (EEZ Scan 84, Scientific Staff, 1986) and the Gulf of Mexico and Puerto Rico (EEZ Scan 85, Scientific Staff, 1987). The west coast survey of 850,000 km^2 was completed in 96 days, at 9,000 km^2 per day (Tyce, 1986); Gulf of Mexico mapping was completed in 67 days (scale 1:500,000). The GLORIA program operating costs are approximately $5 million annually, and the program will continue through 1991 (Gary Hill, USGS, personal communication).

NOAA signed a memorandum of understanding with the USGS in 1984 to establish an interagency coordinative function for EEZ activities, Joint Office for Mapping and Research (JOMAR), and to do high-resolution mapping in the EEZ with the multibeam bathymetry system, Sea Beam. West coast surveys began in 1984 and continued in 1986-1987 along the west coast, Alaska, and the Hawaiian Islands. Priorities for multibeam mapping will complement GLORIA coverage, and with additional ship time and new systems, most of the high-priority EEZ areas can be surveyed with multibeam bathymetry systems by 1992 (NOAA, 1987). Prioritization is necessary because it will take the higher-resolution bathymetric systems three to ten times longer to cover the areas mapped by GLORIA (Tyce, 1986).

Task-specific efforts are also being conducted by government agencies, including EEZ minerals assessment supported by MMS. Under a cooperative agreement with the Texas Bureau of Economic Geology and the Louisiana Geological Survey, MMS will evaluate nonenergy mineral resources over the Gulf of Mexico continental shelf. Similar efforts have begun along the Atlantic and Pacific coasts and off Hawaii.

The Navy is engaged in research and task-specific studies. Some of this work, conducted by Navy research laboratories, is directed at site evaluations for military use, and is classified. Research-oriented activities funded by the Office of Naval Research (ONR)/Marine Geology and Geophysics Program are conducted primarily by academia.

Industry

Industry mapping activities in the EEZ focus on resource mapping and site-specific evaluations for resource development and applied research. For example, the oil and gas industry routinely maps resource potential throughout the EEZ. Industry also conducts task-specific studies including detailed mapping of seafloor characteristics for undersea cables, pipelines, and oil and gas platforms (Prior and Doyle, 1984). These surveys combine remote acoustic data and geotechnical sampling in depths to 2,500 m in the Gulf of Mexico, employing state-of-the-art survey and data-gathering systems (Prior et al., 1988). A high-resolution bathymetric subbottom profiler, and seisimic survey for approximately 65 km^2 of seafloor requires a total of 15 days to complete at a cost of $250,000 (J. Sides, Chance and Associates, personal communication). Much of this information is held as proprietary for ten years, but the data are provided to MMS for evaluating offshore exploration and development permits.

Applied research mapping is directed toward solving exploration and production problems, such as development of geochemical exploration methods for mapping near-surface sediments, and the relationship of geotechnical sediment properties to acoustic signatures, particularly for exotic, sensitive, gas-rich or hydrate-dominated sediments. Much of this effort is proprietary, although research results and developments are shared to some degree through technical publications and industry conferences.

Academia

EEZ mapping by universities and research institutions includes basic and applied research and some reconnaissance mapping. Financial support comes from NSF, ONR, MMS, NOAA, USGS, and industry, and the research reflects individual or group proposals subject to peer review, rather than a deliberate, coordinated plan to investigate scientific challenges posed by prospective EEZ use.

Examples of resource-relevant academic projects include NSF and industry supported basic research efforts along the continental margins (e.g., Farre and Ryan, 1987). One study addresses the geologic structure between the continental and oceanic lithosphere off Southern California. An ONR-sponsored program addresses sediment resuspension, transport, and deposition on the continental shelf (Nowell et al., 1987), which could affect seabed resources.

Mapping Strategy

In applying mapping systems to potential EEZ uses, it is important to distinguish between reconnaissance mapping and task-specific mapping. The distinction is based on differences in objectives and usefulness of data to address general geologic descriptions or the engineering assessment of particular areas.

Reconnaissance Mapping

Reconnaissance surveys aim at broad regional overviews of seafloor characteristics. Inherently, the data resolution is not capable of addressing site-specific local phenomena. Large-area coverage and general determination of subsurface features is achieved by relatively coarse-resolution imaging systems and medium-penetration profilers. Time and cost of acquiring data over large areas necessitate great distances between survey lines and sample points, and interpretation is usually presented in maps at regional scales (1:100,000 or greater). High-resolution seismic profiling over broadly spaced lines and magnetic surveys also generally fall into the reconnaissance category.

Examples of such reconnaissance data and mapping from broadly spaced survey lines are the GLORIA II images shown in Figures 4-3 and 4-4. Figure 4-9 is a reconnaissance GLORIA II survey grid in the Gulf of Mexico, with line spacing from 26 km in deep water to 7.5 km on the upper continental slope. A 6.5 x 6.5 km survey grid of the upper continental slope is covered by 3.5-kHz subbottom and medium-penetration sparker profiles acquired by the USGS in the mid 1970s (Garrision et al., 1977). This regional survey provides at least one survey line within each oil and gas lease block.

Task-Specific Mapping

Existing and potential seafloor uses involve mapping tasks that address such questions as resource assessment, engineering site evaluation, and research. Data resolutions and mapping scales must be consistent with information needs for a particular task. Task-specific mapping may cover areas of a few square meters to square kilometers. For example, construction of offshore oil production facilities and emplacement of cables and pipelines necessitate mapping of topography, sediment properties, and process factors at a scale and resolution sufficient to determine engineering parameters and site performance over the installation's lifetime. Surveying and mapping guidelines for oil and gas provided by the MMS in notices to lessors (e.g., N.T.L., 83-3, 1983) require dense survey line networks over prospective sites as part of a high-resolution hazard survey (Figure 4-9 inset, from Prior et al., 1988).

Side-scan sonar imagery, subbottom profiles, and medium-penetration data are obtained for correlation with geotechnical properties to quantify site conditions for engineering design.

Use-specific resource and site evaluations and research on the continental slope and rise share the need for deep-tow high-resolution data. Data generated by such systems as SeaMARC I,

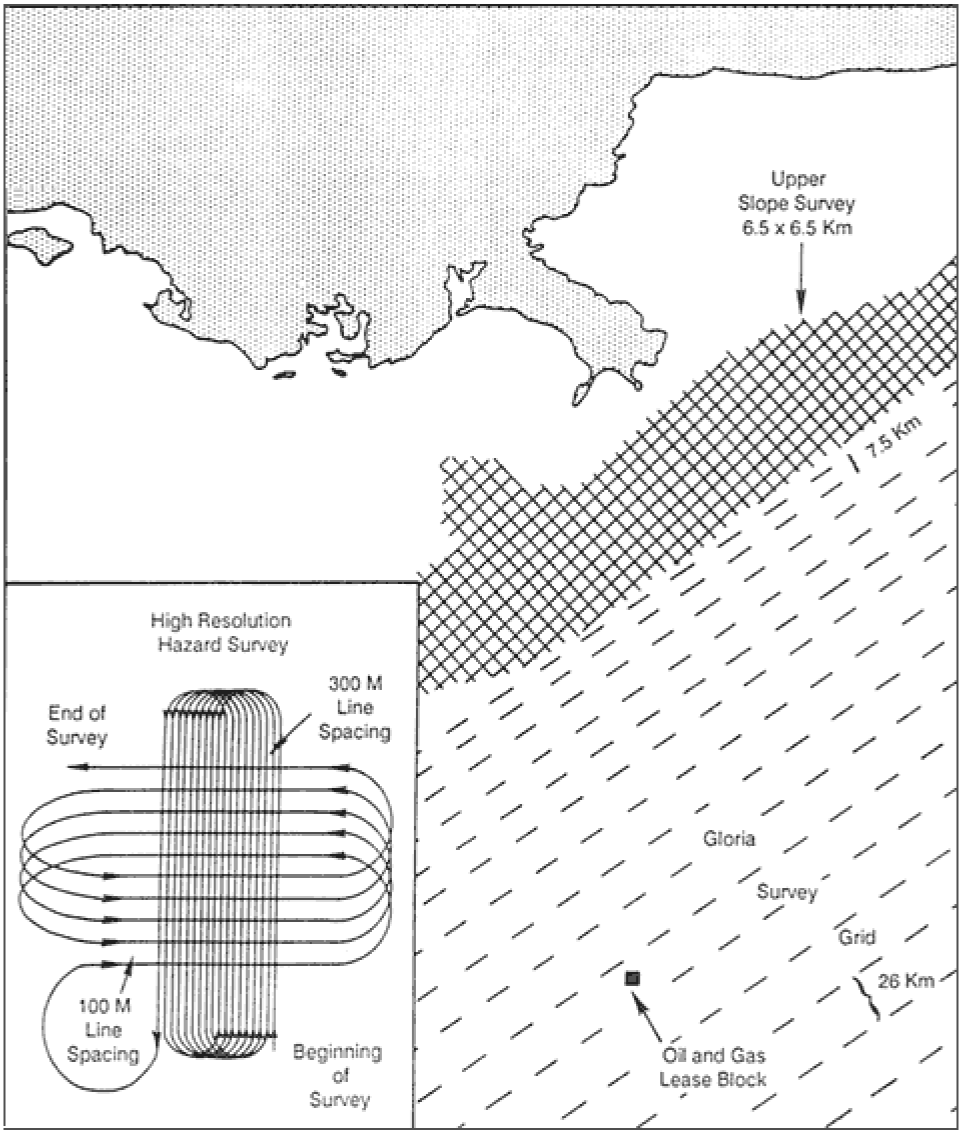


Figure 4-9
Comparisons of survey line spacing and densities for reconnaissance versus sitespecific surveys: a GLORIA regional survey, an upper slope seismic grid, and a high-resolution deep-tow site survey for an offshore oil and gas production site. A typical 3 x 3-nm oil and gas lease block is indicated for scale on both diagrams. Sources: After Garrison et al., 1977; EEZScan 84, 1986; Prior et al., 1988.

EG&G 990, and Edo 4075, supported by high-resolution and medium-penetration seismic profiles and dense sampling networks, are highly desirable. Similarly, swath bathymetry and imagery acquired using closely spaced survey lines with Sea Beam and SeaMARC II can address task-specific issues.

Each potential use of the seafloor requires completion of various tasks involving surveying and mapping. Table 4-3 reflects the multitude of tasks involved with full EEZ development and the relevance of different mapped data. Each prospective use will require site-specific bathymetry, seafloor imagery, near-surface sediment profiles, and sediment property measurements. Precise needs for development applications require further definition, and will evolve as development proceeds and knowledge of the EEZ seafloor improves.

Limitations and Constraints

Existing mapping methods, priorities, and practices must be evaluated in relation to future needs as EEZ use expands and diversifies. Despite recent advances, there are still technological limitations that constrain the effectiveness with which new demands for mapping data can be met. In addition, nontechnical issues affecting mapping include survey policy, implementation practices, prioritization of effort, and funding of research development.

Effectiveness of Profiling Systems

In certain geological conditions—gassy sediments, the presence of gas hydrates, sand and gravel dominated sediments, and cemented and indurated materials—the effectiveness of subbottom profiling systems is severely limited. Acoustic penetration of such materials is poor, and this results in considerable ambiguity in interpretation. The inability to identify and penetrate these sediments is a significant constraint to hazard evaluation and engineering design.

Deepwater engineering structures may have pile or anchor systems that penetrate far below the limits of 3.5-kHz profile data. Available medium-penetration systems (such as the Minisparker) lack sufficient resolution for acoustic evaluation of sediment geometries in the zone relevant to engineering. For oil and gas development, there is an increasing need for improved seismic profiling systems for the 50- to 500-m subbottom depth ranges. Multisource arrays combined with multichannel recording are promising, and must be pursued.

Data Archiving, Processing and Interpretation

Many available survey systems use digital data acquisition techniques to provide data in a form amenable to a variety of processing treatments. There is little standardization, however, of digital formats or data storage and archiving methods, which inhibits full use of the data. Also, while real-time shipboard data processing, display, and image enhancement techniques are quickly being improved, the need for time-consuming post-cruise processing still somewhat constrains full utilization of data sets for cost-effective mapping.

New bottom mapping technologies have revealed new geologic features and contexts in deepwater areas quite different from those in shelf waters. The inability to explain and characterize observed seafloor phenomena in use-related terms continues to pose a potential constraint to development. New interpretation methods and geologic models are needed that combine information extraction synthesis with statistical analysis of landform and sediment associations. Increased quantitative seafloor characterization will gradually improve the understanding of geologic processes for assessment of future resource sites.

Table 4-3

DEVELOPMENT APPLICATION	TASKS	BATHYMETRY		SEA FLOOR IMAGERY		NEAR-SURFACE PROFILES		MEDIUM PENETRATION PROFILES		SEDIMENT PROPERTIES		ANCILLARY	MONITORING
		RECON.	SITE SPECIFIC	RECON	SITE SPECIFIC	RECON	SITE SPECIFIC	RECON	SITE SPECIFIC	RECON	SITE SPECIFIC		
Oil and Gas	Exploration Hazards	□	+	○	+	□	+	+	+	□	+	Exploration	Oceanographic Processes
	Foundations	○	+	○	+	□	+	□	+	□	+	Seismic	Sea Floor Processes
	Resurveys		+		+		+		+		□	Drilling	
Minerals	Reconnaissance	□	□	+	+	+	+	○	+	○	□	Magnetics	
	Prospecting	□	+	+	+	+	+	+	+	○	+	Gravity	Oceanographic Processes
	Development	○	+		+	○	+	□	□	○	+	Drilling	Sea Floor Processes
Waste Materials	Site Selection	□	+	□	+	□	+		□	○	+	Oceanographic	
	Emplacement		+		+	□	+		○	○	+	Process Data	
	Resurveys		+		+		+				+	Biological Data	Sea Floor, Biological Processes
Pipelines and Cables	Site Selection	+	□	+	□	□	+	○	□	□	+	Oceanographic	
	Emplacement	□	+	□	+	□	+	○	□	□	+	Process	Sea Floor Processes
	Resurveys	○	+	○	+		+		○		+	Data	
Military	Site Selection	+	+	+	+	□	+	○	□	□	+	Oceanographic	
	Emplacement	□	+	□	+	+	+	○	○	□	+	Process	Sea Floor Processes
	Resurveys		+		+		+		○		+	Data	
Biological Resources	Habitat Assessment	□	+	□	+	○	+		○	○	+	Biological/	
	Resurveys		+	□	+	○	+		○		+	Population Data	Biological Processes
Energy Conversion	Site Selection	□	□	○	+	○	+	○	○	○	+	Oceanographic	
	Construction		+		+	○	+		□	○	+	Process Data	Sea Floor Processes
Cultural Resources	Archeology	○	□	○	+	□	+	○	○	○	□	Historical Data	
	Sanctuaries	□	+	○	+	□	+		○	○	+	Biological Data	Biological Processes
Research	Margin Structure	+	○	+		□		+		○		DSDP	
	Regional Framework	+	□	+	□	+	□	+	+	□	□	Oceanographic	
	Process Studies	□	+	○	+	+	+	□	□	+	+	Process Data	Sea Floor Processes

+ ESSENTIAL □ USEFUL ○ BACKGROUND

Mapping Needs For EEZ Seabed Uses

A natural adjunct to improved mapping is the need to acquire long-term, site-specific data that directly measures bottom processes and sediment behavior. For example, sites of potentially active turbidity currents, landslides, or sediment property changes from earthquake loading or fluid expulsion may be successfully determined from mapped data. Without improved data on the mechanics of such processes, however, the interpretations of such mapped data will be severely restricted.

Direct Sampling Problems

Mapping based on direct sampling methods suffers from two principal disadvantages: direct sampling is time consuming and inefficient, especially in deep water; and some EEZ areas exhibit great spatial variability in features, sediments, and processes. Improved techniques now make it possible to carry out in situ measurements of seafloor properties that formerly required laboratory analysis. The construction of maps of sediment property variations, however, even at a site-specific level, remains difficult and expensive. The present inability to reliably cross-correlate high-resolution acoustic data (backscatter or penetration) with directly sampled seafloor properties is a constraint to both site-specific and reconnaissance mapping.

Development Costs and Limited Markets

Initial development costs of mapping and surveying systems are high, and high pricing limits markets, which combine to make these systems limited in availability. GLORIA (British) and SAR (European consortium) are of foreign design and manufacture, as are several new multibeam bathymetry systems. Some foreign countries consider direct support of research and development of advanced survey systems to be in their national interest. GLORIA, for example, was developed by the British Government's Institute of Oceanographic Sciences. Some of the costs of developing new systems are presently shared by group partnerships in consortia (Spiess, 1987; Ross et al., 1989). For example, a new system designed and built at Texas A&M University that combines swath bathymetry with side-scan sonar imagery (SeaMARC TAMU^2) is the result of a university-industry-government laboratory partnership, with a total development budget of $2.5 million (T. Hilde, Texas A&M University, personal communication).

Survey Cost Effectiveness

Existing swath mapping systems have widely different rates of coverage that result from the tradeoffs among swath widths, vehicle speeds, and data resolution. For example, GLORIA II and SeaMARC II cover large areas relatively quickly, but effective swath width and data quality at longer ranges are uncertain, particularly with GLORIA (Davis et al., 1986). Task-specific site evaluations in deep water rely on data from SeaMARC II, and deeply towed systems such as SeaMARC I and Edo 4075 systems. But the low coverage rate with deep-tow systems on long tow cables constrains task-specific surveys, especially for large areas.

Improvements in cost effectiveness will require better systems and survey procedures. Multifrequency, multisensor packages deployed in autonomous vehicles or using improved fiber-optic cable technology appear promising. Separate surveys of the same areas using different systems (such as GLORIA and Sea Beam) is another cost-effectiveness issue. Reducing cost of repeated surveys of the same area can be achieved by increased use of multipurpose cruises, with multisensor survey systems capable of simultaneous acquisition of complementary data sets. Finally, acquisition of data in arctic areas such as the Beaufort Sea is expensive because of ice cover, and will require development of specialized under-ice survey technology.

Summary

Within the EEZ, large areas of seafloor, depth ranges, geologic variability, diversity of potential uses, and time and cost factors all dictate that a coordinated plan be developed for surveying and mapping. The plan should include identification of specific user groups involved in EEZ development and their appropriate mapping needs for particular areas of the EEZ over defined time frames. Proper planning will require prioritization of data acquisition for high-interest areas, at suitable resolutions, with the most cost-effective use of existing technology.

A plan for reconnaissance-level mapping of the entire EEZ with GLORIA and Sea Beam bathymetry has been coordinated by JOMAR, and additional EEZ mapping in the 1990s is planned. The relative roles of other government agencies, industry, and academia in setting EEZ mapping priorities, as well as participating in coordinated surveys, remains to be addressed. A related issue is the need to balance efforts and resources among high-resolution, site-specific surveys and ongoing reconnaissance.

While the specific types of mapped data needed for each EEZ development activity require further definition, there is overlap and commonality in the areas, data types, scales, and resolutions required for many different anticipated EEZ uses. High-resolution data requirements for oil and gas production, cables and pipelines, military uses, and waste disposal should to the greatest extent possible be collaboratively defined so that multiobjective surveys can be coordinated to achieve cost-effective use of ship time and equipment.

The limitations of present mapping technology will have increasingly negative effects as new long-and short-term mapping needs arise. Research and development for improved mapping systems are expensive, and may require no less than a coordinated technology development program focused specifically around EEZ needs to ensure adequate equipment development as EEZ use progresses. Such a venture would require collaboration by government, industry, and academia to identifying technology priorities and provide sufficient funding.

SEABED GEOTECHNICAL DATA

Background

Accurate characterization of a proposed development site requires meaningful measurements of seabed and sediment properties to be made by three different methods:

1. sampling and laboratory testing,
2. in situ testing, and
3. experimental model testing.

Seafloor sediment samples are necessary to provide ground truth information for geophysical surveys performed as part of the mapping programs. They are obtained through site investigation using shallow drop-core or deep-penetration downhole samplers. These samplers provide detailed information on stratigraphy, sediment types, and physical properties, such as density, strength, and deformational characteristics.

Since the first offshore borings were drilled in about 6 m of water in 1947, the technology for offshore drilling and sampling of sediments has advanced with the move into deeper water (McClelland and Ehlers, 1986). Until the mid 1970s, offshore site investigations on the continental shelf generally were made with a portable geotechnical drill rig mounted on a moored vessel (Figure 4-10; McClelland, 1972). As exploration and production moved to depths greater than 300 m, needs emerged for new and improved technology to compensate for increased costs and risks of the deepwater environment. In the mid 1970s, dynamically positioned geotechnical drill ships and specialized in situ testing equipment were introduced to improve the data quality required for these more difficult areas of the EEZ (Figure 4-11).

Figure 4-10
Oil field supply vessel outfitted with a portable drilling rig.
Source: McClelland and Ehlers, 1986.

During the past decade, there has been a major shift to in situ testing, which involves thrusting a sensor (such as a cone penetrometer or an in situ vane shear device) into the sediments to measure physical, geological, or engineering properties. This shift toward more in situ testing is the result of a number of factors. Economic incentives for offshore petroleum development provided the impetus to improve site investigation methods; major technological developments allowed more practical, reliable, and efficient in situ testing equipment; and investigators demonstrated the benefits of in situ test data for engineering analysis and design (Young et al., 1988a).

Experimental model testing of foundation elements has had limited application in the last decade to provide direct measurements of seabed response characteristics, such as foundation-bearing capacity, that are required to evaluate siting and design of bottom-mounted facilities. The high costs of full-scale foundation tests in remote EEZ areas will place greater emphasis on the smaller scale type of experimental testing.

The present ability to acquire geoscience data by sampling, and by in situ, laboratory, and experimental testing varies according to geographical area and water depth. Data acquisition systems are highly developed for water depths less than 300 m (Table 4-4), whereas only moderate or little development has occurred for the Arctic or in water depths exceeding 300 m.

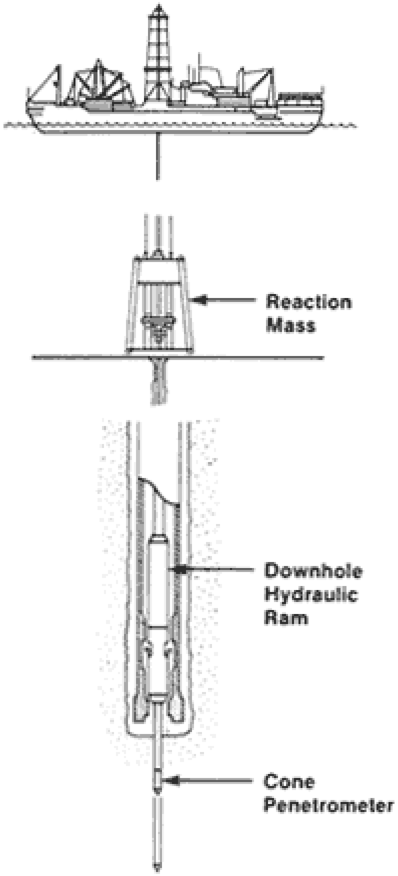


Figure 4-11
Dynamically positioned geotechnical drill ship with specialized equipment for in situ testing and downhole sampling. Source: McClelland and Ehlers, 1986

TABLE 4-4 Assessment of Capabilities for Geotechnical Data Acquisition Systems

	EEZ areas		
Systems	Shallow water (< 300 m)	Deep water (>> 300 m)	Arctic
Deployment	A	B	B
Sampling	A	B	B
In situ	A	B	B
Laboratory	A	B	C
Experimental model	B	C	C
Applications	A	B	B

A = Very highly developed
B = Moderately developed
C = Little developed

Deployment Systems

Deployment systems used for sampling or in situ or experimental testing (Figure 4-12) can generally be divided into three broad categories: self-contained units, drilling rigs, and submersibles. Table 4-5 lists the various deployment systems and types of vessels or underwater vehicles suitable for operations involving seabed penetrations of less than or greater than 10 m.

Self-contained units are the simplest, least expensive, and require the least complex support equipment. Sampling and in situ and experimental testing can be performed with these systems and carried out from almost any vessel equipped with the appropriate winches. The complete self-contained sampling or testing system is lowered to the seafloor by cables, which allows the operations to be performed with fairly loose ship positioning.

Various submersible systems—manned submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs)—can be used to deploy coring devices. Although these deployment systems have seldom been used to date, technological improvements in energy, navigation, autonomous guidance and control, sensors, and robotics will enhance the opportunity to use them in the future. Manned submersibles have been used to place instruments, retrieve samples, or carry survey sensors for seabed evaluation. Their advantage over other deployment systems is that engineers and scientists can participate directly, while their disadvantages, compared to ROVs and AUVs, are

- operational cost and complexity,
- limited bottom time and extensive turnaround or refurbishment periods between dives,
- inability to use smaller vessels of opportunity, and
- availability to perform in situ operations.

It is expected that use of ROVs and eventually AUVs will increase, while use of manned submersibles will not. Operations conducted under ice may be one application with an increased role for manned submersibles, since ROV use is limited in this area. However, risk to personnel has limited the use of manned submersibles under ice, and this limitation will continue to be a constraint in the future.

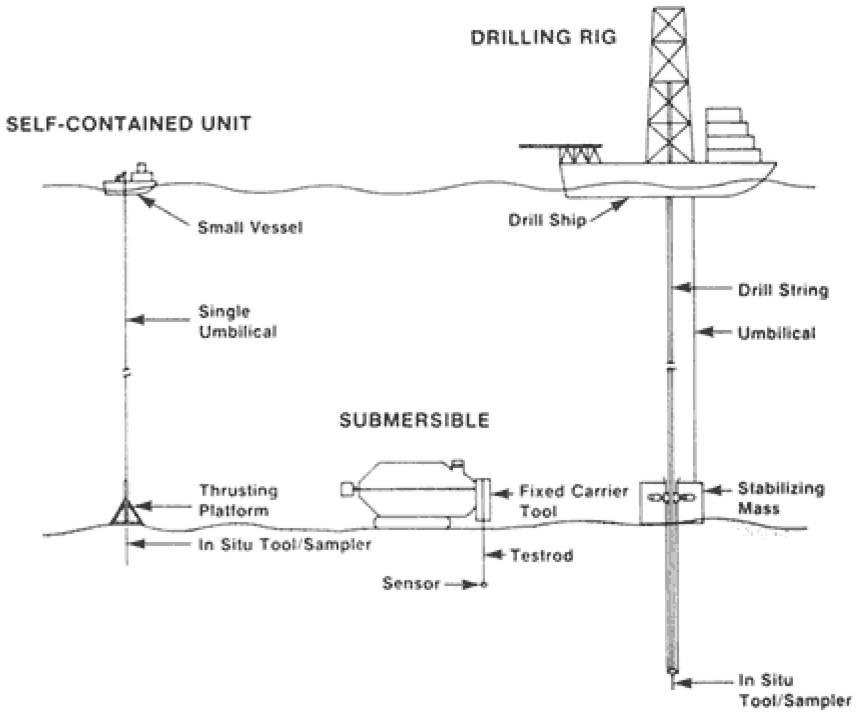


Figure 4-12
Deployment systems used for sampling, in situ, and experimental testing.

TABLE 4-5 Deployment Systems

System	Support[a]	Penetration below seafloor
Self-contained	UM, M, DP	< 10 m
Drilling	M, DP	> 10 m
Submersible	S, ROV, AUV	< 10 m

[a] UM-Unmoored vessels
M-Moored vessels
DP-Dynamically positioned vessels
S-Submersibles
ROV-Remotely operated vehicles
AUV-Autonomous underwater vehicles

ROVs have been utilized since the 1960s to support both commercial and military marine activities. Technological advances in vehicle navigation, command and control, power and propulsion, acoustic and optic sensors, robotics, and support and handling systems have allowed ROVs to be built that can operate in water depths up to 3,500 m from a multitude of support platforms in the open ocean. An ROV can be supported, powered, and controlled from a surface vessel; the system has proven it can support acquisition of samples, in situ measurements, and visual observations of the seabed. Sensor packages required for in situ testing can be placed on the seabed or integrated into an ROV to allow retrieval of recorded or real-time data via fiber optic data links. The size of many instrument packages is easily accommodated by the payload capacities (0.22 to 2.2 kg) of off-the-shelf ROVs. Larger in situ sampling systems, such as coring units or small drilling rigs, will require specially designed ROVs that are capable of being remotely maneuvered, landed, and operated on the seafloor (Geise and Kolk, 1983).

AUVs, vehicles programmed to function completely autonomously and exhibit some decision-making capability, will eventually provide an adjunct to ROVs for EEZ exploration and in situ measurements. Although still at the prototype stage, AUVs have been employed to a limited degree in subsea survey and mapping work. These vehicles have demonstrated some facility at autonomous or semi-autonomous operations to obtain acoustic profiles of the seafloor. The Canadian-built ARCS was developed to obtain bathymetry under ice and has been demonstrated in the Arctic (Jackson and Ferguson, 1984). This semi-autonomous vehicle is capable of preprogrammed maneuvers or can be controlled through an acoustic link. The French-built *Epaulard* has been used for autonomous deep-sea photography and topographical profiling. It can also be controlled via an acoustic communications link (Galerne, 1984; Michel et al., 1984). AUVs are less affected by water depth, currents, and weather conditions than ROVs, but their cost is three to four times greater (an estimate based on personal experience in developing similar commercial vehicles, which may be much greater for complex, long-range AUVs for military application).

Autonomous guidance and control systems for AUVs are based on algorithmic or deterministic software systems to achieve preprogrammed maneuvers and simple way-point navigation. This allows little ability to account for unknowns or changes in circumstances that could not be predicted during vehicle mission programming. Future AUVs will be based on rule-based, probabalistic-software concepts known as expert or knowledge-based systems (a form of artificial intelligence), which are still being developed. It is anticipated to be three to five years before operationally effective AUVs can perform difficult seabed sampling and coring operations (Geise and Kolk, 1983). These systems will eventually be used for commercial seabed reconnaissance and exploration, but their role will probably be limited to specialized tasks. These tasks must provide a clear economic or operational advantage over ROVs, such as Arctic operations under ice.

Sampling Systems

Sampling equipment may be divided into two broad categories, depending on whether the systems are used in a downhole or seafloor deployment mode (Table 4-6) (Young, in press). Sampler deployment with the seafloor mode can be used in any type of vessel, including small oceanographic vessels (less than 45 m). Seafloor deployment generally limits penetrations to 10 m or less, except for the giant piston corer (Hollister et al., 1973). Although cores up to 16 m long were obtained in 4,500 m of water during Woods Hole's long coring program in the 1970s, most seabed samplers are gravity driven and are traditionally operated in depths up to 2,000 m, except the vibracorer sampler, which is powered by pneumatic, hydraulic, or electrical units that require special power systems or power supply cables to operate in these extreme depths.

Downhole samplers can be used in conjunction with an uncompensated or motion-compensated drill string (Table 4-5). Although both types have traditionally been limited to water depths up to 1,200 m with vessels installed with a permanent drilling or portable rig, the Ocean Drilling Program (ODP) has demonstrated through its international program that the advanced piston corer has the capability to acquire downhole samples in water depths up to 6,000 m using the ODP highly specialized, deepwater drilling vessel (Peterson, 1984).

Samplers used with an uncompensated drill string require that the device be isolated from drill pipe motion caused by the heaving vessel. The wireline percussion sampler has been standard for this type of operation since the early 1960s, when it was first used for anchored supply vessels as shown in Figure 4-10 (Emrich, 1971). Its major shortcoming is sample disturbance, which decreases shear strength and alters other physical and engineering properties of the sediment. Because of the inability to compensate for these effects, the "push" sampler was developed in the late 1970s (Young et al., 1983). The push sampler is operated by latching a thin-walled sampling tube beneath the drill bit allowing the weight of the drill string to push the tube into the sediment beneath the borehole.

Soil samplers developed since the mid 1970s use a stabilized drill string that requires a heave compensator on the vessel to vertically stabilize the drill string with reference to the seabed. These samplers allow high-quality samples to be taken with push, piston, or core barrels in water depths up to 1,200 m. These sampling systems require a large seafloor reaction frame that clamps the drill pipe and holds it stationary while the downhole tool provides the thrust for sampling (Figure 4-11).

In Situ Testing Systems

Over the past decade, there has been an increased emphasis on determining various sediment properties by in situ testing techniques because stress relief and disturbance effects during sampling often alter physical and engineering properties of the recovered sediment (Kirkpatrick and Kahn, 1984). Table 4-7 lists various in situ testing devices and the sediment properties measured with each.

Some in situ equipment can only be used from self-contained units in the seafloor operational mode, which limits seabed penetrations to 10 m or less. Other devices operate in a downhole mode, allowing measurements to be made at seabed penetrations up to 300 m. When used downhole, in situ tools also require a motion compensator and a large seafloor reaction mass; thus, in situ tools require a specialized dynamically positioned drilling vessel that can maintain location over the seabed position of the reaction frame (Figure 4-11).

TABLE 4-6 Deployment Modes for Sampling Equipment

Penetration	Tools
Shallow seabed < 10 m	Piston coring Gravity coring Drop cores Benthic layer samplers Vibracorer
Deep downhole > 10 m	Percussion/driven sampler Push samplers Piston samples Core barrels Sidewall samplers

TABLE 4-7 Deployment Systems for In situ Testing Devices

	Type		
Tools	Shallow seabed penetration < 10 m	Deep downhole penetration > 10 m	Measurements
Cone penetrometers	X	X	Strength
Vane shear	X	X	Strength
Drop Penetrometers	X		Strength
Pressuremeter	X	X	Stiffness
Logging	X	X	Density
Seismic	X	X	Stiffness
Thermistors	X	X	Temperature
Hydrophones	X		Acoustic
Densiometers	X		Density
Piezo cone	X		Pressure
Gradient		X	Pressure

Laboratory Testing

Conventional laboratory testing is performed to determine geological and geotechnical properties of samples acquired during offshore site investigation. Some of these tests require high-quality undisturbed samples, while others are performed on highly disturbed samples. Most laboratory tests are performed onshore, so sample packing, transporting, and storing are critical to minimize moisture loss or physical disturbance (Young et al., 1983). During the past five to ten years, portable testing laboratories on vessels have allowed more routine strength and classification tests to be performed at sea so that data can be acquired on samples before the full effects of stress relief occur.

Most existing and projected uses of the EEZ seafloor will require measurement of various sediment properties, while others will use geotechnical data only as background information. Although in situ testing will continue to increase, laboratory testing will continue to play a major role for most studies for a variety of reasons (Lee, 1985). One major reason is that in situ measurements are difficult to use in interpreting geological processes. Samples provide confidence to the user by providing ground truth to in situ tests. A variety of different stress conditions may be imposed on samples over longer time periods than is possible with in situ tests, which is important in measuring drained, cyclic, or creep properties.

Standardized laboratory procedures to test samples for a variety of properties (Sullivan et al., 1980) are available to determine the following:

- sediment identification and classification,
- behavior under various stress and strain levels,
- compressibility characteristics under sustained load, and
- stress-strain characteristics and pore pressure response under cyclic loading.

State-of-the-art laboratory testing is a mature technology, as evidenced by the numerous books that detail procedures and equipment, but further improvements are needed and additional work will be required to improve understanding of differences between laboratory and in situ test data (Lee, 1985).

Experimental Model Testing Systems

Many foundation design procedures used in geotechnical engineering have relied on small-and full-scale testing to verify their validity. This type of testing, when performed onshore, typically consists of axial or lateral pile load tests or large-scale plate load tests. Results from some experimental tests that look promising are described below. The high costs of performing full-scale tests in deep water and the Arctic precludes their use, and use of experimental model testing to improve understanding of seafloor responses to various foundation loadings has increased in the last decade.

Plate load tests using the Seacalf jacking system to load a seafloor plate have been used in the North Sea to determine soil stiffness and seafloor bearing capacity (Andresen et al., 1979). A small-scale experimental model has also been used to perform bearing capacity tests of the Mississippi River delta clays (Stremlau and Spencer, 1980). The main limitation to small-scale tests is that only the sediments 1 to 2 diameters below the model foundation can be tested (Poulos, 1988). Hence, a complete vertical profile of soil resistance requires testing at multiple depths.

Experimental model testing can be used offshore to determining pile design parameters. A series of axial load tests has been performed on pile sections installed in a borehole using a modified cone penetrometer loaded by a seabed jacking system (King et al., 1980). A more elaborate small-scale model pile has been used to determine the frictional resistance of a pile while a series of other measurements are being made. This testing is greatly improving the understanding of the pile load-transfer mechanism in many different marine sediments.

Sediment response to a heat source has also been tested with an in situ instrument that measured the thermal, geochemical, and geotechnical properties of sediments in 1,750 m of water in the north central Pacific Ocean (Silva and Wyland, 1987). Establishing the feasibility of certain types of waste disposal, including injection of solidified high-level nuclear waste into geologically stable sediments, will require further experimental testing of this type.

Centrifuge model testing is a developing technology with universal application to seabed engineering problems. Acceleration applied to physical models can be used to induce conditions that accelerate various processes and simulate natural events. Centrifuge testing has been conducted to solve many offshore problems involving quasistatic cyclic loading conditions (Rowe et al., 1976; Craig and Al-Saoudi, 1981; Rowe, 1983). The theoretical principles of operation of the centrifuge have been described by Schofield (1980). This equipment provides the capability to test platform models with diameters up to 100 m, piles with diameters of 2 m, and caissons with diameters up to 12 m. Its key benefit is the economy for experimentally checking models described by complicated analytical procedures. Increased use of centrifuge modeling is expected to enhance the understanding of the mechanism of foundation behavior and to provide direct design parameters for performance predictions.

Technology Limitations/Needs

The technology for acquiring samples, performing laboratory tests, and obtaining in situ and experimental geotechnical data is technically mature for water depths to 300 m within the continental shelf areas (see Zuidberg et al., 1986; Briand and Meyer, 1983). Development activities in the Arctic and off the continental shelf in depths exceeding 300 m will depend not only on advances in technology but on the availability of research vessels. For example, a dynamically positioned drill ship is necessary to acquire geoscience data in water depths greater than 300 m when seafloor penetrations greater than 10 m are required. However, there are only two of these specialized vessels capable of working in these extreme water depths, and both are foreign-flagged and stationed in the North Sea. Use of these vessels in U.S. EEZ waters will require costly mobilization, which restricts their use except for the most extensive developments, such as site investigations for oil and gas production facilities. The drill ships operated under the Deep Sea Drilling Program (DSDP) and the Ocean Drilling Program (ODP) operate under international scientific agreements and are not available for use for national resource assessment purposes. The restricted availability of these vessels has limited major research programs to quantifying near-seafloor characteristics.

The limited availability and high cost of geotechnical research drill ships could be mitigated by development of a rapidly transportable seafloor deployment system (Figure 4-13) that could be operated from a surface vessel, an ROV, a manned submersible, or a submarine (Young et al., 1988b). The system needs to be compact, possess onboard memory, and be capable of thrusting geotechnical probes and samplers to relatively deep penetrations (as much as 100 m) below the seafloor. If operated from an ROV, it should be capable of being deployed from a small supply or oceanographic vessel without fixed mooring. The various development applications within the EEZ may impose exceptional requirements on the capabilities of the device as presented in Table 4-8.

In situ probes and sensors have been developed and used extensively over the past decade to acquire geotechnical data. In situ and laboratory test results have been used successfully in water depths to 300 m; however, stress relief and soil degassing will intensify in samples obtained from deeper water, which will complicate data interpretation. Additional improvements in in situ data interpretation will be needed to confirm the reasonableness of the data for design purposes. The capability to measure true, in situ ambient pore pressure to determine the existence of hydraulic gradients in various geological environments will also require special attention in the future, because knowledge of in situ ambient pore pressures will provide a better understanding of altered pore pressures induced in samples obtained from extreme water depths (Denk et al., 1981). Samplers and in situ testing probes and sensors feature a number of different designs, and standardization of test procedures will be needed in the future. For example, the location of measurement sensors and test speed are known to influence pore pressure measurements, which could complicate data interpretation for design purposes.

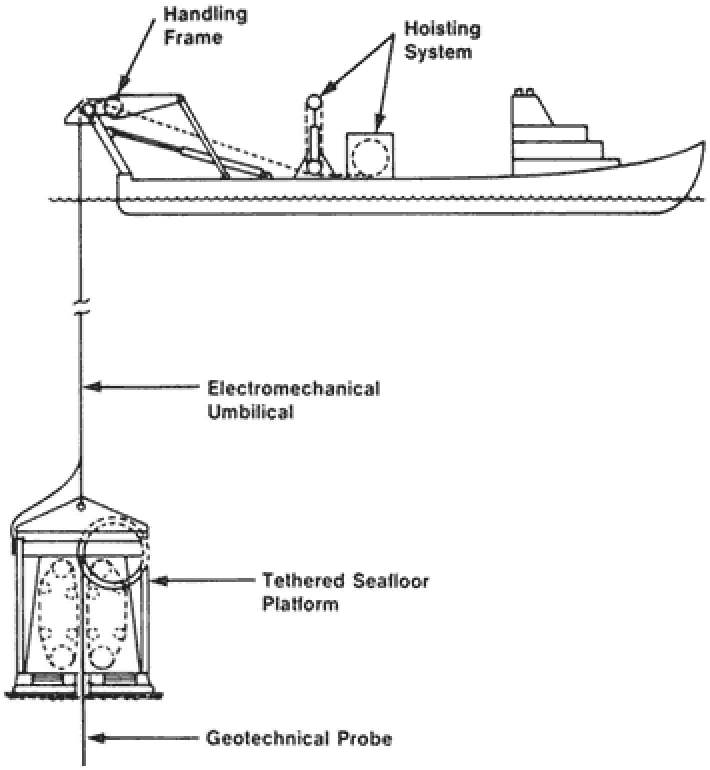


Figure 4-13
Rapidly transportable deployment systems. Source: Young et al., 1988b

TABLE 4-8 Exceptional Testing Requirements for Various EEZ Development Applications

Development application	Exceptional requirements
Oil and gas	Large penetrations beneath seabed Wide variety of tests
Waste disposal	Site variability definition Chemical and thermal characteristics Permeability and absorbent characteristics
Military	Rapid deployment Acoustic characteristics Bottom signatures
Pipelines and cables	Rapid, route deployments Thermal characteristics (Arctic)
Minerals and mining	Rapid, area, region deployments Consideration, concentration, chemical characteristics

Summary

The capability to acquire geotechnical data by sampling and by in situ, laboratory, and experimental testing has improved greatly over the past decade, and this technology is relatively highly developed for shallow-water areas (less than 300 m). Advancing to deeper water and the Arctic will depend on further development of improved sampling and in situ testing equipment capable of determining sediment properties in difficult offshore environments. It will also require improved experimental testing methods capable of measuring seabed properties and behavior in a more controlled manner. Compact deployment systems are needed that can operate rapidly and automatically to measure engineering properties or sample seabed sediments. As activities expand into EEZ frontier areas, new geologic models will be required to characterize sediment properties and behavior in engineering terms. New interaction problems between sediments and foundation elements arising from innovative structures, such as tension leg platforms, will require development and verification of analytical models and field monitoring of the structures.

New and improved data acquisition systems will allow accurate and meaningful data to be collected that better describe engineering properties and geologic conditions that could strongly influence the design, location, construction, operation, and maintenance of engineering projects planned for the EEZ. However, their development will require a thorough technical evaluation. Future proposals for technology development by government and industry must consider priorities and objectives for various data acquisition systems because of their complexity, cost, and time frames.

EEZ SEABED MONITORING

The seabed of the U.S. EEZ is almost as varied as the seabed of the entire ocean, and the environmental consequences of expanded activities in this region will be difficult to predict in advance. Environmental monitoring provides a basis on which such predictions can be made, but past EEZ monitoring has had mixed results. During the 1970s, $27 million was spent on background studies for environmental impact statements for OCS oil and gas (MMS, 1973–79). However, the biological data were collected over such a large area that the impact of subsequent operations on local organisms and environments was difficult to assess. A more focused and useful effort conducted on Georges Bank in the late 1970s occupied monitoring stations at various distances from drilling vessels during all drilling phases. The effects of drilling muds on sediments were well documented, biological impacts were easier to ascertain, and the observed changes provided criteria for modifying discharge requirements in future drilling operations (NRC, 1978).

Several possibilities for structuring an EEZ monitoring program have been suggested (Segar, 1986):

- monitor to verify or refine models of the transport, fate, and impact of materials;
- monitor to determine if the response of specific indicator organisms to pollutant levels is sufficient to trigger remedial action;
- establish background levels of critical substances prior to using a particular area and then monitor to evaluate temporal and spatial changes (trend assessment monitoring); and
- monitor to assess compliance with water or sediment quality regulations and environmental use-permit requirements (compliance monitoring).

Based on these past efforts and evaluations, this report will focus on three types of monitoring.

1. *Reference monitoring* establishes transects or sites that can be occupied for years, collecting measurements that yield general baseline reference data for time-series considerations. These data

may or may not be linked to a specific process or activity and will aim to provide critical insights about the variability of the seabed environment.

2. *Process-oriented monitoring* is conducted where important near-bottom processes can be easily studied to understand and predict their interaction with EEZ uses.
3. *Use-related monitoring* is the measuring of parameters to assist a proposed or ongoing seabed use and evaluate its impact.

Reference Monitoring

Interpreting information gathered during EEZ surveys or studies of basic processes often suffers from insufficient knowledge of the long-term environmental context. Natural temporal and spatial variations in physical, chemical, and biological properties must be understood in order to realistically interpret any observed changes. Proper design of use-related monitoring programs requires such long-term knowledge.

One approach to reference monitoring is to designate specific long-term benthic reference sites or transects in the EEZ. How many of them should be designated, how they should be selected, and where they should be located will depend on their purpose and on available personnel and resources. It is not physically or fiscally possible to continually monitor large areas or an extremely large number of smaller areas. Criteria and considerations necessary for selecting specific reference sites are examined in depth in the report of a National Academy of Sciences panel (NRC, 1984).

Because the U.S. EEZ is so vast and monitoring time-scales can range from minutes to decades, selecting reference locations may depend on considerations such as those that follow.

- The number of locations needs to be large enough to cover several characteristic types of seabed environment and small enough to permit the intense sampling required to detect higher frequency events.
- Locations could be similar in concept to the Long-Term Ecological Reference (LTER) sites on land (Callahan, 1984). They could be placed either in typical seabed regions to optimize their basic research value or in areas where future seabed uses are anticipated to permit acquisition of truly long-term baseline information.
- Reference locations may also be selected in areas designated as preservation areas.

Achieving a consensus on selection criteria will require considerable input from the scientific community, environmental groups, and potential seabed users, and will depend on the projected resources for long-term sampling and monitoring.

Sampling strategies at the reference sites may follow two major phases:

1. initial high-frequency sampling to establish the characteristic scales of temporal and spatial variations, and
2. long-term sampling programmed to maximize information return and performed at optimal frequencies based on phase 1 results.

Protocols for seabed and near-bottom reference sampling will depend on the phenomena being studied and the terrain. Complex seabed terrain with large relief will *a priori* be a candidate for higher density sampling than low-relief seabed or gradually changing water depths. Basic measurements include water transport (currents, turbulence), water properties (salinity, temperature, suspended particle concentrations, nutrients, and dissolved oxygen, etc.), biological diversity and abundance, and sediment properties. Utilizing the latest monitoring technologies will increase cost effectiveness: for example, measurement of current patterns by acoustic tomography (Munk and Worcester, 1988) and measurement of sediment erodibility by instrumented flumes. Although very little reference-site monitoring is being done now, the next ten years should see increased activity.

By then, appropriate techniques should have been perfected to such a degree that reference monitoring could remain at a steady level into the future.

An aspect of reference monitoring that may indicate pollutant levels near the seabed and provide early warnings of environmental degradation uses "sentinel" organisms along with measurements of sediments. Such early warnings can be followed by detailed specific investigations. The sentinel approach is analogous to NOAA's National Status and Trends (NS&T) Program in coastal and estuarine environments (NOAA, 1984). (NS&T also includes a specimen bank so substances that may be designated pollutants in the future may be evaluated in previous environments.) An "EEZ-NS&T" program would not necessarily be linked to a specific seabed use or to reference-site monitoring. Because of EEZ water depths and seafloor environment diversity, choosing sentinel organisms and sediment analysis methods might be more difficult than in the NS&T program. If a consensus could be reached, however, an EEZ NS&T program could be pursued for 10 or even 25 years, with organisms and pollutants updated as necessary.

Process-Oriented Monitoring

The objective of process-oriented monitoring is to acquire detailed knowledge of natural processes that have intense effects on specific seafloor areas and that cannot be adequately studied with reference monitoring. The two monitoring approaches may overlap to some degree if important processes happen to occur in reference areas. As interest in various processes wanes or waxes, some process-oriented monitoring sites will be abandoned and new ones chosen, thus making process-oriented monitoring inherently shorter-term than reference monitoring.

Typical processes that have been studied include the following.

- Shifts in major ocean currents that impinge on the bottom, such as those examined in the mid-Atlantic region (Lee et al., 1981, 1982). Their study focused on physical and chemical changes associated with the Gulf Stream moving onto the U.S. continental shelf, but did not include consequences to benthic organisms.
- Grounding of sea ice and its impact on sediment properties and seabed communities off Alaska has been investigated by the Navy and by oil and gas industries (AOGA, 1978), but techniques for observing it directly are not well developed, and many questions remain (NRC, 1985).
- Mass wasting of sediment near the shelf break, at the head of submarine canyons, or in other EEZ areas has been studied for many years (see Chapters 2 and 3) and very likely will be continued and expanded.

Parameters to be measured and monitoring frequency (from minutes to years) and duration will vary by process and proposed use. Important parameters include temperature, salinity, geotechnical properties, near-bottom turbidity, dissolved substances (nutrients, oxygen, and trace metals), current speeds and directions, and pollutants in both the seabed and the adjacent water column.

The need for process-oriented monitoring will increase in the next 25 years as EEZ uses increase. Two uses of the seafloor near the shelf break expected to expand in the next 10 years—oil and gas production and undersea submarine surveillance—will require better ways to predict physical and chemical consequences of shelf-break erosion or sediment loss. The effects of these processes will need to be studied well in advance of installation of bottom-tethered equipment because of the large variety of potential sites and length of time over which predictions must be made.

Use-Related Monitoring

Use-related monitoring ensures that seabed installations function properly and determines whether remedial action is necessary if a particular EEZ use (waste disposal or mineral exploration, for example) poses hazards to human health, living marine resources, or overall quality of the marine environment. Monitoring for use-related impact is the most common form of monitoring conducted today, particularly trend assessment and compliance monitoring.

Waste Disposal

A conceptual model setting the framework for waste-related environmental impact monitoring and its associated decision-making process proposed by an NRC panel on particulate wastes (NRC, 1989) focuses on how and over what time scales organism-sediment interactions may be affected by changes in particulate material composition or character on the seabed, and on the feedback of monitoring data to modify a permitted dumping protocol (Figure 4-14).

To restrict scattering, particulate wastes dumped at sea are typically placed in long-term repositories in areas thought to be quiescent. To confirm the suitability of potential waste sites, a monitoring program normally includes short-(days) and long-term (seasons to years) measurements of water flow and circulation.

In the initial stages of dumping, short-term baseline monitoring of the water and the physical and biological characteristics of the sediments around dumpsites may be advisable. A technique that may prove useful is the technology of remotely sensing the seafloor using optical data on the upper sediment. Its appeal is the ability to survey large areas (i.e., square kilometers) of the seabed in only a few days (Rhoads and Germano, 1986). Remote sensing technology is particularly effective for evaluating the depth to which dissolved oxygen penetrates the sediment, which is critical to the mobility of both contaminants and benthic organisms. Because of speed and low cost, some improved version of this technology will probably be employed to survey areas around dumpsites and

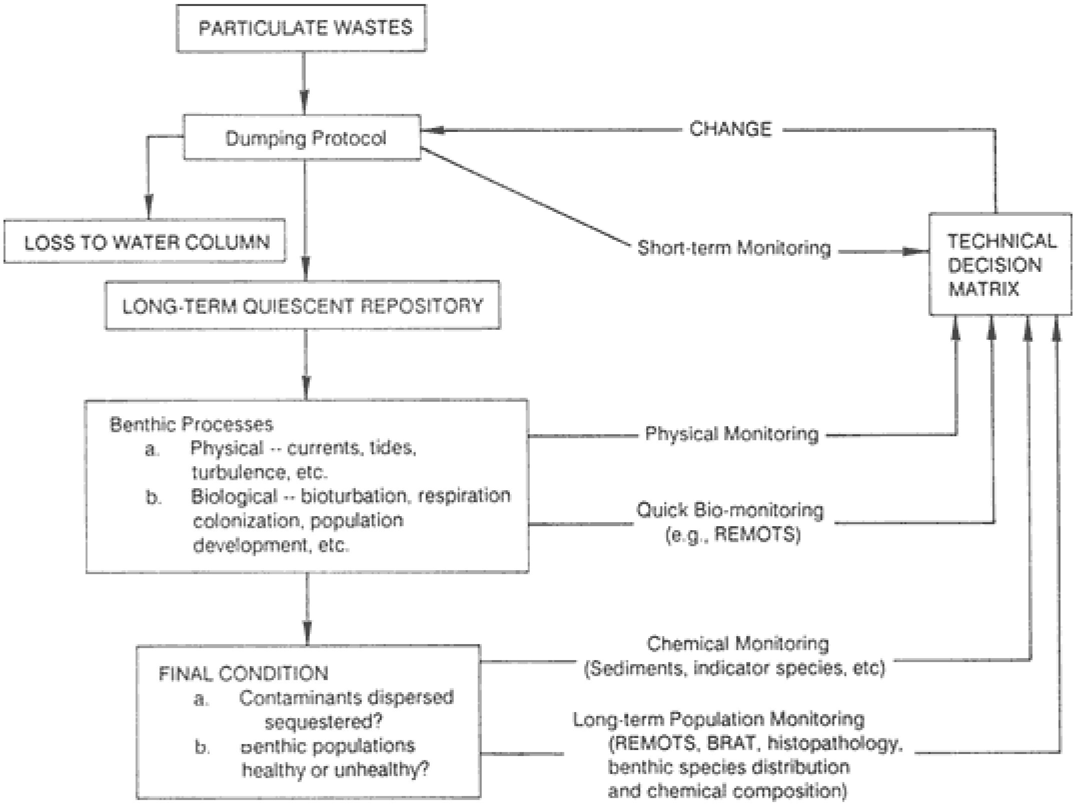


Figure 4-14
A monitoring decision model for waste dumping in the EEZ.

determine which ones need more detailed, longer-term studies. Remote sensing technology is limited to providing a quick scan of a vertical section and does not produce information about complex benthic interrelationships.

Long-term monitoring (Figure 4-14) will also involve a more complete benthic evalution of sediment and fish or benthic animals living in (infauna) or on (epifauna) the sediments at sites likely to be affected by dumping (Rhoads and Germano, 1986). This longer-term monitoring will also include histopathologic studies of collected organs and tissues of animals, which are the easiest and most effective way to assess their physiological condition or "health" (Yevich and Barscz, 1983).

The single most important consequence of waste-disposal monitoring should be a rapid response to detected changes. Dumpsite monitoring data fed into a Technical Decision Matrix at several stages of dumping (Figure 4-14) can indicate unacceptable environmental departures from previously established limits. In such a situation, a speedy regulatory decision to modify the dumping protocol will minimize damage to the biological community at the site.

Some projections can be made about waste disposal monitoring over the next ten years. For dredged material disposal, the Army Corps of Engineers has designed a project using a more elaborate version of Figure 4-14 to anticipate the impact of dredged material deposited in New England coastal waters (NRC, 1989; Fredette et al., 1986). A similar approach may be increasingly employed to follow and manage dredged material dumping in the EEZ, and could also be applied to fly ash and incineration ashes. However, greater water depth and more varied terrain will require modification of the monitoring decision protocol. For example, wastes dumped into deeper waters will be more dispersed and diluted than in shallow water, so more sensitive surveying and sedimentary analysis techniques will be required. This problem was highlighted by the difficulty of finding dumping residues at deepwater dumpsite 106 off the east coast (O'Connor et al., 1983). Further, management decisions may have to be made on the basis of fewer samples, because of the difficulty and greater costs of deepwater sampling.

Over the next ten years disposal of "packaged" wastes (i.e., ash and sludge blocks or containerized nuclear wastes) is anticipated (Manheim and Vine, 1987). Packaging of incineration ash and hazardous waste in stabilized blocks may require special monitoring strategies that will differ from those discussed above because interactions between the benthos and the package itself will have to be considered (Roethel et al., 1986; Shieh et al., 1989; Manheim and Vine, 1987). These interactions will be important to predicting package lifetimes and waste release rates. Packages may attract or repel species, thus different indicator organisms may be needed and sampling strategies may require sampling near the packages without disturbing them.

Oil and Gas

Monitoring associated with oil and gas exploration and production has two purposes: to guarantee stability of pipelines and platforms, and to ascertain and minimize environmental damage during drilling and production. Stability assurance requires pre-use, site-specific information on subsea and seafloor characteristics, and historical data on winds, waves, and currents. Process monitoring will determine the magnitude and velocity of the seafloor sediment movement and seismic surveys of active surface faults (e.g., the Santa Barbara Channel), will estimate potential effects of fault motion on structures, and will determine if fault motion is influenced by production operations.

Exploration and drilling in the deeper water and the arctic EEZ will probably increase most rapidly over the short term (ten years). In deeper waters, monitoring will have to be modified to cope with the rigors of greater depths. This may result in reliance on remotely operated vehicles and sampling systems. In the Arctic, ice floe movements, seasonal ice presence, and marine animal migration and life cycle patterns need to be predicted both regionally and at specific exploration and production sites. Tracking ice by satellites using microwave radiation in synthetic aperture radar

(SAR) may become important because of SAR's ability to penetrate cloud cover. SAR's large power requirements are a problem that will have to be overcome, however.

It should be noted that there is no procedure presently set up to follow the long-term effects of a large oil spill that happens to reach the EEZ seabed.

Minerals

Monitoring needs of EEZ seabed mining are difficult to forecast. If sand and gravel mining in water s increases and moves to deeper deposits, pre-use and use-related monitoring would be indicated (U.S. Bureau of Mines, 1987). For any mining activity, impacts on benthic communities at the mine site and surrounding areas large enough to evaluate far-field effects that need to be assessed include recolonization rates, metabolic energy fluxes, sensitivity to sedimentation, and other ecosystem relationships. Mining of iron-manganese crusts could cause serious environmental impacts, but few studies of undersea mining impacts on surrounding environments have been done (Manheim, 1986). Research for environmental impact analysis (fates and effects of suspended sediments in surface water and composition and dynamics of benthic ecosystems, for example) needs to keep pace with the schedule of commercial development.

Military

Use-related monitoring of military activities in the EEZ seabed occupies a curious position because so much data is and probably will remain classified. Weather-related data are not generally available to other EEZ users, and other data (e.g., from the Fleet Numerical Weather Facility) may have only limited availability due to the Navy's need to keep sampling locations secret. Naval test ranges are used throughout the EEZ, but it is not clear if there will be environmental investigations related to this use. Recent changes in policy have opened up much of the bathymetry to the public domain. The accessibility of Navy monitoring data of disposed equipment is better. For example, as part of the CHASE (Cut Holes And Sink 'Em) scuttling operations, environmental evaluations were performed to assess impacts, and the data are generally available. Navy monitoring of disposal of surplus or outdated equipment and supplies will probably continue over the next 25 years, and data will likely be available.

Monitoring Needs

Pollutant Detection

Detecting sewage sludge in sediments at deepwater dumpsites (such as Site 106 off the New York Bight), may be extremely difficult because the presence of existing nonsludge sediment and the feeding and movement of seabed organisms lower the sludge content of the sediments (O'Connor et al., 1983). The sediment analysis may not accurately reflect the extent of the environmental damage. Also, the coarse-grained sediments in the shelf-edge portions of the EEZ are more difficult to analyze than the finer-grained coastal and estuarine sediments analyzed under NOAA's NS&T program, since pollutants are primarily associated with clays. In these situations sediment traps might be used to collect sinking particles and estimate the rain of pollutants to the seabed. There are problems with sediment traps (e.g., the hydrodynamics of particles), however, and research on trapping techniques is still required (NRC, 1984).

Which pollutants should be measured in EEZ monitoring has not been addressed either. The organic and trace-metal pollutants monitored under the NS&T program (NOAA, 1984) might be adopted for the entire seabed region of the EEZ, with some adjustments made for substances to be measured and tissues to be analyzed.

Biological Assessments

Choosing sentinel or indicator organisms may be more difficult in the EEZ than in coastal waters. Benthic life in the EEZ differs from that of coastal waters. For example, increasing depth works against the presence of large multicellular plants (macroalgae) on the seabed because overlying water absorbs too much light. Also, assessing species populations over the larger areas and great variety of benthic environments in the EEZ will be a lengthy process using conventional techniques, such as taking core or sediment samples, sorting animals into size fractions with sieves, and identifying and determining their condition. This work is expensive and takes days to weeks to do for a single site. A well-conceived monitoring program will have to consider many sites spread over a large area, some of which will be reoccupied continuously. Demand for data will require continued development of remote sensors of physical, biological, and chemical conditions on the EEZ seabed.

Sampling Strategies

Determining sampling frequencies and technologies to define a given phenomenon are difficult because time and space capabilities of sampling devices or platforms have to be matched to the domain of the phenomenon being studied (Figure 4-15). For example, a single ship cannot determine synoptic spatial distribution of phenomena that recur every few days because it cannot return to a given location in an area that may cover hundreds or thousands of square kilometers. Sampling frequency is also affected by costs, since the magnitude of sampling needed may be financially prohibitive even though the technology exists to do it. Reaching compromises between optimum sampling schemes, available technologies, and funding resources will probably be among the thorniest issues to be faced by EEZ monitoring programs.

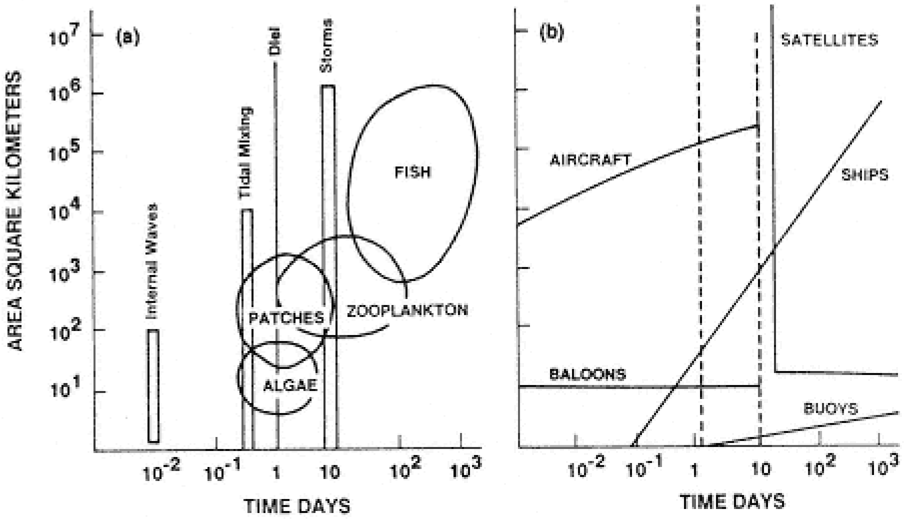


Figure 4-15 (a)
Time and space domains of circulation events, habitat variance, and biological abundance in relation to (b) duration and scale of sampling platforms. Source: After Walsh, 1988.

Frontier Environment Considerations

Monitoring instrumentation needs for the EEZ are those needed to adapt to deeper water and arctic environments. Instruments left for longer exposure times (due to sampling frequency requirements or longer distances) and in deeper water may face problems of fouling, stability, and calibration of physical and chemical sensors. In the Arctic, technology improvements are needed to follow ice movements and study ice gouging in detail (NRC, 1985). SAR power and data storage requirements of synthetic aperture radar are too great, and the minimum sizes of ice floes detectable by other remote techniques are too large.

Technology Advances

Advances in measurement technologies that will improve monitoring over the coming years include

- acoustic tomography to obtain large-scale pictures of water-mass movements in short time periods (Munk and Worcester, 1988),
- lasers to study movement of suspended particles (Carder et al., 1982),
- instrument packages with oxygen microelectrodes to investigate sediment chemistry on millimeter scales (Revsbeck et al., 1986), and
- rapid acquisition of data from monitoring buoys using satellites.

Nontechnical Problem Resolution

The principal nontechnical constraints to EEZ monitoring are monitoring priorities, designation of monitoring organizations, determination of monitoring frequency and duration, quality control, protocol for monitoring data release, and adequate funding. Information sharing among EEZ seabed users will be a problem because there is no central repository for monitoring data that can provide timely access for users (see "Data Management" for a more complete discussion). Given the many and varied U.S. monitoring efforts, a single project will probably not obtain all the data that will ultimately be needed. Especially important are data taken simultaneously from many locations, which are vital to devising computer models that can predict actual events as closely as possible to real time frames. Delays in data delivery will make short-term predicting (hours to days) after a monitored event extremely difficult.

Another data-sharing problem is the classified or proprietary nature of Department of Defense (DOD) and industry monitoring data. For example, DOD may choose to classify bathymetry data in areas that are also important for such uses as deciphering the shape of terrain around waste-disposal sites. Mechanisms to speed review and release of such data would be useful.

Summary

Monitoring will provide vital data on natural variability and baseline information about benthic processes that affect areas of proposed or ongoing EEZ use. Linking use monitoring data to regulatory decisions will allow rapid response to hazardous situations. The magnitude of the EEZ area, variety of benthic environments, and greater depths will affect what is selected for monitoring, how much it will cost, how long it will take, and what kind of technology is needed. Accomplishing EEZ monitoring will require planning and commitment of resources adequate to the task. Without them, data quality and quantity could be inadequate for making sound decisions regarding permitted uses, perhaps ultimately leading to inadvertant and unacceptable environmental damage. 3

DATA MANAGEMENT

As development of the EEZ progresses, enormous amounts of data will be collected by government agencies, industry, and academia using the technologies described in this chapter. Already very large data sets exist or are being developed, including bathymetry, seafloor imagery, subsurface seismic profiles, bottom samples, and cores, together with oceanographic and biological data for the seafloor and benthic boundary layer. These data are widely dispersed and exist in different formats and archiving styles, a situation that lends itself to a distributed network rather than a centralized system. Much of the data gathered by government agencies are archived at NOAA's National Geophysical Data Center and are publicly available. By comparison, seismic data, particularly multichannel exploration profiles, are collected by industrial groups and are proprietary. Various projects, including CONMAP (USGS) and the Strategic Assessment Atlas Project are compiling inventories of EEZ data. Industry consortia projects frequently combine and phase data for mutually agreed tasks for particular EEZ areas, but there are no shared data inventories.

Management objectives for rapidly expanding the EEZ data base are the efficient use of available data and the reduction of unnecessary duplication by facilitating data accessibility and exchange. While EEZ data sets are large and will expand dramatically in the future, data management hardware is not a problem. The computer industry is aggressively competing to develop more capable components and systems for data handling, manipulation, transmission, and storage. Nonhardware problems do exist, however, including appropriate management systems and diversity in hardware, software, networks, and user operation conditions. Various data management options need to be examined within an actual, defined framework of what data exists, what will be acquired, and how available they are. Compiling a basic inventory of industry, government, and academia data collections, formats, styles, quality, and availability is the logical next step.

Geographical information systems (GIS) are effective data storage and retrieval tools in which geographic location and areal distributions are important attributes. An EEZ GIS could combine data on water depth, bottom gradients and roughness, sediment types and thicknesses, seafloor biology, and bottom processes with precise locations of sample sites, monitoring sites, boreholes, and survey lines. Additional data would include past, present, and anticipated manmade features, such as wrecks, dumpsites, cables, pipelines, abandoned wells, and bottom structures.

Data that might be contributed to an EEZ management system come in a variety of forms, so any system will face the special challenges of not only locating and cataloging data, but describing specific formats and providing instruction as well. Thus establishing standard formats and guidelines for directories, catalogs, and networks is an essential preliminary task for achieving effective data management.

Another important problem is the diversity of existing computer facilities and networks. Since this situation is unlikely to change, there is a need to link various existing computer networks. Such development requires leadership, which could be provided by a committee of EEZ data system participants, a U.S. government interagency group, or an academic or industrial systems organization.

Security of data will require careful attention, especially in an open, highly distributed, data management system. There are three main aspects to securing data: control of access, control of expenditure of resources, and damage to data sets and other resources.

Government leadership will be vital for establishing a comprehensive data management system and implementing standards to facilitate the easy exchange of data, while at the same time maintaining the appropriate level of security. The most important function of such a system is to provide coordination and management of a widely dispersed database. Users must be able to access information *about* data, i.e., what data are available and how to obtain them.

5

The Challenges of EEZ Use

The EEZ seabed represents a diverse, poorly understood, difficult, and sensitive environment that differs fundamentally from coastal and terrestrial areas, where engineering practice and experience are more advanced (see Chapter 2). Present and potential uses of the EEZ seabed will involve a wide range of activities that may include trenching, excavation, drilling, pile driving, and anchoring. These activities will support the placement of cables, pipelines, instruments, and structures (see Chapter 3).

The major challenge is to achieve the efficient use of the EEZ seabed, which will require a thorough understanding of seabed characteristics and processes at prospective sites for specific activities. Achieving this goal entails two interrelated tasks:

1. The impact of seafloor characteristics and processes on the proposed engineering activity must be rigorously defined for cost-effective and safe planning, design, construction, and maintenance.
2. The impact of the proposed activity on seafloor characteristics must be carefully determined and monitored to minimize use-related changes and environmental degradation.

Accomplishing these tasks depends on the ability to gather various kinds of data and integrate them into a framework for site evaluation. The common elements of such a framework and the overarching technology systems needed to acquire such data across various uses are analyzed in this chapter.

A FRAMEWORK FOR SITE EVALUATION

A realistic assessment of the constraints to engineering development and the impacts of EEZ use at specific sites will require a systematic integrated approach. An organized framework of investigation involving oceanographic, geologic, geotechnical, and biological data is needed to recognize the interrelationship of each on overall site performance. This approach involves the development of a site performance model in which seafloor characteristics are quantified and interrelated to give predictive capability (Figure 5-1). Each model relates to a specific use or combination of uses and is intended to focus on the possible constraints to and impacts of use and the data needed for assessment. Such models are generally independent of resource evaluation.

For any EEZ use, all the components of a particular location on the seafloor need to be evaluated, especially linkages and feedbacks. Clearly, the effects of geology, geotechnical properties, oceanography, and biology will vary from one site to another.

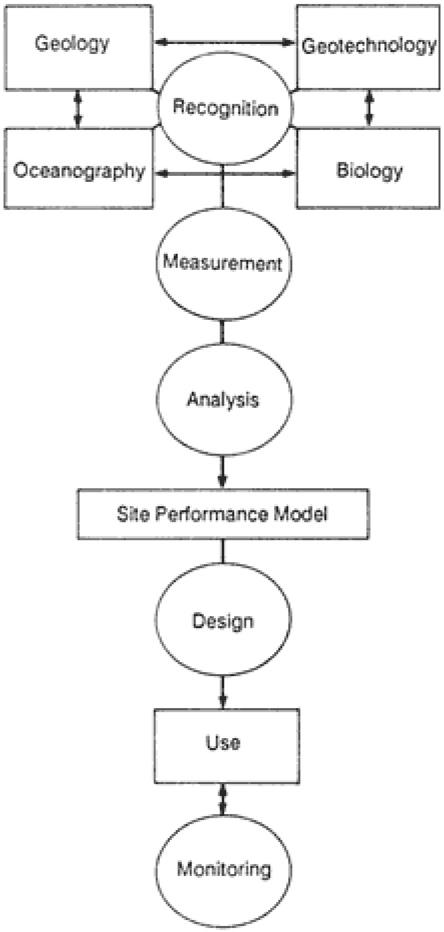


Figure 5-1
Site performance model.

For example, a prospective location for deepwater oil and gas development may be geologically active or benign, possess strong or weak sediments, experience imperceptible or energetic currents, and have simple, resilient, or complex and vulnerable biological communities.

A first step in an integrative process (Figure 5-1) is recognizing the balance of conditions at a site, which can be achieved by mapping and sampling. Measurement of seabed conditions and processes involves a range of in situ sampling, monitoring, and laboratory techniques. Data for geologic characteristics (origins, ages, and process activity), geotechnical properties (strengths, variability), near-bottom oceanography (physical and chemical), and biological populations (structure and interdependence) are combined and analyzed into a comprehensive assessment of the site. The more detailed and integrated the assessments in terms of history and present behavioral status, the more powerful its predictive capability.

The site-performance model leads to optimum design and planning of engineering tasks. As development proceeds, site monitoring ascertains site behavior and departures from that predicted by the model, enabling remedial action. Experience has shown that this type of integrative, focused framework is essential for efficient engineering of the seabed. This approach has been used to successfully design, install, and maintain oil and gas facilities in hazardous offshore regions and is the basis of site assessments in such frontier areas as the continental slope of the Gulf of Mexico. The technical constraints associated with specific development activities indicate that there is a shared need for site performance models for each use, based on very similar or identical suites of information. Following is a general review of the major categories of information needed.

Geology

Analysis of the geologic characteristics of engineering sites aims at comprehensive evaluation of present three-dimensional sediment and structural geometry, site history, and future geologic behavior. Geologic data allow identification of constraints to engineering provided by existing site conditions and forecasts of possible magnitudes and distributions of geologic processes during the engineering design lifetime.

Each use of the seabed will be affected by different properties of the site in different ways. For any development area, however, there is a shared need for information on bottom roughness, seafloor slope, sediment types and geometries, seafloor and near-surface processes, and the regional and subsurface context.

Bottom roughness is the local variability in seafloor morphology and is determined from sonar or camera imagery. Roughness varies in relief scale and origin. Low-relief roughness can be due to sediment texture contrasts (e.g., clay to boulders) or to current-induced bedforms (ripples and dunes). Large-relief roughness can be caused by concretionary areas, carbonate mounds, or clefts, fissures, and steps on rock outcrops. Roughness affects the design and emplacement of structures that rest on the seafloor, such as templates, pipelines, and cables.

Seafloor slope is determined from bathymetric profiles or high-resolution swath bathymetry and is usually represented as three-dimensional displays. Slope variability can be extreme. Shelves, basins, or rise areas can be flat or very gently sloping. Faults, diapir slopes, or eroded canyon walls can be very steep (up to 40 degrees). Present seafloor engineering practice for templates, piles, and seafloor-supported structures is to avoid gradients greater than 10 to 15 degrees. Pipelines and cables are less constrained by absolute gradient than by abrupt changes.

Near-surface sediment distributions and geometries are usually determined by acoustic profiling and sampling. Geologic properties of sediments reflect their origins, modes of deposition, and post-depositional modifications, with corresponding variability in geotechnical properties. Geologic site mapping usually distinguishes conformable layered sequences, unconformities indicating erosion or nondeposition, chaotic or deformed sedimentary units, and acoustically transparent, homogeneous layers or zones. There is often considerable ambiguity in interpretation of acoustic data, and the engineering constraints to site development can be determined only by combinations of geological and geotechnical information.

Geologic processes that can constrain development include faulting, subsidence, tectonic uplift, erosion, turbidity currents, and various types of mass movement. Where engineering design does not match the magnitude and frequency of process action, the natural geologic processes can be hazardous to seafloor development activities. Prediction of process magnitude and frequency by both geologic and geotechnical data and incorporation into design leads to reduced hazard potential. The development of oil and gas resources using specially designed and constructed platforms in the Mississippi delta mudslide area is an example of practical, economic engineering in a geologically active region.

Geologic information for development sites aims at recognizing processes and assists in analyzing their potential effects. Seafloor morphology and near-surface sediments contain the accumulated partial signatures of long-term environmental and geologic process events. Hindcasting and reconstruction, supported by geologic dating, reveals the types, magnitudes, sequences, and distribution of past processes. When such information is combined with geotechnical, oceanographic, and biological data (Figure 5-1), future trends for site behavior may be anticipated. For example, evidence from former landslide deposits, erosional unconformities, or fault displacement rates can be used to forecast landsliding, erosion, or faulting.

Prudent site evaluation studies also consider the *regional geologic context* of neighboring areas and the deeper subsurface geologic conditions. Regional geologic data provide perspectives on geologic processes that may extend into the engineering site. For example, pipelines, cables, waste disposal, and mining activities may be impacted by landslide processes initiated upslope from the actual seafloor use. Similarly, deep subsurface conditions, such as faulting, may impact seafloor engineering because of upward extension of displacements or gas leakage.

Geotechnical Properties

Most activities planned for the EEZ will require some type of installation or facility that will depend on seabed foundation support or subsurface installation. There are a large number of different foundation types and installation procedures required to accommodate the wide range of sediment conditions encountered throughout the EEZ.

Present geotechnical engineering practice offers highly advanced field investigation methods and analytical procedures available for design that will help achieve risk-free installation and performance. Good quality geotechnical data required at the development site most often will consist of the sediment profile (stratigraphy), sediment type (classification), and sediment engineering properties (density, strength, deformational characteristics, and permeability). These data are traditionally acquired by performing laboratory tests on recovered samples, although in situ testing in recent years has provided an improved method for obtaining meaningful measurement of sediment characteristics.

Geotechnical data requirements will vary depending on the type of activity planned at the site. For example, uses by the military most often will require data to only a few meters depth for the small foundations and cables placed on or near the seafloor. On the other hand, deep foundations, such as the piles supporting the massive production platforms for the oil and gas industry, often require geotechnical data to depths of at least 200 m. Disposal of wastes within the subsurface sediments may require different types of data (such as permeability) to tens of meters below the seafloor. Thus, each proposed activity will require that geotechnical data be acquired specifically to the depth of interest for the proposed activity at the site. A brief description of how the geotechnical properties influence various types of seabed uses is presented in the following sections.

Sediment profiles are needed for almost any activity associated with the seabed that requires a thorough understanding of the variation of sediment conditions with depth below the seafloor (stratigraphy). Sediment stratigraphy is important because the physical, chemical, and biological characteristics of marine sediments are closely linked to the overall engineering behavior associated with in situ stresses applied to the sediment strata by loads imposed from various activities. Since sediment types may range from extremely weak sensitive clays to highly cemented rocks, it is essential to understand the variation of the sediment throughout the profile. Depending on the type of sediment, the type and size of foundation or anchor, and the applied loads, a geotechnical investigation will be required using sampling techniques described in Chapter 4.

Sediment classification tests are performed to categorize the sediments according to color, grain-size distribution, and plasticity characteristics once sediment samples have been obtained at a prospective site. These tests provide the basic framework to understand composition and consistency necessary for assigning other types of laboratory tests. Classification test results are also important to the design of the foundation support/restraint system, because they provide the first indication of whether the sediment behaves as a cohesive or noncohesive material.

Sediment engineering properties are required to allow clear accurate analysis of the behavior of marine sediments, which depends on appropriate modeling of the strength and stiffness variation with depth in the deposit. For example, the design of foundation piles to support various types of structures will require shear strength parameters and stress-strain characteristics to significant depths below the seafloor to predict the pile performance under various axial and lateral loads.

Consolidation tests also may be required if load-settlement characteristics are to be investigated for a gravity-type platform, or if stress history of the sediment is important in interpreting strength data.

For some uses, such as burial of wastes in sediment or mining, it is necessary to determine other properties and behavior. For example, permeability (or hydraulic conductivity) is a key parameter in the assessment of the possible migration of contaminants through the sediment. For some types of mining activities it is necessary to determine the engineering properties of the surficial sediments (upper 0 to 1 m) in order to assess trafficability characteristics for bottom-crawling equipment and to assess rippability of surface ore bodies.

The laboratory tests should model the initial and final status of stress, drainage, and loading conditions within the sediment mass as accurately as possible with respect to field conditions. Thus, a thorough understanding of environmental conditions is essential to ensure that the impact of the proposed activity on the seabed leads to risk-free performance in terms of both engineering and biological impact.

Oceanography

For a prospective EEZ seabed utilization site, the principal components of oceanographic information critical to recognition of the balance of conditions and to the resulting site-performance model are water depth, seawater motion, sediment chemistry, and variability at or near the site. Some of the information on the geology and biology of the site also has oceanographic relevance.

Water depth is important for several reasons. First and probably foremost, seawater is an "overburden" that has to be dealt with during any use of the EEZ seabed because, *a priori*, a greater water depth implies greater problems in the installation and operation of facilities and equipment for seabed resource recovery. In addition, there are depth zonations to the physical, chemical, biological, and geological processes that may affect the site use and provide insight into the processes to be investigated.

Seawater motion at a particular site has several components that should be considered in use-related planning. The most obvious is the *current pattern*, which is the distribution of discrete, near-bottom seawater flows moving in identifiable directions. Sometimes these flows are large and reasonably well defined—e.g., where the Gulf Stream impinges on the southeastern continental margin, or where the western boundary undercurrent contacts the Atlantic continental slope. Other flows may be much smaller and have a shorter lifetime, such as the storm-wind-generated downwelling on the northeastern U.S. continental shelf. Another important process is *wave-bottom interaction*, derived either from wind-driven surface waves on shallow continental margins or from various forms of internal waves. A seawater motion that occurs everywhere in the EEZ is *near-bottom turbulence* , the random motion of water parcels of widely varying size in the vicinity of the seabed. All of these forms of seawater motion can contribute to or influence the *sediment transport rate*, which is one of the most critical geological parameters relating to the use of the EEZ seabed.

Many aspects of the *sediment chemistry* impact seabed use. *Mineralogy and chemical composition* affect geotechnical properties, sediment erodibility, and the production and community structure of benthic organisms. A particularly important chemical parameter is the *sedimentary oxidation-reduction profile*. The thickness of the upper oxidizing zone and the contrast between the abundance and nature of its oxidizing compounds and the abundance and nature of the underlying reducing compounds influence the corrosion rates of emplaced structures, the vertical transport of sedimentary pollutants like metals, and the functioning of benthic communities. *Bioturbation rate*, the "stirring speed" of sediments by organisms, both alters and is in turn affected by sediment chemistry.

The *variability* of the diagnostic parameters just discussed is also a critical part of the oceanographic information necessary for the responsible recovery of EEZ seabed resources. Without adequate knowledge of the range and frequency of the variations in those parameters, it will not be possible to forecast the duration and consequences of a proposed use, construct an effective site performance model that also minimizes environmental damage, or determine if a particular use has caused any subsequently observed environmental changes.

Biology

Typically, biological characteristics of a particular site are measured and incorporated into an assessment of possible environmental impacts from a proposed use. Unfortunately, these exercises usually provide a picture of the biological characteristics and site properties at only one time. Even less appreciated are the effects that organisms have on the geological, geotechnical and oceanographic properties of the EEZ seafloor. A fuller understanding of biological effects on seafloor uses and, conversely, the possible impacts of a use on biological communities, requires knowledge of the temporal variability in communities, production rates of benthic organisms, and the structure of benthic food webs and bioturbation rates.

The notion of *community structure* embodies a variety of concepts, most notably the number of species present and the relative abundance of individual species. Changes in community structure over time are expressed as the stability and resilience of the community. In a stable community, the structure changes little, either because the organisms in the community are long-lived or because loss rates and recruitment are approximately balanced. Resilience refers to the ability of a community disrupted by either natural or anthropogenic disturbances to return to its original structure. The tolerance of individual species to disturbances and the rates at which they can recolonize the seafloor determine community resilience. Most research on the stability and resilience of benthic communities has focused on nearshore rocky habitats; understanding of the dynamics of benthic communities throughout the EEZ is limited. For example, the long-term effects on community structure of sediment disruption or resuspension arising from a use such as seafloor mining cannot be predicted with any confidence.

Food web structure of a biological community consists of the connections between benthic prey and predators. Many commercially valuable species prey on organisms living in sediments. In turn, these prey often obtain their nutrition from organic matter in sediments. This network takes on crucial importance if it becomes a pathway to mobilize materials placed in or on the seafloor. Furthermore, the production rate of benthic organisms must be considered, since it will affect the rate of transfer of materials through a food web. For example, highly productive areas of the seafloor might be more likely to lead to food-web magnification of waste materials deposited on the seafloor. As a rule of thumb, the production rate of benthic communities decreases with increasing water depth or with increasing distance from land, but localized exceptions to this general trend can occur.

Bioturbation, the mixing and stirring of sediments by organisms, alters geotechnical properties of sediments, such as water content, shear strength, and near-surface stratigraphy. Bioturbation also modifies sediment erodibility and the direct physical exchange of dissolved and particulate materials between the seafloor and the water column. Thus any use of the seafloor requiring evaluation of these characteristics (for example, pipelines, anchors, waste disposal, etc.) must consider the role of bioturbation. Bioturbation rates and vertical extent in the sediment column depend on the species present and their abundance (community structure), and the physical and chemical properties of sediments. Understanding these dynamic processes, both in general and for specific sites, is a necessary component for determining long-term effects of developing and using seabed resources.

TECHNOLOGY SYSTEMS FOR THE SEABED

Evaluating the suitability and vulnerability of particular EEZ sites for use and development is a complex task. Predictive site performance models require integrated geologic, geotechnical, oceanographic, and biologic data at scales, coverages, and resolutions appropriate to the site and the proposed use. The acquisition of such suites of data for the EEZ seafloor involves three interrelated and complementary technologies: surveying and mapping, sampling and in situ measurement of seafloor properties, and monitoring of changes in processes. The specific technology requirements for particular uses is described in Chapter 3. A comprehensive examination of technologies for mapping and surveying, acquiring geotechnical data, and monitoring is presented in Chapter 4. Following is an overview of the present status of and development needs for major technology systems required for seafloor investigation.

Mapping and Surveying

The acquisition of task and site-specific seafloor data for mapping is a fundamental necessity for EEZ development. Locations and time frames for needed data will be determined by the specific development or engineering activity. For example, mapping in support of oil and gas development is dictated by exploration targets and production schedules.

The specific types of mapped data needed for each EEZ development activity require further definition. The survey tools and grids will vary with the local characteristics of the area and the proposed activity. But for oil and gas production systems, mining and waste disposal sites, military installations (in fact, for most of the anticipated EEZ uses), there is overlap and commonality in the maps, scales, and resolutions required. Each use shares the need for mapping for site selection, site appraisal, evaluation of direct engineering effects, and long-term site behavior. Combinations of mapped data, including bathymetry, seafloor imagery, near-surface sediment profiles and properties, are appropriate.

The capability of marine survey techniques has developed rapidly over the last two decades. A powerful suite of acoustic tools exists, able to address survey needs at various scales and resolutions. Both reconnaissance-scale and task-specific survey systems are presently at work, mapping the EEZ seabed over the full range of water depths. Multisensor systems and combined-mission cruises offer economy in data acquisition, providing complementary data sets from a single survey traverse.

Intermediate-scale regional mapping of high-interest areas has already proven extremely valuable in support of EEZ activities. Regional acoustic surveys over medium-spaced line grids (e.g., < 10 km x 10 km) represent a balance between high-resolution data, density of coverage, and time and costs of surveying. Such selected-area surveys give the regional and technical context for design and interpretation of site-specific surveys. Reconnaissance mapping provides a general overview of large areas of the EEZ or its entirety. Operational and cost factors dictate either generalized coverage of large seafloor features (e.g., GLORIA) or very lengthy surveys (e.g., Sea Beam). Reconnaissance mapping provides a general background for more detailed site-and task-specific surveying.

The principal technical constraints to surveying and mapping the EEZ for development are now mainly operational, involving questions of rates of coverage, resolution, system efficiency, and cost-effectiveness. Some of the required technical developments include

- rapidly traversing bottom vehicles capable of acoustic/in situ property cross correlation;
- deep-tow systems with multifrequency, multisensor packages in autonomous vehicles or improved towing and cable technology;
- multipurpose systems with vessels dedicated to routine multipurpose surveying with a wide range of tools aimed at extensive suites of seafloor data acquired in single traverses;
- multipurpose sensors from which simultaneous bathymetry, seafloor imagery, and subbottom profiles can be obtained;
- improvements in acoustic sources, arrays, variable and multifrequency profiling systems, together with real-time processing, to address difficult geologic terrain and the requirements for engineering data at greater depths below the seafloor;
- common, mutually compatible formats for digital recording and processing to facilitate exchange of data; and

- new geologic interpretation modes (involving synthesis of traditional acoustic data, with statistical analysis procedures and integration with geotechnical data) for effective use of survey data.

The principal nontechnical constraints to surveying and mapping of the EEZ are primarily organizational, involving questions of planning; prioritization of surveying technology resources; cooperation among different agencies, groups, and organizations; and data availability. Expense, different time frames for development, and the challenges of a largely unknown, difficult environment all dictate planning and organization of effort for successful and cost-effective EEZ mapping. Further improvements in the technical and operational effectiveness of surveying methods will be costly. Because of overlap in interests, missions, and mapping needs, the benefits of improved technology will be shared among government agencies, the military, and industry.

Geotechnical Data

Certain types of geotechnical data are necessary to characterize the sediment properties at the site of a proposed activity and within the general area. This detailed knowledge of seabed sediments will require meaningful measurement by sampling, in situ testing, and experimental testing. The ability to acquire geotechnical data by these three methods varies according to the area being investigated. The various data acquisition systems are highly developed for water depths less than 200 m, whereas only moderate or little development has occurred with acquisition systems that can be used in arctic or deepwater regions. Present systems can be summarized as follows:

- *deployment systems*, which can be divided into three broad categories: (1) self-contained units, (2) drilling rigs, and (3) submersibles (ROVs and AUVs);
- *sampling systems*, which may be divided into downhole or seafloor deployment modes;
- *in situ testing*, which is used to determine sediment properties and has been emphasized increasingly in the past decade because stress relief and disturbance associated with recovering samples from boreholes in deep water often alters sediment physical and chemical properties; and
- *experimental model testing systems* which began to be used during the last decade in the marine environment to develop methods of predicting the field performance of various foundation design elements. Another long-term experimental testing system utilizes instrumentation to measure thermal, geochemical, and geotechnical responses of sediments when an experimental heat source is embedded into the seafloor sediments. Results of all these types of small-scale experimental tests look promising and have provided insight into the behavior of full-scale foundations and the effects of various activities on sediment properties.

Development of the EEZ in the Arctic and off the continental shelf in water depths exceeding 200 m will depend on further development of the following systems:

- instruments capable of providing data for analyzing long-term sediment stability;
- improved sampling and in situ testing devices for determining sediment properties in more difficult offshore environments; improved experimental testing methods that will allow the properties and behavior of the seabed to be reliably observed and predicted in a more controlled environment; and
- compact deployment systems that can operate in a rapid transit mode and that will automatically measure seafloor properties or sample the sediments.

A further nontechnical issue for acquiring geoscience data is the need to develop a coordinated research and development plan involving different agencies and industry user groups and academia in a cooperative effort to develop improved systems for sampling and performing in situ and laboratory tests on seafloor sediments.

Monitoring

The environmental consequences of expansion of U.S. activities into the EEZ are difficult to predict in advance. Monitoring projects on the scale of years to decades will be necessary to acquire real data on seafloor process activity. Such data on seafloor behavior, processes, and causative factors is a key element in predictive site evaluations and will expand the usefulness of mapped data.

Technology will, in a sense, "drive" environmental studies. As new measurement technologies are perfected so that they can be routinely used, new monitoring will be possible. There are several technology needs associated with conducting monitoring programs in the EEZ.

- A satisfactory method of measuring pollutants in EEZ sediment needs to be developed.
- The ability to quickly assess populations or organisms in the seabed during monitoring studies needs improvement.
- Time and space capabilities of the sampling device or platform need to be matched with the time and space domains of the phenomenon of interest.

SUMMARY

Collecting and disseminating data from EEZ mapping, surveying, research, and monitoring activities as a base for planning various uses of the EEZ seabed represent a scientific and technical challenge similar to the challenge of exploring space. The magnitude of data to be analyzed and the needs for technology entail long-term national commitments of funds and expertise. Such commitments require planning and coordination among the various communities who are involved in this undertaking. These issues are addressed in the next chapter.

6

Coordination and Planning

This section looks beyond scientific and technological questions to examine nontechnical issues related to timely acquisition of data and understanding needed for rational development of the EEZ. They fall into two categories:

1. issues related to regulation and management of EEZ uses, and
2. issues involving broader questions of government policy with regard to the EEZ.

Although these issues do not directly involve the committee's main focus of science and technology, they will play a significant role in the pace and efficiency with which the nation studies and develops the EEZ. Lack of an adequate regulatory regime can slow or prevent research and development; lack of effective national planning and coordination can increase EEZ research and data acquisition costs; and failure to include adjacent coastal states in research and exploration can reduce state enthusiasm at the development stage.

REGULATORY CONSIDERATIONS

The Complexities of the EEZ

On December 27, 1988, President Reagan issued a proclamation extending the U.S. territorial sea from 3 to 12 miles in width, an action justified as necessary to protect national security interests and one fully consistent with international law. Indeed, this action brought the United States into conformity with most other coastal nations with regard to territorial sea width. The U.S. EEZ now begins at 12 miles from shore and extends to 200 miles, and is 188 miles in extent.

EEZ resources, for the most part, are controlled ("sovereign rights") by the national government, and, in the absence of legislation assigning responsibility to a specific entity, the broad missions of many federal agencies include EEZ interests and activities. For example:

- NOAA and USGS—science, mapping, and surveys;
- Coast Guard—surveillance and enforcement;
- EPA—water quality;
- NMFS—fisheries and marine mammals;
- USGS, MMS, and the Bureau of Mines—hydrocarbons and minerals;
- DOD (especially the Navy)—national security;
- NSF—university-based research.

Coastal states also have limited extra-territorial powers extending seaward into the EEZ. The Coastal Zone Management Act of 1972 (CZMA), the Deepwater Port Licensing Act, and the Ocean Thermal Energy Conversion Licensing Act give states some influence over federal actions affecting their coastal zones, and the Outer Continental Shelf Lands Act (OCSLA) of 1978 gives states avenues to affect decisions involving EEZ offshore oil and gas activities. In addition, coastal states have strong economic and environmental interests in the adjacent ocean and therefore in plans and activities related to EEZ development. Furthermore, since economic development of resources is generally undertaken by the private sector, commercial firms are also involved in research and exploration activities that precede resource development.

An additional complexity associated with this region is that the EEZ retains a substantial measure of international character. While the United States has jurisdiction over the resources, the EEZ is *not* U.S. territory. Except for resource related activities, it is similar under international law to the high seas: other nations have freedom of navigation over, under, and on the surface, the right to lay pipelines and cables, and may enjoy other non-resource related high seas freedoms. Thus, U.S. use of the EEZ and its resources occurs in an area where other nations also can reasonably freely exercise their rights.

The economic status of the EEZ and its resources also affects private sector interest in resource development. The problem stems from the nature of common property or open access resources, because without an exclusive stake in the resources in question, a potential private developer may have little incentive to conserve or manage wisely for the future (Hardin, 1969).

Within the general jurisdictional framework of the EEZ, more limited jurisdictions have been created that remove portions from open-access but do not create private property. The Magnuson Fisheries Conservation and Management Act (MFCMA) created a 200-mile fishery management zone where access is still free and open to all U.S. comers, except for some notable exceptions where entry is limited. Under the OCSLA, offshore tracts are leased exclusively to private concerns for hydrocarbon exploration and production, an approach that comes closer to assigning property rights. Other laws have created special ocean dumpsites, vessel traffic lanes, marine protected areas, and defense operating zones. A major governance problem of the EEZ is that such single-purpose legislation tends to pay relatively little attention to the effect of any particular use on others, such as displacement or adverse effects on other activities.

The multiplicity of legislation and interests in the EEZ also affects research. Numerous government agencies, their contractors and grantees will be involved in EEZ research along with industry and academia. It is clear that all scientists and engineers conducting research in this region would benefit from a more collaborative approach to research, mapping, and surveying, with improved coordination and joint advance planning.

Multiple-Use Conflicts

As discussed earlier in this report, the oceans and the seafloor are home to many different uses: some are compatible, others are less so, and some are in conflict. Surface uses such as navigation and water column activities like fishing tend to be transient, while seafloor utilization usually requires emplacement of equipment, facilities, or structures, and hence commitment of a specific area to an exclusive use. This occupation can be relatively short, as in some scientific or monitoring studies; up to tens of years for exploitation; or very long-term, such as emplacement of containerized waste. Long-term occupation of the seafloor is a consequence of at least four ocean activities: offshore oil and gas development (platforms, pipelines, subsea production facilities); ocean mining (mine sites); military installations (test ranges, acoustic arrays); and waste disposal (dumpsites). In addition, intermittent uses occur in fixed areas, such as trawling for bottom fish or submarine navigation in specified lanes.

All of these uses are likely to increase in the future, and since some conflicts among them are already occurring, still further use of the EEZ will depend on effective mechanisms for accommodating multiple uses (including research and technology development). Similar pressures in the coastal zone led to the enactment of the CZMA and emplacement of federally approved state programs to manage coastal zone conflicts within the states' three-mile jurisdictional limits. There are no mechanisms yet in place to encourage or facilitate federal interagency planning and coordination to reduce or eliminate such conflicts in the EEZ. The present EEZ planning and regulatory framework is composed of individual laws, each pertaining to the management of a single resource or use and each with its own established regulations, administration, and so on. Furthermore, except for the Presidential approval required to designate a marine sanctuary, decisions regarding a specific ocean use are made exclusively by the responsible federal agency. In the absence of better mechanisms, federal agencies comment on specific environmental impact statements to communicate their concern about proposed ocean activities. Ad hoc approaches are also used, such as the communications between the Departments of the Interior and Defense over potential conflicts between offshore oil development and military uses.

In the sections below, the adequacy of both the existing regulatory framework and the present system to govern the EEZ are examined.

The Regulatory Framework

The existence of a regulatory system that is appropriate to the activity being regulated and one that leads to predictable outcomes based on an accepted public policy framework is essential to private sector investment decisions. Inappropriate, incomplete, or burdensome regulatory systems can have a chilling effect on orderly development and utilization of EEZ resources, and on research and exploration. For a regulatory system to be adequate and equitable, it must be technically appropriate for the resource in question; protect the interests of resource owners (the public in this case); deal equitably with unavoidable spillovers and side effects that adversely affect other ocean users and adjacent state and local interests; and promote research, efficient exploitation, and conservation of the resources in question. The existing EEZ regulatory systems for oil and gas, minerals, and fisheries are examined below.

Oil and Gas Regulation

EEZ oil and gas development is regulated principally by the OCSLA and elements of the CZMA, the Endangered Species Act, and the National Environmental Policy Act. Individual firms or consortia bid for exploration leases of 5 to 10 years duration. If commercial-size deposits of hydrocarbons are discovered, the lessee submits a plan to the Department of the Interior to develop the deposit—install platforms, lay pipelines, and so on—and production begins and continues for 20 to 30 years.

The OCSLA regulatory framework attempts to balance environmental concerns and spillover effects on other ocean users with the need for accelerated development of domestic oil and gas supplies. This is accomplished using a five-year leasing plan, environmental studies program, and environmental impact statement at the lease sale stage, with site-specific lease stipulations. Environmental impact statements are required in connection with review and approval of development and production plans and the agency's decision-making process. Although all of the decisions are ultimately made by either the MMS or the Secretary of the Interior, the process allows for input from the public and governors of coastal states. Yet several states—most notably California, Alaska, and Massachusetts—and a number of environmental groups, have gone to court and to Congress to argue for a more direct voice in offshore oil and gas decision making. At present, a virtual stalemate exists with regard to future federal leasing offshore of many coastal states.

Hard Minerals

EEZ hard mineral deposits, especially sand and gravel and placers, may be economically feasible to develop within the next two to five years, but such development could be delayed by lack of an appropriate regulatory framework (Chapter 3). There are two problems related to a regulatory regime for ocean minerals. The first involves the portion of the EEZ overlying the continental shelf. The Department of the Interior position is that the regulatory regime created by the OCSLA is appropriate for continental shelf hard minerals even though that regime was designed principally for oil and gas. The second problem involves minerals beyond the continental shelf but within the EEZ. Again, Interior interprets the OCSLA as covering this area, but representatives of the mining industry, coastal states, and environmentalists, testifying before Congress, have argued that new, specialized legislation to cover seabed mining in the EEZ is needed (U.S. Congress, 1989). These issues are the subject of legislation currently under consideration.

Fisheries

The MFCMA created a 200-mile fishery conservation zone and put in place a unique regulatory framework consisting of a decision-making partnership between the federal government (Secretary of Commerce), state governments, industry, and the public. Management plans are prepared by regional fishery management councils, submitted to the Secretary of Commerce for approval, and administered and enforced by NOAA's National Marine Fisheries Service. Individual coastal states continue to manage fish stocks in their own territorial waters. The regulatory system works reasonably well, although the inefficiencies of open-access fisheries are becoming more and more evident. For example, excess fish catching capacity in one west coast fishery has resulted in the allowable catch for the entire year being taken in a single 36-hour "season." (Personal communication, Steve Rebuck, Pacific Coast Federation of Fisherman's Associations, 1989)

Federal Licensing of Ports and Offshore Facilities

Two additional regulatory regimes—federal licensing of offshore ports and ocean thermal energy facilities—are of interest because they require comprehensive environmental impact analysis and explicitly build a coastal state role into the federal decision-making process. In both cases, federal laws give affected coastal states concurrent decision-making authority with the federal government because of the direct connection (e.g., pipelines or cables) between offshore facilities and the state's coastal zone and potential impacts of the two activities on the coastal environment and its inhabitants. The principles established in these two pieces of legislation (the Deepwater Port Licensing Act and Ocean Thermal Energy Conversion Act) could form the basis for a state role in governance of the EEZ.

Existing Planning and Coordination Processes

As mentioned above, there are few processes in place for planning and coordinating EEZ activities, yet given the numerous jurisdictions and interests involved, planning and coordination are essential. One can group ongoing EEZ activities into four categories:

1. research;
2. mapping, surveying, and technology development;
3. site-specific exploration; and
4. resource exploitation and use.

The federal government, industry, and academia are involved in all of these activities, and benefits would accrue to all from improved planning and coordination. Increases in both efficiency and effectiveness of current activities are possible. For example, scientists working in the EEZ believe that research costs could be reduced by greater use of piggybacking of noninterfering experiments on available platforms.

The only formal planning and coordinating effort now in existence at the national level is the joint USGS-NOAA JOMAR mapping and research program created by the Secretaries of the Interior and Commerce in December 1987. JOMAR is intended to be a formal mechanism for coordinating federal EEZ mapping and research activities. According to JOMAR's charter, coordination "will avoid duplication of activities, assure adequate response to the needs of users and provide for timely delivery of products and services and exchange of data," and is intended to "facilitate private sector involvement in the direction and use of EEZ-related data products." The charter also indicates that JOMAR is to "provide leadership for the design, implementation, and coordination of a national EEZ program of mapping and research and investigation of the nonliving resources of the EEZ seafloor" and "ensure participation by all interested groups in the formulation of goals, objectives, and priorities for a national EEZ mapping and research program." Thus JOMAR is principally concerned with the coordination of USGS and NOAA mapping programs for the EEZ. It is not clear whether this program could serve as the basis for the broad-based coordination of government, industry, and academic research efforts in the EEZ that will be required in the future. Other potential users of the seabed, especially states and private industry, need to be included in future planning efforts.

PLANNING AND GOVERNANCE

The previous discussion centered on the regulation of particular EEZ uses or activities insofar as regulation affects data and information acquisition. A broader concern is by what means are national interests incorporated into EEZ decision making. Similarly, by what processes are the interests and well-being of coastal populations reflected in these decisions? Finally, if these interests diverge, how is the balancing done and by whom? Governance issues are important, because controversy or disagreement among federal, state, and local governments can slow efforts to gather requisite information about the EEZ and its resources.

Balancing Different Interests

As EEZ uses grow in magnitude and variety, coastal states have made it clear that they expect to play an increasingly important role. States can be active supporters of EEZ development and are eager for data and information concerning the ocean resources and environments adjacent to their shores. States have strengthened their capacity to deal with ocean and coastal issues as a result of their participation in the coastal zone management program, the Interior Department's OCS leasing program and its MMS-operated federal-state minerals working groups, and regional fisheries councils under the MFCMA. The coastal states have the potential to become constructive and contributing partners with the federal government in EEZ exploration and development. Yet, the relationship between some coastal states and the federal government has become adversarial because states believe their interests are not given adequate attention in federal decision making. This situation has led states, in some cases, to block federal EEZ research efforts. For example, EPA's recent efforts to conduct research burning to test the effectiveness of ocean incineration of toxic wastes was stopped by massive state and local opposition.

How decisions are made and who makes them is always a matter of keen interest to governments and their agencies. Coastal states with important economic and environmental interests at stake believe they should be "at the table" when decisions are made concerning the EEZ adjacent to their coastal waters. Issues that are not resolved early in the national EEZ planning process have the potential to cause serious problems and delays later.

Based on experience with ocean resource development activities, concerns that could generate opposition to EEZ development in some coastal states include the following:

- possible damage to the ocean environment or the renewable resource base;
- possible adverse impacts on other ocean uses of economic or social interest to the state, such as fishing;
- possible impacts on the state of increasing activity in the EEZ without a voice in federal decision making concerning those activities; and
- possible exposure of coastal state populations to greater risks without offsetting benefits.

COORDINATION AND POLICY CONSIDERATIONS

Next to be examined are EEZ issues that involve national policy interrelationships among the federal government, industry, and academia. For example:

- Does the inherent importance of the EEZ and the magnitude of information necessary to develop it require a more focused and better directed national effort?
- Does the scientific and technological effort now underway with regard to the U.S. EEZ have the desired coherence or is a more formally defined national program needed?
- Are present policies or practices inhibiting efficient and timely exploration and utilization of the EEZ?
- Recognizing the large volume of research, mapping, and resource surveys needed in the EEZ, would new policies or approaches significantly speed up this information-gathering process?

These questions are examined below.

A National Policy for the EEZ

While one can take the position that President Reagan's 1983 proclamation provides a fully adequate statement of national policy regarding the EEZ, an alternative view is that until the Congress formulates a policy, national EEZ policy remains unclear or at least incomplete. The President's proclamation does not contain certain elements necessary to a formal national policy. For example, to provide a sense of national urgency or priority, a statement of national policy might contain findings in support of a national interest in a particular field or activity, outline an approach or general direction to be followed by the federal government and policy goals related to the new activity or area; and provide a mandate for development of a national plan to achieve specified national policy goals. This last step is typically accompanied by designation of a lead federal agency and interagency coordinating committee of some sort. In some cases, an outside group (commission or council) is established to bring nonfederal interests (for example, industry, academia, and state and local governments) into the national development process.

National policy pronouncements contained in legislation enacted into law serve the important purpose of indicating both congressional and executive branch support for certain policies and mechanisms. Experience suggests, however, that national policy pronouncements that contain only findings and exhortations and no new mechanisms or programs are not very effective. For example, several pieces of legislation have proclaimed a national policy relative to strategic minerals, but with little visible effect.

While the case for EEZ policy legislation is not overwhelming at this time, such legislation may be the only way to improve coordination and increase efficiency. Although mechanisms can probably be created within the Executive Branch to improve coordination to some extent, it is doubtful that nonfederal groups and interests can be given meaningful roles in such a coordination device.

Optimizing Research Investments and Capability

Given the number of organizations and interests involved, it is understandable that current research efforts in the EEZ sometimes appear fragmented. The cost of research and the magnitude of scientific work to be undertaken suggests that increased efficiency is needed. Suggestions about the kinds of collaboration and coordination that might be feasible, along with *functions* needed to be undertaken, fall into two categories:

1. *Scientist-related functions* meet the needs of the individual scientists actively engaged in EEZ studies. Periodic, informal meetings of government, industry, and academic scientists and engineers actively involved in EEZ research are needed to review ongoing programs; exchange new data and results; develop joint programs and piggyback research efforts; identify dead-end projects; and join together in experiments, modeling, data analyses, and other activities appropriate to individual investigators and their research programs.
2. *Agency-related functions* are necessary to improve the efficiency and effectiveness of government agency programs pertaining to the EEZ (e.g., mapping, resource surveys). Mechanisms are needed to perform joint planning and coordination of mapping and survey plans and programs, research, and technology development; share EEZ information and data; cooperatively develop multiple-use approaches; conduct cooperative research among the federal government, academia, and industry; and identify and resolve conflicts among ocean users.

Coordinating Mechanisms

Before considering possible coordination mechanisms, it is useful to examine other national research program areas in which decisions have been made to improve coordination. These involve arctic and ocean pollution research. An examination of the Arctic Research and Policy Act of 1984 and the 1986 amendments to the National Ocean Pollution Policy Act suggest that these pieces of legislation (and the coordination mechanisms contained therein) were motivated by

- the need to stimulate greater investment in research in those areas;
- the need to promote greater efficiency in expensive research activities by reducing overlap and duplication;
- the need to ensure that federal research benefits other interests (such as state and local governments, native groups, and industry); and
- the need to ensure that research programs focus adequate attention on issues deemed important from a national policy perspective.

To the extent that such needs may also apply to the EEZ, it is appropriate to examine mechanisms in the two pieces of legislation. They are as follows:

The Arctic Research and Policy Act

- establishes a national plan for arctic research;
- establishes an Arctic Research Commission (composed largely of nonfederal interests) to promote arctic research and recommend an "integrated Arctic research policy";
- establishes an Interagency Arctic Research Policy Committee to develop the five-year arctic research plan; and
- designates the National Science Foundation (NSF) as the lead agency for implementing arctic research policy.

The National Ocean Pollution Policy Act

- establishes a five-year plan for the overall federal effort in ocean pollution research;
- establishes a National Ocean Pollution Policy Board to coordinate planning, research, and programs; review agency budget requests; and establish interagency groups as needed; and'
- creates an office in NOAA to coordinate the program.

These two acts have three elements in common: each establishes a five-year national research plan; each establishes an interagency board or commission to set policy and oversee development of the plan; and each designates a federal agency to lead or coordinate the program. One important difference is that the arctic legislation specifically incorporates nongovernment interests into the process.

One possible option to improve the direction and coherence of a national EEZ research effort would be legislation involving a similar three-element approach or some variant. Other options might employ less formal mechanisms, such as consideration of new NSF centers for science and technology or use of the National Research Council or other nongovernmental institutions to convene discussions of research results and design cooperative programs. For example, annual conferences could be hosted, on a rotating basis, by government, academe, and industry to design cooperative undertakings, test new models, and discuss research, mapping, and surveying priorities.

SUMMARY

The great costs involved in exploring and understanding the EEZ and its resources and the long lead times needed require a level of planning and coordination not usually present in studies of the coastal ocean. The committee found that it was difficult to separate preliminary activities—such as research, surveys, and mapping—from subsequent resource exploration and development. As the EPA's ocean incineration program shows, unless there is general agreement among affected interests regarding a new ocean use or development, even early research can run into serious difficulty. Hence, it is important to examine the existing regulatory framework and overall governance arrangements in the EEZ as they affect relationships between the federal government and coastal states.

Many uses of the EEZ seafloor are likely to require exclusive or near exclusive occupation of a fixed portion of the seafloor for a relatively long time (ten years or more), in contrast to water column or surface uses, many of which tend to be transient in character. This increases the importance of developing effective multiple-use planning mechanisms for the EEZ. Similarly, rational development could be affected by legal frameworks used to regulate various activities, which is especially problematical for hard minerals development. The lack of a specific regulatory regime for EEZ hard minerals could deter the exploration and exploitation of these mineral resources.

The EEZ is a new type of ocean jurisdiction, one that is coupled both to the high seas beyond its outer boundary and waters under coastal state control at the territorial sea boundary. Thus, in developing EEZ resources, the federal government has responsibilities both to the community of nations (to allow freedom of navigation and other high seas freedoms) and to coastal states (to ensure that state and local interests are not compromised in the name of national interest). Coastal states often have strong economic and environmental interests in the EEZ beyond their coastal waters. Given these interests, and because shore-based facilities such as ports and harbors are essential to EEZ resource development, coastal states believe that rational development demands close and positive working relationships between the federal government and themselves. The committee endorses this view and encourages the federal government to work with the states to forge such a partnership.

The CZMA created a national program to encourage and assist in the development of state programs to manage the coastal zones and territorial seas in a more comprehensive manner: 29 of the 35 eligible states and territories now have such programs. However, no such effort exists in ocean waters under federal jurisdiction (the EEZ). For example, no federal agency has responsibility for

- overseeing development of a national ocean policy;
- resolving conflicts between federal ocean activities; or
- coordinating federal programs of mapping, surveying, and research (except for JOMAR).

While it is beyond the committee's charge to deal with such issues as national ocean policy formulation, the present national EEZ program suffers from overall lack of coordination of ocean activities within the federal government. Mechanisms are needed to better plan and coordinate a national EEZ effort, and although the needs are different, individual researchers and government agencies would benefit from improved coordination.

While the formation of JOMAR by NOAA and USGS is a step toward a cooperative effort, it is not yet clear whether JOMAR will be able to bring nonfederal interests (industry, academia, and state governments) into the planning and coordination process on an equal footing with federal agencies. Also, the extent to which this mechanism can obtain (and retain) the positive involvement of key federal ocean agencies beyond NOAA and USGS remains to be seen.

7

Conclusions and Recommendations

The investigations of the committee resulted in two major conclusions about the future uses of the seabed in the Exclusive Economic Zone (EEZ). First, it is highly probable that the uses of this region will increase in the next 20 years. These include exploration for and development of oil and gas resources, waste disposal, emplacement of cables for civilian and military purposes, harvesting of fisheries resources, recovery of certain hard minerals, and designation of cultural resources such as marine sanctuaries. Potential uses of the EEZ seabed related to a broader spectrum of mineral exploration and development, other biological resources, development of ocean energy systems and technologies, and recreational uses are less likely to expand significantly in the near term, but will probably become more important in the time frame beyond 20 years.

The second major conclusion of this study is that for all foreseeable uses of the EEZ seabed, improved coordination and increased joint planning are needed to implement effective and efficient systematic mapping and surveying programs and develop or improve the technology needed to support them, improve access to and sharing of EEZ data, develop approaches for multiple uses, identify and resolve potential conflicts among various users, and ensure environmental protection. Such a strategy would provide the nation with the foundation for a coherent plan for developing its ocean territory.

In order to accomplish these objectives, the committee recommends the following actions be initiated:

COORDINATION AND PLANNING

Economic and institutional pressures will lead to increasing use of the U.S. EEZ seabed for a variety of purposes, some of which are likely to conflict. Additional planning efforts among federal and state governments, industry, academia, and representatives of public interest groups will lead to more efficient, orderly, equitable, and environmentally sound development of EEZ resources.

Recommendations

1. Congress should enact legislation that creates a formal joint planning and coordination process that includes a lead agency mandated to develop a national EEZ plan, an external commission composed of representatives of industry, academia, and public interest groups, and an internal interagency committee. Based on the recommendations and advice of the commission and interagency committee, and in cooperation with the coastal state governments, the federal government should formulate a national management policy for EEZ uses that identifies the needs of specific user groups and determines ways of enhancing cooperation and efficiency of operations

among the various agencies and industries and identifying and resolving potential conflicts among users.

2. As part of the planning and coordination process, federal agencies with EEZ programs should pursue cooperative and joint agreements with coastal state governments in planning and implementing EEZ activities.

SPECIFIC USES

Certain uses of the EEZ will require special policy action at the federal level in order to plan for future development. For example, development of mineral resources and use of the EEZ seabed for waste disposal are potential activities that are unlikely to proceed until more comprehensive national policies are devised. Other uses, both existing and potential, will also benefit from improved regulatory policies.

Recommendations

3. The U.S. Congress should ensure that a coherent policy is developed that addresses specific concerns of industry and coastal states with regard to economic and environmental issues affecting the development of EEZ mineral resources. Appropriate agencies should provide the leadership to ensure development of the necessary science and technology for assessment, evaluation, and verification of critical hard mineral resources.
4. A comprehensive long-term national waste management policy based on an evaluation of waste disposal in all media, including land and ocean disposal options, should be formulated by Congress to provide a predictable framework for planning and developing acceptable ocean waste disposal strategies.

RESEARCH AND TECHNOLOGY DEVELOPMENT

The seabed of the EEZ is a new frontier that includes a broad range of seafloor morphology, water depths, sediment types, and environmental conditions that affect its use. The complexity of the EEZ seabed requires multidisciplinary research efforts that are costly in terms of both technology and time required to obtain and analyze data.

The various potential uses of the EEZ share the need for reconnaissance survey data and for task and site-specific information. The variety of acoustic and optical technologies for collection of bathymetry, bottom imagery, and near-surface sedimentary data are costly in time and resources. The mapping priorities and geographic areas of interest in the EEZ require further definition as a first step toward planning the efficient sharing of mapping activities, survey and ship time, and equipment. Deepwater areas of known or potentially high resource value and other potential uses should have higher priorities than those areas for which no use is envisaged in the foreseeable future.

Recommendations

5. Research activities in the EEZ should be coordinated through a designated agency to enhance cooperation and efficiency of operations among various agencies, industries, and academia, and promote basic research efforts that will increase understanding of seabed processes in the EEZ.
6. As a part of the national EEZ plan, a formal government/industry/academia EEZ program should be established to set priorities for seabed surveying and mapping activities and promote the development of technologies for obtaining EEZ seabed data. The technological developments

should include expanded use of multisensor systems for both task-specific and reconnaissance surveys in frontier areas, use of autonomous and towed vehicles, and improved techniques for processing and interpreting remotely acquired seabed data.

7. The agency designated to coordinate EEZ research activities should ensure that programs are set in place to develop the necessary technology for geotechnical and geological data acquisition in concert with the projected uses and needs. These systems and techniques will include improved sampling and in situ testing equipment for use from surface and submerged vessels in frontier areas, field monitoring of installations, and laboratory experimental modeling for seabed-structure interaction studies.
8. Government should provide leadership in fostering communication and exchange of data among all agencies and other organizations conducting research in the EEZ through development of a comprehensive EEZ data management system.

ENVIRONMENTAL MONITORING

A clear need has emerged for a nationally coordinated and supported effort in monitoring selected portions of the EEZ seabed in connection with future uses. As EEZ use expands, the lack of such a program will increase the risk of inadvertent and unacceptable damage to the EEZ environment. The required monitoring will fall into three categories: (1) reference monitoring to determine the natural range and variability of environmental parameters of the EEZ seabed, (2) process-related monitoring to understand major EEZ seabed processes, and (3) use-related monitoring to evaluate the suitability of EEZ sites for specific uses and their environmental consequences.

Recommendation

9. In conjunction with the joint planning and coordination process and the research efforts recommended above, a national EEZ monitoring program should be established with input from industry; federal, state, and local governments; academia; and public interest groups to determine EEZ monitoring priorities and strategies and the commitments by government and users required to implement them. Such a program should be based on the framework of projected uses of the seabed and should include long-term reference monitoring, seabed process-related monitoring, and use-related monitoring at specific sites. It should also incorporate the capability to respond to detrimental impacts.

PROTECTION OF UNIQUE AREAS

Identification and protection of unique underwater areas and habitats under the National Marine Sanctuaries Program has to date been a limited effort. In order to designate and subsequently manage a marine sanctuary, a substantial amount of information is needed on the resources and physical environment of the area.

Recommendation

10. Federally sponsored EEZ activities should include a marine sanctuary reconnaissance component for discovery and identification of unique areas of the seafloor deserving such long-term protection. Such designations should occur well in advance of resource development in EEZ areas to forestall potential conflict among competing uses.

References

CHAPTER 1

McGregor, B. A. and M. Lockwood. 1985. Mapping and Research in the Exclusive Economic Zone. Reston, Virginia: U.S. Geological Survey (USGS). 40 p.

Booda, L. L. 1989. A relic of the past fades away. Sea Technol. 30(3):7.

CHAPTER 2

Seabed Characteristics

McGregor, B. A. and M. Lockwood, 1985. Mapping and Research in the Exclusive Economic Zone. Reston, Virginia: USGS. 40 p.

External Environmental Effects

Barnes, P. W. and E. Reimitz. 1974. Sedimentary processes—arctic shelves off the northern coast of Alaska. *In* The Coast and Shelf of the Beaufort Sea, O. C. Reed and J. E. Saler, eds. Arlington, Virginia: Arctic Institute of North America. Pp. 439–476.

Bea, R. G. 1978. Earthquake criteria for platforms in the Gulf of Alaska. J. Petrol. Technol. 3:325–340.

Butman, B., M. Noble, and D. W. Folger. 1979. Long-term observations of bottom current and bottom sediment movement on the Mid-Atlantic continental shelf. J. Geophys. Res. 84(C3):1187–1205.

Campbell, K. J., J. R. Hooper, and D. B. Prior. 1986. Engineering implications of deepwater geologic and soil conditions, Texas-Louisiana Slope. Proceedings of the 18th Offshore Technology Conference (OTC). Richardson, Texas: OTC.

Heezen, B. C. and C. D. Hollister. 1984. Deep-sea current evidence from abyssal sediments . Mar. Geol. 1: 141–174.

Hollister, C. D., A. M. Nowell, and P. Jumars. 1984. The dynamic abyss. Sci. Am. 250(3):42–53.

Teleki, P. G., M. A. Hampton, and L. E. Garrison. 1979. Environmental hazards on the United States continental shelf. Proceedings of the 5th International Conference on Port and Ocean Engineering, Trondheim, Norway. Pp. 435–448.

Sediment Properties

Aller, R. C. 1982. The effects of macrobenthos on chemical properties of marine sediment and overlying water. *In* Animal Sediment Relations, P. L. McCall and M. J. S. Tevesz, eds. New York: Plenum Press.

Bennett, R. H., L. Lehman, M. H. Hulbert, G. R. Harvey, S. A. Bush, E. B. Forde, P. Crews, and W. B. Sawyer. 1985. Interrelationships of organic carbon and submarine sediment geotechnical properties. Mar. Geotechnol. 6(1):61–98.

Booth, J. S. and A. G. C. Dahl. 1986. A note on relationships between organic matter and some geotechnical properties of a marine sediment. Mar. Geotechnol. 6(3):281–298.

Brooks, J. M., H. B. Cox, W. R. Bryant, M. C. Kennicutt II, R. G. Mann, and T. J. McDonald. 1986. Association of gas hydrates and oil seepages in the Gulf of Mexico. Org. Geochem. 10:221–234.

Brooks, J. M., M. C. Kennicutt II, R. R. Fay, T. J. McDonald, and R. Sassen. 1984. Thermogenic gas hydrates in the Gulf of Mexico. Science 225:409–411.

Chaney, R. C. and H. Y. Fang, eds. 1986. Static and Dynamic Properties of Marine Sediment: A State of the Art, Marine Geotechnology and Nearshore/Offshore Structures. STP 923. Philadelphia: American Society for Testing and Materials (ASTM). Pp. 74–111.

Jumars, P. A. and A. R. M. Nowell. 1984. Effects of benthos on sediment transport: Problems with function group. Cont. Shelf Res. 3:115–130.

Keller, G. H. 1982. Organic matter and the geotechnical properties of submarine sediments. Geo-Mar. Letters 2:191–198.

Rocker, K. Jr. 1985. Handbook for Marine Geotechnical Engineering. Port Hueneme, California: Naval Civil Engineering Laboratory.

Research Activities

Allen, J. S., J. Bane, R. Beardsley, D. Boesch, A. Brandt, K. Brink, B. Butman, D. Caldwell, C. Collins, C. Csanady, R. Davis, R. Garvine, D. Haidvogel, P. Jumars, C. Mooers, P. Niiler, R. Rothschild, T. Royer, and E. Thornton. 1987. Coastal physical oceanography: The next decade. EOS 68:1581–1591.

Anderson, A. L. and W. R. Bryant. 1987. Distribution of seafloor shallow gas in the northwestern Gulf of Mexico. Proceedings of the 19th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 295–299.

Booth, J. S., A. J. Silva, and S. A. Jordan. 1984. Slope-stability analysis and creep susceptibility of Quaternary sediments of the northeastern United States continental slope; Seabed mechanics. Proceedings IUTAM Symposium, University of New Castle Upon Tyne, United Kingdom. London: Graham and Trotman Limited. Pp. 65–79.

Brink, K. H. 1987. Coastal ocean physical processes. Rev. Geophys. 25:204–216.

Campbell, K. J., J. R. Hooper, and D. B. Prior. 1986. Engineering implications of deepwater geologic and soil conditions, Texas-Louisiana Slope. Proceedings of the 18th Offshore Technology Conference. Richardson, Texas: OTC.

Grant, W. D., L. F. Boyer, and L. P. Sanford. 1982. The effects of bioturbation on the initiation of motion of intertidal sands. J. Mar. Res. 40:654–677.

Hammer, S. 1983. Airborne gravity is here! Geophys. 48:213–223.

Heacock, J. G. 1988. Geology and Geophysics Program, Summary for FY '87. Environmental Sciences Directorate, Office of Naval Research (ONR) Code 1125GG, Pub: #OCNR 1125GG88, 7. Arlington, Virginia: ONR.

Jacobson, R. S. 1987. Geology and Geophysics Program Summary for FY '86. Environmental Sciences Directorate, ONR Code 1125GG, Pub: #OCNR 1125GG87, 10. Arlington, Virginia: ONR. 223 p.

Jumars, P. A. and A. R. M. Nowell. 1984. Effects of benthos on sediment transport: Problems with function group . Cont. Shelf Res. 3:115–130.

LaBrecque, J. L., J. Brozena, S. Cande, R. Bell, C. Raymond, M. Keller, J. C. Parra, and G. Yanez. 1986. Aerogeophysical survey yields new data in the Weddell Sea. Antarctic J. of the U.S. 21:69–70.

Lockwood, M. 1989. A status report on the EEZ: Planning for the next 10 years. Sea Technol. Feb.:37.

Lockwood, M. and B. A. McGregor, eds. 1988. Proceedings of the 1987 Exclusive Economic Zone Symposium on Mapping and Research: Planning for the next 10 years. Circular 1018. Reston, Virginia: USGS. 175 p.

McCammon, H. M. 1988. Coastal Ocean Margins Program. DOE/ER 402. Washington, D.C.: Department of Energy (DOE). 19 p.

McGregor, B. A. and M. Lockwood. 1985. Mapping and Research in the Exclusive Economic Zone. Reston, Virginia: USGS. 40 p.

Milliman, J. D., J. Zhuang, A. Li, and J. I. Ewing. In press. Late Quaternary sedimentation on the outer and middle New Jersey continental shelf: Results of two local deglaciations? J. Geol.

National Science Foundation (NSF), Advisory Committee on Ocean Sciences. 1987. A Unified Plan for Ocean Science: A Long Range Plan for the Division of Ocean Sciences of the NSF. Draft. NSF, Washington, D.C. May.

Nelson, J. M. and J. D. Smith. 1989. Dynamics of debris flow in Natural Channels. Proceedings of the 3rd National Conference on Hydraulic Engineering: International Symposium on Sediment Transport Modeling. New York: American Society of Civil Engineers (ASCE). in press.

Nowell, A. R. M. and C. D. Hollister, eds. 1985. Deep ocean sediment transport. Mar. Geol. 66:1–4.

Nowell, A. R. M., P. A. Jumars, and J. H. Kravatz. 1987. Sediment transport events on shelves and slopes (STRESS) and biological effects of coastal ocean sediment transport. EOS 68–35:722–724.

Schock, S. G., L R. LeBlanc, and L. A. Mayer. 1989. Chirp subbottom profiler for quantitative sediment analysis. Geophys. 54(4):445–450.

Sea Grant Abstracts. 1988. Publications from the Nation's Sea Grant Programs 3(1):ISS-0887-4220.

Seymour, R. S. and W. C. Webster, eds. 1987. Ocean Engineering Research Needs. NSF Workshop on Ocean Engineering Research Needs for EEZ Resource Characterization, University of California, San Diego. IMR Reference #87–5. Washington, D.C.: NSF. 22 p.

Silva, A. J., H. G. Brandes, M. H. Sadd, D. Karamanlidis, W-M. Tian, and E. P. Laine. 1989. Experimental and analytical study of creep deformations of submarine slopes. Proceedings, Oceans '89. Washington, D.C.: Marine Techology Society (MTS).

Silva, A. J. and J. S. Booth. 1985. Creep behavior of submarine slope sediments. Geo-Mar. Letters 4:215–219.

Webster, W. J. Jr., P. T. Taylor, C. C. Schnetzler, and R. A. Langel. 1985. Magnetic field of the Earth: Performance considerations for space base observing systems. IEEE Trans. on Remote Sensing GE-23:541–551.

Yamamoto, T. and T. Torii. 1986. Seabed shear modulus profile inversion using surface gravity (water) wave-induced bottom motion. J. Geophys. Res. 85:413–431.

Yuen, P. C. 1987. Engineering Solutions for the Utilization of EEZ Resources. Honolulu: University of Hawaii, College of Engineering.

CHAPTER 3

Corell, R. W. 1998. Advance technology and science: A key to oceanic development. Mar. Technol. Soc. J. 22(1):50–57.

Pontecorvo. G. 1989. Contribution of the ocean sector to the United States economy: Estimated values for 1987-A technical note. Mar. Technol. Soc. J. 23(2):7–14.

Oil And Gas

American Petroleum Institute (API). 1987. Planning, Designing, and Constructing Fixed Offshore Platforms. Dallas: API.

American Society of Civil Engineers (ASCE), Committee on Reliability of Offshore Structures. 1983. Application of reliability methods in design and analysis of offshore platforms. J. Structural Engrg. 109(10): 2265–2291.

Anon. 1988. Federal OCS Platform Directory Gulf of Mexico. Grapevine, Texas: James C. Dobson Co.

Bettenberg, W. D. 1987. The outer continental shelf program: Status, prospects, and information needs. Proceedings of the 1987 Exclusive Economic Zone Symposium on Mapping and Research: Planning for the Next 10 Years, M. Lockwood and B. A. McGregor, eds. Circular 1018. Reston, Virginia: USGS. Pp. 27–30.

Brooks, J. M., B. H. Cos, W. R. Byant, M. C. Kennicutt II, R. G. Mann, and T. J. McDonald. 1986. Association of gas hydrates and oil seepage in the Gulf of Mexico. *In* Advances in Organic Geochemistry, D. Leythaeuser and J. Rullkotter, eds. Organic Geochem. 10:221–234.

Campbell, K. J., J. R. Hooper, and D. B. Prior. 1986. Engineering implications of deepwater geologic and soil conditions, Texas-Louisiana Slope. Proceedings of the 18th Offshore Technology Conference. Richardson, Texas: OTC.

Campbell, K. J., G. W. Quiros, and A. G. Young. 1988. The importance of integrated Studies to deepwater site investigation. Proceedings of the 20th Offshore Technology Conference. Richardson, Texas: OTC.

Esrig, J. I. and R. C. Kirby. 1977. Implications of gas content for predicting the stability of submarine slopes. Mar. Geotechnol. 2:81–100.

Hooper, J. R. and W. A. Dunlap. 1989. Modeling soil properties on the continental slope, Gulf of Mexico. Proceedings of the 21st Offshore Technology Conference. Richardson, Texas: OTC. Pp. 677–688.

Hooper, J. R. and A. G. Young. 1989. Engineering solutions for deepwater foundation problems using integrated investigations. International Ocean Technology Congress. Honolulu, Hawaii. January 22–26.

Kraft, L. M. Jr. and M. R. Ploessel. 1985. Stability of submarine slopes. *In* Planning and Design of Fixed Offshore Platforms. New York: Van Nostrand Reinhold. Pp. 440–516.

LeBlanc, L. A. 1983. Exxon installs first guyed tower. Offshore 43(9):37–38.

McClelland, B. and C. J. Ehlers. 1986. Offshore geotechnical site investigations. *In* Planning and Design of Fixed Offshore Platforms. New York: Van Nostrand Reinhold. Pp. 224–265.

Mclver, R. D. 1982. Role of naturally occurring gas hydrates in sediment transport. Am. Assoc. Petrol. Geol. Bull. 66(6):789–792.

Minerals Management Service (MMS). 1987. Federal Offshore Statistics: 1985. OCS Report MMS 87-0008. Washington, D.C.: U.S. Department of the Interior (DOI).

National Research Council (NRC). 1986. Understanding the Arctic Seafloor for Engineering Purposes. Washington, D.C.: NRC, Marine Board.

National Research Council. 1985. Oil in the Sea: Inputs, Fates, and Effects. Washington, D.C.: National Academy Press.

National Research Council. 1979. Inspection of Oil and Gas Platforms and Risers. Washington, D.C.: NRC, Marine Board.

National Research Council. 1977. Verification of Fixed Offshore Oil and Gas Platforms. Washington, D.C.: NRC, Marine Board.

Nehring, R. 1981. The Discovery of Significant Oil and Gas Fields in the United States. Santa Monica, California: Rand Corp.

Ocean Oil Weekly Report. 1987. Exploration and Production. 22(3):3. September 28.

Ocean Oil Weekly Report. 1988. Drilling slated for November on Shell's Bullwinkle project. 23(8):3. October 31.

Ocean Oil Weekly Report. 1989. Gas hydrates, complex formations challenged Conoco TLWP designers. 23(35):2. May 8.

Office of Technology Assessment (OTA). 1985. Oil and Gas Technologies for the Arctic and Deepwater. OTA-0-270. Washington, D.C.: OTA.

Prior, D. B., E. H. Doyle, and M. Kaluza. 1989. Evidence for sediment eruption on deep sea floor, Gulf of Mexico. Science 2:517–519.

Tyce, R. C. and P. E. Pryor. 1988. Workshop 6: Technology needs to characterize the EEZ. *In* Proceedings of the 1987 Exclusive Economic Zone Symposium on Mapping and Research: Planning for the Next 10 Years, N. Lockwood and B. A. McGregor, eds. Circular 1018. Reston, Virginia: USGS. Pp. 101–114.

U.S. Geological Survey (USGS). 1986. Proceedings, The Exclusive Economic Zone Symposium. Exploring the New Ocean Frontier, M. Lockwood and G. Hill, eds. Reston, Virginia: USGS.

Whelan, T. III, J. M. Coleman, J. N. Suhayda, and H. H. Roberts. 1977. Acoustical penetration and shear strength in gas-charged sediment. Mar. Geotechnol. 2:147–159.

Wickizer, C. L 1988. Challenges of future deepwater operations examined. Oil and Gas J. 8:61–68. October 24.

Yokel, F. Y. and R. G. Bea. 1986. Mat Foundations for Offshore Structures in Arctic Regions . NBSIR 86–3419. Washington, D.C.: National Bureau of Standards (NSB).

Young, A. G., L. Babb, and R. Boggess. 1988. Mini-probes: A new dimension in offshore in situ testing. Proceedings, Oceans '88. Washington, D.C.: MTS. Pp. 423–427.

Mineral Exploration and Development

Broadus, J. M. 1987. Seabed materials. Science 235(4791):853–860.

Cruickshank, M. 1987. Marine Mining on the Outer Continental Shelf: Environmental Effects Overview. OCS Report 87–0035. Washington, D.C.: DOI.

Francis, T. J. G. 1987. Marine minerals: Advances in research and resource assessment. *In* Proceedings of the NATO Advanced Research Workshop on Marine Minerals: Resource Assessment Strategies. Gregynog, Wales, U.K.: NATO.

Katz, K 1987. McCormack mines the ocean floor. Rock Products. August. P. 47

Minerals Management Service (MMS). 1987. Prospecting in the outer continental shelf for minerals other than oil, gas, and sulfur. Proposed Rules Part I. Federal Register. Vol. 52, March 16, 1987.

Minerals Management Service. 1988a. Leasing in the outer continental shelf for minerals other than oil, gas, and sulfur . Proposed Rules Part II. Federal Register. Vol. 53(160). August 18, 1988.

Minerals Management Service. 1988b. Operations in the outer continental shelf for minerals other than oil, gas, and sulfur. Proposed Rules Part III. Federal Register Vol. 53(160). August 18, 1988.

National Research Council (NRC). 1975. Mining in the Outer Continental Shelf and in the Deep Ocean. Marine Board, Panel on Operational Safety in Marine Mining. Washington, D.C.: NRC.

Office of Technology Assessment (OTA). 1987. Marine Minerals: Exploring Our New Ocean Frontier. Washington: OTA.

Pendley, W. P. 1989. It ain't broke—don't fix it: Mining in America's Exclusive Economic Zone requires no new legislation. Mar. Technol. Soc. J. 23(1).

Tyce, R. C. and D. E. Pryor. 1988. Technology needs to characterize the EEZ. *In* Proceedings of the 1987 EEZ Symposium on Mapping and Research: Planning for the Next 10 Years, M. Lockwood and B. A. McGregor, eds. USGS Circular 1018. Reston, Virginia: USGS.

U.S. Congress, Mining and Mineral Resources Subcommittee of the House Interior and Insular Affairs Committee. 1989. Joint Statement of the Working Group on EEZ Hard Minerals. May 4.

U.S. Department of the Interior (DOI). 1987. The Mineral Position of the United States. Annual Report of the Secretary of the Interior. Washington, D.C.: DOI.

Wickizer, C. L. 1988. Challenges of future deepwater operations examined. Oil and Gas J. 8:61–68. October 24.

Waste Disposal

Benefenati, E., R. Pastorelli, M. G. Castelli, R. Fanelli, A. Carminati, A. Farnaeti, and M. Lodi. 1986. Studies on the tetrachlorodibenzo-p-dioxins (TCDD) and tetrachlorodibenzofurans (TCDF) emitted from an urban incinerator. Chemosphere 15(5):557–561.

Benestad, C., A. Jebens, and G. Tveten, 1987. Emission of organic micropollutants from waste incineration. Chemosphere 16(4):813–820.

Bokuniewicz, H. J. 1983. Submarine borrow pits as containment sites for dredged sediment. *In* Wastes in the Ocean, Volume 2, Dredged Material Disposal in the Ocean, D. R. Kester, B. H. Ketchum, I. W. Duedall, and P. K. Park, eds. New York: Wiley and Sons. Pp. 215–227.

Colombo, P., R. M. Neilson Jr., and M. W. Kendig. 1983. Analysis and evaluation of a radioactive waste package retrieved from the Atlantic Ocean. *In* Wastes in the Ocean, Volume 3, Radioactive Wastes and the Ocean, P. K. Park, K. R. Kester, I. W. Duedall, and B. H. Ketchum, eds. New York: Wiley and Sons. Pp. 237–268.

Duedall, I. W., D. R. Kester, P. K. Park, and B. H. Ketchum, eds. 1985. Wastes in the Ocean, Volume 1, Industrial and Sewage Wastes in the Ocean. New York: Wiley and Sons. 818 p.

Francis, C. W. 1984. Leaching Characteristics of Resource Recovery Ash in Municipal Waste Landfills. Final Report, DOE Project No. ERD-83-289. Oak Ridge, Tennessee: Oak Ridge National Laboratory. 14 p.

Heath, G. R., C. D. Hollister, D. R. Anderson, and M. Leinen. 1983. Why consider subseabed disposal of high-level nuclear wastes? *In* Wastes in the Ocean, Volume 3, Radioactive Wastes and the Ocean, P. K. Park, D. R. Kester, I. W. Duedall, and B. H. Ketchum, eds. New York: Wiley and Sons. Pp. 303–325.

Kamlet, K. S. 1983. Dredged material ocean dumping: Perspectives on legal and environmental impacts. *In* Wastes in the Ocean, Volume 2, Dredged Material Disposal in the Ocean, D. R. Kester, B. H. Ketchum, I. W. Duedall, and P. K. Park, eds. New York: Wiley and Sons. Pp. 29–70.

Kester, D. R., B. H. Ketchum, I. W. Duedall, and P. K. Park. 1983. Have the questions concerning dredged material disposal been answered? *In* Wastes in the Ocean, Volume 2, Dredged Material Disposal in the Ocean, D. R. Kester, B. H. Ketchum, I .W. Duedall, and P. K. Park, eds. New York: Wiley and Sons. Pp. 275–287.

Lear, D. W. and M. L. O'Malley. 1983. Effects of sewage sludge dumping on continental shelf benthos. *In* Wastes in the Ocean. Volume 1, Industrial and Sewage Wastes in the Ocean, I. W. Duedall, B. H. Ketchum, P. K. Park, and D. R. Kester, eds. New York: Wiley and Sons. Pp. 99–121.

Morton, R. W. 1983. Precision bathymetric study of dredged-material capping experiment in Long Island Sound. *In* Wastes in the Ocean, Volume 2, Dredged Material Disposal in the Ocean, D. R. Kester, B. H. Ketchum, I. W. Duedall, and P. K. Park, eds. New York: Wiley and Sons. Pp. 99–121.

National Research Council (NRC). 1989. Monitoring particulate waste in the oceans . Unpublished report of the Panel on Particulate Waste in the Oceans, Committee on Systems Assessment of Marine Environmental Monitoring. Marine Board, NRC, Washington, D.C.

O'Connor, J. M., J. B. Klotz, and T. J. Kneip. 1982. Sources, sinks, and distribution of organic contaminants in the New York Bight ecosystem. *In* Ecological Stress and the New York Bight: Science and Management, G. F. Mayer, ed. Columbia, South Carolina: Estuarine Research Federation. Pp. 631–653.

Office of Technology Assessment, U.S. Congress. 1987. Wastes in Marine Environments. OTA-334. Washington, D.C.: U.S. Government Printing Office.

Peddicord, R .K. and J. C. Hansen. 1983. Technical implementation of the regulations governing ocean disposal of dredged material. *In* Wastes in the Ocean, Volume 2, Dredged Material Disposal in the Ocean, D. R. Kester, B. H. Ketchum, I. W. Duedall, and P. K. Park, eds. New York: Wiley and Sons. Pp. 71–88.

Reed, M. and V. J. Bierman, Jr. 1989. A protocol for designation of ocean disposal sites. *In* Oceanic Processes in Marine Pollution, Vol. III, Marine Waste Management—Science and Policy, M. A. Champ and P. K. Park, eds. Malabar, Florida: Krieger Publishing.

Sawyer, T. K. and S. M. Bodammer. 1983. Marine amoeoae (Protozoa: Sanoodina) as indicators of healthy or impacted sediments in the New York Bight Apex. *In* Wastes in the Ocean, Volume 1, Industrial and Sewage Wastes in the Ocean, I. W. Duedall, B. H. Ketchum, P. K. Park, and D. R. Kester, eds. New York: Wiley and Sons. Pp. 337–352.

Stanford, H. M., J. S. O'Connor, and R. L. Swanson. 1981. The effects of ocean dumping on the New York Bight ecosystem. *In* Ocean Dumping of Industrial Wastes, B. H. Ketchum, D. R. Kester, and P. K. Park, eds. New York: Plenum Press. Pp. 53–86.

U.S. Environmental Protection Agency (EPA). 1976. Bioassay Procedures for the Ocean Disposal Permit Program. EPA-600/9-76-010. Gulf Breeze, Florida: Environmental Research Laboratory. 96 p.

Cables and Military Uses

Anon. 1989. Notes on the News. Telecommunications Reports, Feb. 27. P. 56.

Federal Communications Commission. 1988. FCC Docket 79–184, Report and Order 88–179. Released June 24, 1988.

National Telecommunications Information Agency (NTIA). 1984. 1984 World's Submarine Telephone Cable Systems. NTIA-CR-84-31. Washington, D.C.: Department of Commerce.

BIOLOGICAL RESOURCES

Booth, W. 1987. Combing the earth for cures to cancer, AIDS. Science 237:969–970.

Cavanaugh, C. M. 1983. Symbiotic chemoautotrophic bacteria in marine invertebrates from sulphiderich habitats. Nature 302:58–61.

Felbeck, H. and G. N. Somero. 1982. Primary production in deep-sea hydrothermal vent organisms: Roles of sulfide-oxidizing bacteria. Trends in Biochem. Sci. 7:201–204.

Greene, C. H., P. H. Wiebe, J. Burczynski, and M. J. Youngbluth. 1988. Acoustical detection of high-density krill demersal layers in the submarine canyons off Georges Bank. Science 241:359–361.

Jannasch, H. W. 1989. The microbial basis of life at deep-sea hydrothermal vents. ASM News 55(8):413–416

O'Bannon, B. K., ed. 1988. Fisheries of the United States, 1987. Washington, D.C.: National Oceanic and Atmospheric Administration (NOAA).

Roberts, L. 1987. Discovering microbes with a taste for PCBs. Science 237:975–977.

Ocean Energy Resources

Baggott, M. and R. Morris. 1985. Wave power prototype nears construction phase. Power Engrg. Feb.:35–38.

Cohen, R. 1982. Energy from the ocean. Phil. Trans. R. Soc. London A 307:405–437.

Lockwood M. and B. A. McGregor. 1988. Proceedings of the 1987 EEZ Symposium on Mapping and Research: Planning for the Next 10 Years, M. Lockwood and B. A. McGregor, eds. USGS Circular 1018. Reston, Virginia: USGS.

McCormick, M. E. 1981. Ocean Wave Energy Conversion. New York: John Wiley and Sons.

Rogers, J., F. Matsuda, L. Varga, and P. Takahashi. 1988. Converting ocean thermal energy for commercial use in the Pacific. Sea Technol. 29(10):23–29.

Cultural and Recreational Resources

Foster, N. M. and J. H. Archer. 1988. Introduction: The National Marine Sanctuary Program: Policy, education, and research. Oceanus 31(1):4–17.

Ryan, P. R. 1986. The *Titanic* revisited. Oceanus 29(3):2–15.

CHAPTER 4

Surveying and Mapping

Anderson, A. L. and W. R. Bryant. 1988. Geocoustic significance of gassy sediment. Abstract. *In* ONR Geology and Geophysics Program, FY 87 Summary. Arlington, Virginia: ONR. Pp. 188–190.

Davis, E. E., R. G. Currie, B. S. Sawyer, and T. G. Kosalos. 1986. The use of swath bathymetric and acoustic image mapping tools in Marine Geoscience. Mar. Technol. Soc. J. 20(4):17–27.

EEZ-Scan 84, Scientific Staff. 1986. Atlas of the Exclusive Economic Zone, Western Coterminus, United States. Miscellaneous Investigation Series I-1792. Reston, Virginia: USGS. 152 p.

EEZ-Scan 85, Scientific Staff. 1987. Atlas of the Exclusive Economic Zone, Gulf of Mexico. Miscellaneous Investigation Series I-1864-A. Reston, Virginia: USGS. 104 p.

Farre, J. A. and W. B. F. Ryan. 1987. Surficial geology of the continental margin offshore New Jersey in the vicinity of deep-sea drilling project sites 612 and 613 . *In* Initial Reports of the Deep Sea Drilling Project, Vol. XCV, C. W. Poag et al., eds. Washington, D.C.: U.S. Government Printing Office. Pp. 725–759.

Garrison, S. E., T. E. Tatum, J. S. Booth, and S. M. Casby. 1977. Geologic hazards of the upper continental slope, Gulf of Mexico. Proceedings of the 9th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 51–58.

Kastens, K. A. and A. N. Shor. 1985. Depositional processes of a meandering channel on the Mississippi Fan. Am. Assoc. Petrol. Geol. Bull. 69(2):190–202.

Kelland, N. C. 1988. Accurate acoustic position monitoring of deep water geophysical towfish. Proceedings of the 20th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 322–327.

Kosalos, J. G. 1984. Ocean bottom imaging. Proceedings of the 16th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 65–72.

McClelland Engineers. 1982. Offshore Site Evaluations. Houston, Texas: McClelland Engineers Inc. 83 p.

McQuillin, R. and D. A. Ardus. 1977. Exploring the geology of shelf areas . London: Graham & Trotman. 234 p.

National Oceanic and Atmospheric Administration (NOAA). 1987. Plan for Mapping the Sea Floor of the U.S. Exclusive Economic Zone, 1988–92. Washington, D.C.: NOAA. 562 p.

Nowell, A. R. M., P. A. Jumars, and J. H. Kravitz. 1987. Sediment transport events on shelves and slopes (STRESS) and biological effects of coastal ocean sediment transport (BECOST). EOS 68:34.

Prior, D. G. and E. H. Doyle. 1984. Geological hazard surveying for exploratory drilling in water depths of 2,000 m. Proceedings of the 16th Offshore Technology Conference. Richardson, Texas: OTC.

Prior, D. B., E. H. Doyle, M. J. Kaluza, M. W. Woods, and J. R. Roth. 1988. Technical advances in high-resolution hazard surveying, deepwater Gulf of Mexico. Proceedings of the 20th Offshore Technology Conference. Richardson, Texas: OTC.

Ross, D. A., C. E. McLain, and J. E. Dailey. 1989. The ocean enterprise concept: A national strategy for resource development. Sea Technol. January, Pp. 15–20.

Spiess, F. N. 1987. Seafloor research and ocean technology. Mar. Technol. Soc. J. 21(2):5–17.

Trabant, P. K. 1982. Applied High-Resolution Geophysical Methods. Boston: International Human Resources Development Corp. 235 p.

Tyce, R. C. 1986. Deep seafloor mapping systems—a review. Mar. Technol. Soc. J. 20(4):40–16.

Tyce, R. C. and Pryor, D. E. 1988. Technology needs to characterize the EEZ. Proceedings of the 1987 Exclusive Economic Zone EEZ Symposium on Mapping and Research: Planning for the Next 10 Years, M. Lockwood and B. A. McGregor, eds. Circular 1018. Reston, Virginia: USGS. Pp. 101–114.

Seabed Geotechnical Data

Andresen, A., T. Berre, A. Kleven, and T. Lunne. 1979. Procedures used to obtain soil parameters for foundation engineering in the North Sea. Mar. Geotechnol. 3(3):201–266.

Briand, J. L. and B. Meyer. 1983. In situ tests and their application in offshore design. *In* Geotechnical Practice in Offshore Engineering, S. G. Wright, ed. New York: ASCE. Pp. 244–266.

Craig, W. H. and N. K. S. Al-Saoudi. 1981. The behavior of some model offshore structures. Proceedings of the 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm. Volume 2. Pp. 83–88.

Denk, E. W., W. A. Dunlap, W. R. Bryant, L. J. Milberger, and T. J. Wheelan. 1981. A pressurized core barrel for sampling gas-charged sediments. Proceedings of the 13th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 43–52.

Emrich, W. J. 1971. Performance study of soil samples for deep penetration marine borings. *In* Proceedings, Sampling of Soil and Rock. STP 483. Philadelphia: ASTM. Pp. 30–50.

Galerne, E. 1984. EPAULARD: A working autonomous survey vehicle system with expanding capabilities. ROV '84 Conference Proceedings. Washington, D.C.: MTS. Pp. 357–359.

Geise, J. M. and H. J. Kolk. 1983. The use of submersibles for geotechnical investigations. SUBTECH '83 Proceedings. November 15–17, London.

Hollister, C. D., A. J. Silva, and A. Driscoll. 1973. A giant piston corer. J. Ocean Engrg. 2:159–168.

Jackson, E. and J. Ferguson. 1984. Design of ARCS—Autonomous Remotely Controlled Submersible. ROV '84 Conference Proceedings. Washington D.C.: MTS. Pp. 365–368.

King, R. W., W. R. Van Hooydonk, H. J. Kolk, and D. Windle. 1980. Geotechnical investigations of calcareous soils of the north west shelf, Australia. Proceedings of the 12th Annual Offshore Technology Conference. Richardson, Texas: OTC. Pp. 303–13.

Kirkpatrick, W. M. and A. J. Khan. 1984. The reaction of clays to sampling stress relief. Geotech. 34(1):29–42.

Lee, H. J. 1985. State of the art: Laboratory determination of the strength of marine soils. *In* Strength Testing of Marine Sediments and In Situ Measurements, R.C. Chaney and K. R. Demars, eds. STP 883. Philadelphia: ASTM. Pp. 181–250.

McClelland, B. 1972. Techniques used in soil sampling at sea. Offshore 2(3):51–57.

McClelland, B. and C. J. Ehlers. 1986. Offshore geotechnical site investigations. *In* Planning and Design of Fixed Offshore Platforms. New York: Van Nostrand Reinhold. Pp. 224–265.

Michel, J. L., P. Borot, and H. Le Roux. 1984. EPAULARD: Experience and Developments. ROV '84 Conference Proceedings. Washington, D.C.: MTS. Pp. 360–364.

Peterson, M. N. A. 1984. Design and operation of an advanced hydraulic piston corer. Technical Report No. 21. Washington, D.C.: National Science Foundation, National Ocean Sediment Coring Program. July.

Poulos, H. G. 1988. Marine Geotechnics. London: Unwin Hyman Ltd. P. 188. Richards, A. F. and H. Zuidberg. 1985. In situ testing and sampling in water depths exceeding 300 m. *In* Offshore Site Investigation. London: Graham & Trotman. Pp. 129–163.

Rocker, K. Jr. 1985. Handbook for Marine Geotechnical Engineering. Port Hueneme, California: Naval Civil Engineering Laboratory.

Rowe, P. W. 1983. Use of large centrifugal models for offshore and nearshore works. *In* Geotechnical Aspects of Coastal and Offshore Structures, Y. Balasubramanian and A. S. Balasubramanian, eds. Rotterdam: A. A. Balkema. Pp. 21–33.

Rowe, P. W., W. H. Craig, and D. C. Procter. 1976. Model studies of offshore gravity structures founded on clay. BOSS '76, Behaviour of Off-Shore Structures, Volume 1. Trondheim, Norway. Pp. 439–448.

Schofield, A. N. 1980. Cambridge geotechnical centrifuge operations. Geotech. 3(3):227–268.

Silva, A. J. and R. M. Wyland. 1987. Autonomous seafloor strength profiler. *In* Field Vane Shear Strength Testing in Soils: Field and Laboratory Studies, A. F. Richards, ed. STP 1014. Philadelphia: ASTM. Pp. 354–371.

Stremlau, T. H. and S. G. Spencer. 1980. In situ bearing capacity evaluations. Proceedings of the 12th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 151–158.

Sullivan, R. A., S. J. Wright, and D. W. F. Senner. 1980. Evaluation of design parameters from laboratory tests. *In* Offshore Site Investigation. London: Graham & Trotman. Pp. 201–15.

Young, A. G. In press. Marine Foundation Studies. *In* Handbook on Ocean Engineering, Volume 2, J. Herbich, ed. Houston: Gulf Publishing.

Young, A. G., L. Babb, and R. Boggess. 1988b. Mini-probes: A new dimension in offshore in situ testing. Proceedings, Oceans '88. Washington, D.C.: MTS. Pp. 423–427.

Young, A. G., B. McClelland, and G. Quiros. 1988a. In situ vane shear testing at sea. *In* Vane Shear Strength Testing in Soils: Field and Laboratory Studies, A. F. Richards, ed. STP 1014. Philadelphia: ASTM. Pp. 46–47.

Young, A. G., G. W. Quiros, and C. J. Ehlers. 1983. Effects of offshore sampling and testing on undrained soil shear strength. Proceedings of the 15th Offshore Technology Conference. Richardson, Texas: OTC. Pp. 193–204.

Zuidberg, H. M., A. F. Richards, and J. M. Geise. 1986. Soil exploration offshore. Fourth International Geotechnical Seminar, Field Instrumentation and In Situ Measurements, Singapore. Pp. 3–11.

Monitoring the Seabed of the EEZ

American Oil and Gas Association (AOGA). 1978. American Oil and Gas Association, Arctic Research Committee Presentation to the Beaufort Sea Synthesis Meeting, BLM-NOAA/OCSEAP, Barrow, Alaska . January 23.

Carder, K. L., R. G. Steward, and P. R. Betzer. 1982. In situ holographic measurements of the sizes and settling rates of oceanic particulates. J. Geophys. Res. 87:5681–5685.

Callahan, T. 1984. Long term ecological research. Bioscience 34:363–367.

Fredette, T. J., G. Anderson, B. S. Payne, and J. D. Lunz. 1986. Biological monitoring of open-water dredged material disposal sites. Proceedings, Oceans '86. Washington, D.C.: MTS. Pp. 764–769.

Keystone Ocean Project. 1987. A Decision Making Process for Evaluating the Use of the Oceans in Hazardous Waste Management. Keystone, Colorado: Report of the Keystone Center.

Lee, T. N., L. P. Atkinson, and R. Legeckis. 1981. Observations of a Gulf Stream frontal eddy on the Georgia continental shelf. Deep Sea Res. 28:347–378.

Lee, T. N., E. Daddio, and G. C. Han. 1982. Steady-state diagnostic model of summer mean circulation on the Georgia Shelf. J. Phys. Oceanogr. 12:820–838.

Manheim, F. T. 1986. Marine cobalt resources. Science 232:553–684.

Manheim, F. T. and A. Vine. 1987. Options for radioactive and other hazardous waste siting within the U.S. Exclusive Economic Zone. Technical Report WHOI-87-12. Woods Hole, Massachusetts: Woods Hole Oceanographic Institution.

Minerals Management Service (MMS). 1973–1979. Marine Mineral Science. Environmental Studies Program, Gulf of Mexico Office, Expenditures by Study Topic, End Fiscal Year 1973–1979. Washington, D.C.: DOI.

Munk, W. H. and P. F. Worcester. 1988. Ocean acoustic tomography. Oceanography 1(1):8–10.

National Oceanographic and Atmospheric Administration (NOAA). 1984. The National Status and Trends Program for Marine Environmental Quality. Program Description, FY 1985. Rockville, Maryland: NOAA.

National Research Council (NRC). 1989. Monitoring particulate waste in the oceans. Unpublished report of the Panel on Particulate Waste in the Oceans, Committee on Systems Assessment of Marine Environmental Monitoring. Marine Board, NRC, Washington, D.C.

National Research Council (NRC). 1985. National Issues and Research Priorities in the Arctic. Polar Research Board. Washington, D.C.: NRC.

National Research Council (NRC). 1984. Global Ocean Flux Study. Proceedings of a Workshop, Woods Hole, Massachusetts, September 10–14. Board on Ocean Policy and Study. Washington, D.C.: National Academy Press.

National Research Council. 1978. OCS Oil and Gas: An Assessment of the Department of the Interior Environmental Studies Program. Commission on Natural Resources, Environmental Studies Board. Washington, D.C.: National Academy Press. 109 p.

O'Connor, T. P., A. Okubo, M. A. Champ, and P. K. Park. 1983. Projected consequences of dumping sewage sludge at a deep ocean site near the New York Bight. Can. J. Fish. Aquat. Sci. 40(Suppl. 2):228–241.

Revsbeck, N. P., B. Madsen, and B. B. Jorgensen. 1986. Oxygen production and consumption in sediments determined at high spatial resolution by computer simulation of oxygen microelectrode data. Limnol. Oceanogr. 31:293–304

Rhoads, D. C. and J. D. Germano. 1986. Interpreting long-term changes in benthic community structure: A new protocol. Hydrobiologia 142:291–308.

Roethel, F. J., V. Schaeperkoetter, R. Gregg, and K. Park. 1986. The Fixation of Incineration Ash: Physical and Leachate Properties. Interim Report to New York State Legislative Committee on Water Research Needs of Long Island, N.Y. Stony Brook, N.Y.: State University of New York at Stony Brook.

Shieh, C. S., I. W. Duedall, E. H. Kalajian, and J. R. Wilcox. 1989. Stabilization of oil ash for artifical reefs: An alternative to the disposal of oil ash waste. Environ. Profess. 11:64–70.

Segar, D. A. 1986. Design of monitoring studies to assess waste disposal effects on regional to site specific scales. *In* Public Waste Management and the Ocean Choice, K. D. Stolzenbach, J. T. Kildow, and E. T. Harding, eds. MITSG-85-36. Cambridge, Massachusetts: Massachusetts Institute of Technology Sea Grant Program. Pp. 189–208.

U.S. Bureau of Mines. 1987. An economic reconnaissance of selected sand and gravel deposits in the U.S. Exclusive Economic Zone. Open File Report 3–87. Washington, D.C.: DOI.

Walsh, J. J. 1988. On the Nature of Continental Shelves. New York: Academic Press.

Yevich, P. P. and C. A. Barscz. 1983. Histopathology as a monitor for marine pollution. Results of the histopathologic examination of the animals collected for the U.S. 1976 Mussel Watch Program. Rapp. P.-v R'eun. Cons. Int. Explor. Mer 182:96–102.

CHAPTER 6

Hardin, G. 1968. The tragedy of the commons. Science 162:1243–1245.

U.S. Congress, Subcommittee of the House Interior and Insular Affairs Committee. 1989. Joint Statement of the Working Group on EEZ Hard Minerals. May 4.

Legislation and Presidential Proclamations Cited

Arctic Research and Policy Act of 1984, P. L. 98–373.

Clean Water Act, P. L. 92–500, 33 U.S.C. 1251, et seq. (Also known as the Federal Water Pollution Control Act; and Public Law 92–500, as amended.)

Coastal Zone Management of Act of 1972, as amended, P. L. 92–583; 16 U.S.C. 1451, et seq.

Deepwater Port Act, 33 U.S.C. 1501 et seq.

Endangered Species Act of 1973, as amended, P. L. 93–205; 16 U.S.C. 1531, et seq.

Magnuson Fisheries Conservation and Management Act of 1976, P. L. 83–212, 67 Stat. 462 (1953), 43 U.S.C. 1331–1356.

Marine Protection, Research and Sanctuaries Act of 1972, P. L. 92–532; 33 U.S.C. 1401, et seq.

National Environmental Policy Act of 1969, as amended, P. L. 91–190, 42 U.S.C. 4321, et seq. 42 U.S.C. 4321–4347.

National Ocean Pollution, Research, Development and Monitoring Planning Act of 1978, 33 U.S.C., 1701 et seq.

Ocean Dumping Ban Act of 1988, P. L. 100–688.

Outer Continental Shelf Lands Act of 1953, P. L. 94–265 as amended, 43 U.S.C., 1331 et seq.

Reagan Proclamation, EEZ, Proclamation No. 5030, 48 Fed. Reg. 10605, 3 C.F.R. 5030, 1983.

Truman Proclamation of 1945. Executive Proclamation No. 2667, September 28, 1945. 59 Stat. 884 (1945).

Glossary of Acronyms

AOGA	American Oil and Gas Association
API	American Petroleum Institute
AUV/AOV	autonomous underwater vehicle or autonomously operated vehicle
ASW	anti-submarine warfare
BOM	Bureau of Mines, Department of the Interior
BRAT	Benthic Resource Assessment Technique
CZMA	Coastal Zone Management Act
DOD	Department of Defense
DOE	Department of Energy
DOE	Department of the Interior
DPLA	Deepwater Port Licensing Act
DWPA	The Deep Water Port Act
EPA	Environmental Protection Agency
EEZ	Exclusive Economic Zone
HLW	high level [radioactive] waste
IAEA	International Atomic Energy Agency
JOMAR	Joint Office for Mapping and Research, NOAA and USGS
LDC	London Dumping Convention
LLW	low level [radioactive] waste
MFCMA	Magnuson Fisheries Conservation and Management Act
MMS	Minerals Management Service, Department of the Interior
MPRSA	Marine Protection, Research and Sanctuaries Act
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service, NOAA
NOAA	National Oceanic and Atmospheric Administration
NOPRDMPA	National Ocean Pollution, Research, Development and Monitoring Planning Act
NPDES	National Pollutant Discharge Elimination System
NSF	National Science Foundation
NS&T	National Status and Trends Program, NOAA
OCS	outer continental shelf
OCSLA	Outer Continental Shelf Lands Act
ONR	Office of Naval Research
OTA	Office of Technology Assessment, U.S. Congress
OTEC	ocean thermal energy conversion
REMOTS	Remote Ecological Monitoring of the Sea Floor
ROV	remotely operated vehicle
SAR	synthetic aperture radar
USGS	U.S. Geological Survey, Department of the Interior

Appendix A

Presidential EEZ Proclamation

Exclusive Economic Zone of the United States of America
A Proclamation by the President of the United States of America
March 10, 1983

WHEREAS the Government of the United States of America desires to facilitate the wise development and use of the oceans consistent with international law;

WHEREAS international law recognizes that, in a zone beyond its territory and adjacent to its territorial sea, known as the Exclusive Economic Zone, a coastal State may assert certain sovereign rights over natural resources and related jurisdiction; and

WHEREAS the establishment of an Exclusive Economic Zone by the United States will advance the development of ocean resources and promote the protection of the marine environment, while not affecting other lawful uses of the zone, including the freedoms of navigation and overflight, by other States;

NOW, THEREFORE, I, RONALD REAGAN, by the authority vested in me as President by the Constitution and laws of the United States of America, do hereby proclaim the sovereign rights and jurisdiction of the United States of America and confirm also the rights and freedoms of all States within an Exclusive Economic Zone as described herein.

The Exclusive Economic Zone of the United States is a zone contiguous to the territorial sea, including zones contiguous to the territorial sea of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands (to the extent consistent with the Covenant and the United Nations Trusteeship Agreement), and United States overseas territories and possessions. The Exclusive Economic Zone extends to a distance 200 nautical miles from the baseline from which the breadth of the territorial sea is measured. In cases where the maritime boundary with a neighboring State remains to be determined, the boundary of the Exclusive Economic Zone shall be determined by the United States and other States concerned in accordance with equitable principles.

Within the Exclusive Economic Zone, the United States has, to the extent permitted by international law, (a) sovereign rights for the purpose of exploring, exploiting, conserving and managing natural resources, both living and non-living, of the seabed and subsoil and the superjacent waters and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds; and (b) jurisdiction with regard to the establishment and use of artificial islands, and installations and structures having economic purposes, and the protection and preservation of the marine environment.

This Proclamation does not change existing United States policies concerning the continental shelf, marine mammals and fisheries, including highly migratory species of tuna which are not subject to United States jurisdiction and require international agreements for effective management.

The United States will exercise these sovereign rights and jurisdiction in accordance with the rules of international law.

Without prejudice to the sovereign rights and jurisdiction of the United States, the Exclusive Economic Zone remains an area beyond the territory and territorial sea of the United States in which all States enjoy the high seas freedoms of navigation, overflight, the laying of submarine cables and pipelines, and other internationally lawful uses of the sea.

IN WITNESS WHEREOF, I have hereunto set my hand this tenth day of March, in the year of our Lord nineteen hundred and eighty-three, and of the Independence of the United States of America the two hundred and seventh.

Statement by the President

March 10, 1983

The United States has long been a leader in developing customary and conventional law of the sea. Our objectives have consistently been to provide a legal order that will among other things, facilitate peaceful, international uses of the oceans and provide for equitable and effective management and conservation of marine resources. The United States also recognizes that all nations have an interest in these issues.

Last July I announced that the United States will not sign the United Nations Law of the Sea Convention that was opened for signature on December 10. We have taken this step because several major problems in the Convention's deep seabed mining provisions are contrary to the interests and principles of industrialized nations and would not help attain the aspirations of developing countries.

The United States does not stand alone in those concerns. Some important allies and friends have not signed the Convention. Even some signatory States have raised concerns about these problems.

However, the Convention also contains provisions with respect to traditional uses of the oceans which generally confirm existing maritime law and practice and fairly balance the interests of all States.

Today I am announcing three decisions to promote and protect the oceans interests of the United States in a manner consistent with those fair and balanced results in the Convention and international law.

First, the United States is prepared to accept and act in accordance with the balance of interests relating to traditional uses of the oceans—such as navigation and overflight. In this respect, the United States will recognize the rights of other States in the waters off their coasts, as reflected in the Convention, so long as the rights and freedoms of the United States and others under international law are recognized by such coastal States.

Second, the United States will exercise and assert its navigation and overflight rights and freedoms on a worldwide basis in a manner that is consistent with the balance of interests reflected in the Convention. The United States will not, however, acquiesce in unilateral acts of others designed to restrict the rights and freedoms of the international community in navigation and overflight and other related high seas uses.

Third, I am proclaiming today an Exclusive Economic Zone in which the United States will exercise sovereign rights in living and non-living resources within 200 nautical miles of its coast. This will provide United States jurisdiction for mineral resources out to 200 nautical miles that are not on the continental shelf. Recently discovered deposits there could be an important future source of strategic minerals.

Within this Zone all nations will continue to enjoy the high seas rights and freedoms that are not resource-related, including the freedoms of navigation and overflight. My Proclamation does not change existing United States policies concerning the continental shelf, marine mammals and fisheries, including highly migratory species of tuna which are not subject to United States jurisdiction. The United States will continue efforts to achieve international agreements for the effective management of these species. The Proclamation also reinforces this government's policy of promoting the United States fishing industry.

While international law provides for a right of jurisdiction over marine scientific research within such a zone, the Proclamation does not assert this right. I have elected not to do so because of the United States interest in encouraging marine scientific research within 200 nautical miles of their coasts, if that jurisdiction is exercised reasonably in a manner consistent with international law.

The Exclusive Economic Zone established today will also enable the United States to take limited additional steps to protect the marine environment. In this connection, the United States will continue to work through the International Maritime Organization and other appropriate international organizations to develop uniform international measures for the protection of the marine environment while imposing no unreasonable burdens on commercial shipping.

The policy decisions I am announcing today will not affect the application of existing United States law concerning the high seas or existing authorities of any United States government agency.

In addition to the above policy steps, the United States will continue to work with other countries to develop a regime, free of unnecessary political and economic restraints, for mining deep seabed minerals beyond national jurisdiction. Deep seabed mining remains a lawful exercise of the freedom of the high seas open to all nations. The United States will continue to allow its firms to explore for and, when the market permits, exploit these resources.

The Administration looks forward to working with the Congress on legislation to implement these new policies.

Appendix B

Committee Biographies

ARMAND J. SILVA, *Chairman*, is Professor and Chairman of Ocean Engineering and Professor of Civil Engineering at the University of Rhode Island. Dr. Silva has more than 30 years experience in research, teaching, and consulting in ocean engineering and geotechnics. He has served on marine geotechnology advisory panels, National Science Foundation proposal reviews, and on the editorial board of Marine Geotechnology, and has written numerous publications concerning geotechnical properties and processes of ocean sediments. He holds B.S., M.S., and Ph.D. degrees in civil and geotechnical engineering from the University of Connecticut, and is a registered Professional Engineer in Connecticut and Massachusetts.

KENT A. FANNING is Professor, Department of Marine Sciences, the University of South Florida. His research and teaching experience in chemical oceanography and geochemistry includes particular emphasis on interstitial chemistry of sediments and transport processes across the sediment-water interface. He has written numerous publications and articles about geochemical processes in rivers and oceans. He holds a B.S. in chemistry from the Colorado School of Mines and a Ph.D. in oceanography from the University of Rhode Island.

LARRY L. GENTRY is Program Manager for Autonomous Underwater Vehicles at Lockheed Missiles and Space Company, Sunnyvale, California. He holds a B.S. degree from Oregon State University and an M.S. from San Jose State University, both in electrical engineering. His engineering and technical management experience in subsea and offshore industries have included installation and operation of seafloor systems for the offshore oil and gas industry, ocean thermal energy conversion systems, seabed mining, and subsea manned and unmanned vehicles. He is a registered Professional Engineer in British Columbia, Canada, and holds several patents.

CHARLES D. HOLLISTER is Vice-President and Associate Director for External Affairs, Woods Hole Oceanographic Institution. He holds a B.S. degree from Oregon State University and a Ph.D. in geology from Columbia University. His extensive teaching, research, and consulting experience in marine geology includes experience in sediment dynamics of the deep seabed and technology for research and disposal of radioactive wastes on the seafloor. He has written many publications in marine geology and the effects of ocean bottom currents on the deep seafloor.

ROBERT W. KNECIFIT is Co-Director of the Center for the Study of Marine Policy and Professor, University of Delaware, and has held positions at the University of California at Santa Barbara and the National Oceanic and Atmospheric Administration. His expertise includes deep seabed mining, ocean thermal energy conversion, management of seabed resources, and coastal zone management. He has served on several National Research Council committees and has published extensively in the areas of ocean policy, coastal zone management, and other topics. He holds a B.S. degree in physics from Union College and M.A. in marine affairs from the University of Rhode Island.

GERRY B. MANNING is Manager, Sea Operations Engineering, AT&T Technologies (Western Electric prior to 1984), where he is responsible for AT&T's ocean cable systems. These activities include underwater acoustics, ocean environmental surveys, navigational aids, ocean cable installation and maintenance, transmission systems, engineering, signal processing, and ship systems development and engineering. He received a B.S. in electrical engineering from Clemson University and an M.S. in industrial engineering from Lehigh University.

DAVID B. PRIOR is Head, Environmental Marine Geology, Atlantic Geoscience Center, Bedford Institute of Oceanography in Dartmouth, Nova Scotia. Before that, he was at the Coastal Studies Institute of Louisiana State University. He holds a B.S. degree in geography and a Ph.D. in geomorphology from the Queens University of Belfast, Northern Ireland. His research, teaching, and consulting experience has included particular emphasis in continental slope processes and offshore geological hazards for engineering. He served as chairman of the National Research Council Committee on Ground Failure Hazards and has written many publications in the areas of marine geology and land geomorphology.

GARY TAGHON is Associate Professor, College of Oceanography, Oregon State University. He holds a B.S. degree in biology from Purdue University, and M.S. and Ph.D. degrees in oceanography from the University of Washington. Dr. Taghon's major research efforts have been in benthic ecology and organism-sediment flow interactions. He served on a National Research Council panel on Deep-Sea Stable Reference Areas, and is the author of numerous publications concerning marine biology and ecology.

ALAN G. YOUNG is President of Fugro-McClelland Geosciences, Inc. In this capacity, he directs the company's financial and technical activities related to marine projects worldwide. His expertise covers deepwater geoscience projects—particularly site analysis for fixed platforms, sediment strength interpretation for various sampling and testing procedures, and foundation studies for mobile jack-up rigs. He has written many publications concerning geotechnical engineering and is a registered Professional Engineer in Texas and Louisiana. Mr. Young holds a B.S. degree from Texas A&M University and M.S. degree from the University of Texas at Austin, both in civil engineering.

Appendix C

Participants of the Workshop on Uses and Technology for the Exclusive Economic Zone Seabed, Keystone, Colorado

Committee on Existing and Potential Uses of the Seafloor

Armand J. Silva, *Chairman*, University of Rhode Island
Kent A. Fanning, University of South Florida
Larry L. Gentry, Lockheed Missiles and Space Company
Charles D. Hollister, Woods Hole Oceanographic Institution
Robert W. Knecht, University of Delaware
Gerry B. Manning, AT&T Technologies
David B. Prior, Bedford Institute of Oceanography
Gary Taghon, Oregon State University
Alan G. Young, Fugro-McClelland Geosciences, Inc.

Government Liaison Representatives

Robert S. Dyer, Environmental Protection Agency
John B. Gregory, Minerals Management Service
Joseph H. Kravitz, Office of Naval Research
Bradley J. Laubach, Minerals Management Service
Herbert Hermann, Naval Facilities Engineering Command
George W. Saunders, Department of Energy
Paul Teleki, U.S. Geological Survey
Joseph R. Vadus, National Oceanic and Atmospheric Administration
Raymond C. Witter, Space and Naval Warfare Systems

Other Government Agency Representatives

William Bettenberg, Minerals Management Service
Rebecca Mullin, Department of the Interior
Richard B. Krahl, Minerals Management Service
John B. Rigg, Minerals Management Service
Kenneth Hawker, Space and Naval Warfare Systems

Invited Guests

Arthur Nowell, University of Washington
Robert Aller, State University of New York
Earl Doyle, Shell Offshore Inc.
Iver Duedall, Florida Institute of Technology
Robert Bea, PMB Systems
William Ryan, Lamont Doherty Geological Observatory
Clifford Curtis, The Oceanic Society
Charles L. Morgan, Honolulu, Hawaii
James Booth, U.S. Geological Survey
J. Robert Moore, University of Texas at Austin
James Kosalos, International Submarine Technology
William G. Gordon, New Jersey Marine Sciences Consortium

Marine Board Staff

Donald W. Perkins, Staff Officer
Joyce B. Somerville, Secretary
Heide Mairs, University of Rhode Island