Woods Hole Oceanographic Institution

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THE USE OF THE COASTAL OCEANS
IN THE 80'S: OPPORTUNITIES FOR
MARINE GEOLOGY

by

David A. Ross
and
David G. Aubrey

April 1980

TECHNICAL REPORT

Prepared with funds from the Department of Commerce, NOAA Office of Sea Grant under Grant #NA 79AA-D-00102.

WOODS HOLE, MASSACHUSETTS 02543

WHOI-80-19

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Approved for Distribution [signature]
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THE USE OF THE COASTAL OCEANS IN THE 80'S: OPPORTUNITIES FOR MARINE GEOLOGY

SUMMARY

Events of recent years have clearly indicated that the United States will be making greater use of its coastal and offshore region in the 1980's. Rational use of this area will require the combined talents of scientists, engineers, politicians, environmentalists and others. There will be pressures and needs to use the coastal ocean for nuclear waste disposal, marine mining, disposal of waste materials, and hydrocarbon exploration; these uses will require new answers and technologies for many important marine geological questions. In an effort to identify these questions and determine what is needed to answer them, a group of approximately sixty geologists and marine scientists from academia, industry and the federal government met for a 2-1/2 day workshop at Woods Hole in October 1979. Initially the group looked at six uses of the offshore region: Nuclear Waste Disposal; Sewage, Industrial and Dredge Material Disposal; Offshore Structures; Marine Mining; Hydrocarbon Exploration and Extraction; and Military Related Activities. For each of these uses, three particular aspects were considered:

<u>Aspect 1.</u> Important scientific marine geology questions concerning the use of offshore areas during the next decade (including biological and physical processes).

<u>Aspect 2.</u> Economic reasons for utilization of U.S. offshore regions in the next decade (including, but not limited to, mineral extraction, waste disposal).

<u>Aspect 3.</u> Engineering, regulatory, environmental, and political requirements and impediments to use of U. S. offshore areas.

Each participant attended one of these three aspect groups and was asked to consider the specific marine geological problems, knowledge gaps, technology needed and some questions concerning funding for each of the six potential uses mentioned above. Following this, focus was turned towards four more specific geological subjects: Slope Stability, Catastrophic Events, Sediment Characteristics, and Shelf Morphology and Bedforms. The same set of questions were considered. The results of the discussions are the basis for this report.

Some basic knowledge gaps are relevant for almost all uses considered and their multiple listing may appear redundant. We decided to repeat these points, when necessary, to make each

section on a particular marine use independent of the other sections. The report presents a framework for future marine geological activities to allow the U.S. to make more effective use of its offshore regions, emphasizing cooperation between industry, academia and the federal government in resolving these important research questions.

Disposal of nuclear waste was considered to be an especially critical marine use, in part due to the recent closing of U.S. land-based, low-level disposal sites. Emphasis was on shelf disposal (either accidental or by design) and subsequent dispersal. Under almost any disposal scenario it would be necessary to have thoroughly characterized the geological structure, stratigraphy and mineralogy of the region, its soil stability or instability, movements of overlying water, and frequency and magnitude of environmental changes. The various groups were generally agreed that nuclear waste problems are immediate and that funding for research should dramatically increase and focus on many of the now critical questions. Especially needed are equipment grants for sensors to measure fluid and sediment properties, together with well-planned field experiments and the development of analytical models for predicting dispersal phenomena. Good coordination between the various governmental agencies considering this problem will be especially needed.

Sewage, industrial and dredge material disposal is another continuing problem that will only get more intense as volume of waste material increases and land-based disposal sites decrease. Regardless of present and pending legislation, the use of the marine environment for disposal will eventually become a necessity. Among the basic questions are: what is the compatibility of the particular material with the environment, how can it be contained (if indeed it need be), and how much pre-disposal treatment (if any) is actually needed. Often the philosophy is the more treatment the better, whereas innovative and perhaps beneficial uses of wastes may be discouraged by policy or regulatory aspects. The study of material disposal is clearly multi-disciplinary, requiring strong government coordination and interaction.

The probable increase use of offshore areas for oil and gas development, mineral extraction, port development, etc. will present challenging scientific, engineering and political problems for emplacement of offshore structures. The specific problems related to an offshore structure are often site specific, but almost any increase in our basic understanding of the marine environment will benefit emplacement of offshore structures. Two important points are the necessity for prediction of rare or catastrophic events, and the effect of the structure on the environment and the ability to change sediment dispersal patterns.

In these geological uses and those related to hydrocarbon exploration, marine mining and other activities, a series of common knowledge gaps was evident. They included important questions about water column motion; near-bottom fluid motion and forces; sediment transport relationships; bedform morphology and rates of movement; sources of sediment and water masses (for use as tracers); stratigraphy of the shelf; physical and chemical characteristics of sediments and rocks; tectonic aspects; slope stability; man's future intervention into the environment; effects of a specific activity on the subbottom; and impacts of catastrophic events. Specific points for each use are described in the text. Similarly, several common technological needs were identified: *in situ* measurement of sediment transport; *in situ* sampling and monitoring techniques to measure various geotechnical and environmental parameters; improved geophysical and geochemical measuring techniques; and the ability to obtain undisturbed samples of the sea floor. These technologies and the answers to the above questions are needed if scientists and planners are going to be able to develop a predictive ability for future uses of the marine environment.

The workshop was not able to assess the costs for various offshore activities, in particular since each case would be tied to different geological and engineering considerations. It was noted, however, that there often is a considerable reluctance to dedicate specific areas of the ocean for specific uses, or likewise to consider multiple uses for a given region. For many activities there is a real need to improve coordination between government agencies and, where possible, to designate one agency as responsible.

David A. Ross
David G. Aubrey
4 April 1980

PREFACE

The past two decades have seen major advances in our knowledge of the marine geological and geophysical processes that influence and control the evolution of the earth. Probably most important has been the development and testing of the seafloor spreading hypothesis and its integration into plate tectonics theory. Major programs such as IDOE (International Decade of Ocean Exploration), JOIDES (Joint Oceanographic Institutions Deep Earth Sampling) and IPOD (International Program of Ocean Drilling) have been responsible for the collection of much of the critical data for these ideas.

In recent years the oceans and sea floor have become a focal point for many new and increased uses, especially as sources of energy but also for other aspects such as waste disposal, siting of offshore facilities, and transportation. These uses are posing new and unique marine geological questions (as well as biological and engineering ones) that need to be answered. This need for increased understanding presents interesting and new challenges and opportunities for the marine research community. For this reason a workshop was proposed to define geological aspects of some of these future problems and mechanisms for their solution.

Initial plans for the workshop were developed in cooperation with the Program Monitor for Mineral Resources and for Coastal Processes at the National Office of Sea Grant, NOAA, Dr. David B. Duane, and the Sea Grant Coordinator at the Woods Hole Oceanographic Institution, Dr. David A. Ross. Subsequently a coordinating committee was formed consisting of Dr. Ross, Dr. Donald F. Squires, Sea Grant Director, SUNY/Cornell, and Dr. David G. Aubrey, Woods Hole Oceanographic Institution. The plan was to invite researchers from academic institutions (emphasizing but not restricted to those with Sea Grant Programs), National Laboratories (such as NOAA Environmental Research Laboratories), other Federal agencies (such as the USGS and NSF), and industrial groups interested or actively involved with marine activities. A letter was sent to about forty potential participants in early June of 1979 along with a Prospectus and Questionnaire (Appendix I).

The Prospectus stated:

> The objectives of the workshop are to develop a plan, or framework, for marine geological research based upon more effective utilization by the U.S. of its offshore regions. The plan,

or framework, will include: the knowledge gaps (questions which need answering), equipment and facilities needed, the accuracy or precision required of the answers, the time scales involved, and probable costs. It should be noted that most marine geologic research previously supported by Sea Grant has emphasized geological aspects of coastal erosion and estuarine problems. This workshop plans to focus on future problems and opportunities in the more offshore areas.

This plan, or framework, should primarily identify that research most suitable for universities to pursue. Secondly, it should identify what problems are most amenable to solution by a university/industry research partnership. Because of the Sea Grant orientation, a tertiary objective will be identification of means of raising, at the local program level, the priorities of marine geological research and improving the quality of those proposals.

The questionnaire solicited specific areas for discussion, additional participants and general comments. Most of the recommended participants were invited and a follow-up letter (Appendix II) was sent in August, 1979.

One problem, often associated with workshops, is that they duplicate past similar efforts. To avoid, or at least minimize, this, highlights (summaries or complete reports) of similar past workshops or meetings were compiled (Appendix III) and sent to the participants.

Based on discussions within the coordinating committee and the written and oral responses to the questionnaire, the following plan resulted.

Three basic <u>aspects</u> concerning the future use of U.S. waters were developed:

<u>Aspect 1.</u> Important scientific marine geology questions concerning the use of offshore areas during the next decade (including biological and physical processes).

<u>Aspect 2.</u> Economic reasons for utilization of U.S. offshore regions in the next decade.

<u>Aspect 3.</u> Engineering, regulatory, environmental, and political requirements and impediments to the use of U. S. offshore areas.

The participants (Appendix IV) were assigned to one of the three aspect groups. Within each aspect group the participants were asked to consider the following possible geological uses of offshore areas:

-Nuclear Waste Disposal
-Sewage, Industrial and Dredge Material Disposal
-Offshore Structures
-Marine Mining
-Hydrocarbon Exploration and Extraction
-Military Related Problems

Within each geologically-related aspect group participants were asked to consider the above uses and answer the following questions:

1. What are the problems?
2. What are the important knowledge gaps?
3. What technology is needed (new, improved or otherwise)?
4 A variety of questions including what type and amount of funding is needed, time frame of work, priorities and responsibilities of academia, government and industry. The answers to these questions were combined for the three aspect groups.

This plan was presented on Wednesday evening, October 10, 1979 and again on Thursday morning, October 11 (bad weather had delayed some participants). Prior to dividing into the three aspect groups, short talks to brief the participants on various ongoing marine geological activities were given by:

Dr. David B. Duane, NOAA, on Marine Geology in Sea Grant
Dr. Anton Inderbitzen, NSF, Division of Applied Research, on Applied Geophysical Program within the Division of Applied Research
Dr. David A. Ross, WHOI, on the Marine Geology and Geophysics Section of NSF (using data supplied by NSF) and on Law of the Sea
Dr. Charles Hollister, WHOI, on High Energy Benthic Boundary Layer Experiment (HEBBLE) and Nuclear Waste Disposal
Dr. James Heirtzler, WHOI, Joint Oceanographic Institutions Program (JOI)
Dr. David Folger, USGS, on Atlantic and Gulf Coast Programs of the U.S.G.S.
Dr. Donald F. Swift, NOAA, Programs at the Atlantic Oceanographic & Meteorological Laboratory
Dr. William Lavelle, NOAA, Programs at the Pacific Marine Environmental Laboratory
Dr. H.E. Clifton, USGS programs in the Pacific area

Following these presentations we divided into the three aspect working groups for the remainder of the morning and the afternoon. Co-chairmen of the three groups presented their preliminary findings, at a working dinner that evening. The co-chairmen were:

Aspect 1 - Dr. David G. Aubrey (WHOI)
Dr. Larry Doyle (Univ. of South Florida)

Aspect 2 - Dr. Frank Manheim (U.S.G.S.)
Dr. Donald F. Squires (SUNY)

Aspect 3 - Dr. Harold Palmer (Dames and Moore)
Dr. Adrian Richards (Lehigh University)

Subsequent discussion, both that evening and on the following morning, indicated that it might be profitable to subdivide further into more subject area oriented groups. This was discussed briefly and four groups were formed and chairmen selected:

Subject Group A - Slope Stability (Dr. Harold Palmer)
Subject Group B - Catastrophic Events (Dr. Don Squires)
Subject Group C - Sediment Characteristics (Dr. Adrian Richards)
Subject Group D - Shelf Morphology and Bedforms (Dr. John C. Ludwick, Old Dominion University)

These four groups met for the remainder of the morning and considered the previously mentioned questions.

Prior to departing, the Chairmen of the Aspect Groups and the Subject Groups left their written reports at Woods Hole. Their notes served as the basis for a first draft of this report. Without the help and hard work of the various chairmen it would have been almost impossible to prepare this report. At the Plenary Sessions several individuals indicated a desire to assist in the preparation of part or all of the report. In early December a draft of the entire report was sent to the following individuals with a request that they comment on the entire text, but especially on specific parts (as indicated).

Dr. Donald F. Squires - (Specific Geological Problems)
Dr. Donald Swift - (Specific Geological Problems)(Dick Bennett of NOAA also helped on geotechnical characteristics)
Dr. Harold Palmer - (Sewage, Industrial and Dredge Material Disposal)
Dr. A.A. Ekdale - (Marine Mining)
Dr. Larry J. Doyle - (Hydrocarbon Exploration and Extraction)

Dr. James L. Harding - (Sewage, Industrial and Dredge Material Disposal)
Dr. Henry Bokuniewicz - (Sewage, Industrial and Dredge Material Disposal)
Dr. James D. Howard - (Hydrocarbon Exploration and Extraction)
Dr. John Zeigler - (Offshore Structures)
Dr. Armand Silva - (Slope Stabilities and Nuclear Waste Disposal)
Dr. Frank Manheim - (Marine Mining)
Dr. Martin Miller - (Thermal Discharge)
Dr. Adrian Richards - (Offshore Structures)
Dr. David B. Duane - (Nuclear Waste Disposal)

Their comments were included in the preparation of the final draft by David A. Ross and David G. Aubrey. There was a wide variety of views on some subjects and we attempted to adequately express the opinions of our colleagues.

Acknowledgements

Many people contributed to the success of the workshop. We especially wish to thank the participants and chairmen of the individual working groups. Dr. Donald Squires aided in the formulation of the workshop, and the above-mentioned voluntary reviewers made the final editing task more successful. Special thanks go to Mrs. Ellen Gately who skillfully handled much of the logistics and workshop planning, and the typing of the final draft, Mr. John Trowbridge who helped in the logistics and Mrs. Pam Foster who typed many drafts of this manuscript. The leadership and guidance from Dr. David B. Duane was critical to the development and implementation of the workshop.

WORKING GROUP REPORTS

NUCLEAR WASTE DISPOSAL

INTRODUCTION

Radioactive materials are used worldwide in a variety of ways for scientific and medical research; industrial processes and inspections; electric power generation; and weapons. The largest volume of civilian radioactive material use, present and future, is in electric power generation. Public acceptance of nuclear power is dependent upon resolving a number of areas of concern; two principal areas are safety in operating generating stations and the safe disposal of radioactive waste.

In the U.S. today, there are 70 nuclear power plants currently licensed and producing electricity. Another 90 are at various stages in the pre-operation process and scheduled for completion in the next decade. Reactor storage needs are estimated to be 530 metric tons of spent fuel by 1983; 3,860 by 1988; and 14,000 by 1993.

There is no present policy in the U.S. regarding long-term nuclear waste disposal and storage although several bills have been produced in Congress to make such policy and further regulate the nuclear industry. There is no consensus in the U.S. about what constitutes a safe disposal method although many believe the techniques and technologies exist. One option being discussed in the U.S. is disposal in the marine environment, specifically within deep-sea sediments.

It is estimated that all radioactive waste introduced into the oceans by man amounts to 0.5 million Curies, while total dissolved material radioactivity in the oceans is 500,000 million Curies. However, it is the localization of man's induced debris which concerns many. Accordingly, to satisfy public concern about ocean disposal requires being able to satisfactorily demonstrate isolation from humankind (for political purposes) and from the ecosystem (for biological purposes).

At this workshop participants did not dwell on deep ocean disposal for that is presently being investigated by the Department of Energy. Rather, effort was directed at the consequences of radioactive material placement upon or within the continental shelf through accidental spillage or by design. Accidental surface emplacement may occur during transport of fuel or work involved in U.S. domestic use, or transport of materials in foreign trade. Purposeful emplacement beneath surface sediments within the U.S. economic zone (rather than mid-oceanic areas) could simplify policing and inspection and reduce debate among the world community. Present oil drilling and well completion technology as well as geologic measurements technology offer the prospect for imme- diate transfer of technology to the evaluation and assessment of the continental shelf for radioactive waste storage.

Different scenarios of emplacement (accidental/surface at one extreme or purposeful/subsurface at the other) require knowledge of processes at different time scales, as well as the frequency of critical events, and the fluid and particle behavior. Thus the participants in the workshop believed it necessary to thoroughly characterize the structure, stratigraphy and mineralogy of the shelf, its stability or instability, and the frequency and magnitude of environmental changes.

SCIENTIFIC PROBLEMS - NUCLEAR WASTE DISPOSAL

The scientific problems for nuclear waste disposal center on the questions of where, in what form, and with what philosophy to dispose of wastes. The problems associated with the disposal of low-level nuclear wastes may differ somewhat from that of high-level wastes. In either case, disposal philosophy must be known: is the material to be permanently stored at a specific site, or is the preferred method to be dispersal of the waste? In case of an accidental spill, the question of dispersal becomes very important. The dispersal method depends on the form of the wastes--whether solid or liquid. The final scientific problems are anthropic: How does one minimize man's ability to impact the disposed wastes and vice versa; and how does one monitor the fate of the nuclear wastes throughout the harmful stages of their existence?

Knowledge gaps

1. Water column motions must be known in order to predict the fate of released material; also to know the effect of the mean flow on the transport of sediment along the bottom, whether waste material or overlying sediments. Information needed includes:
   a. Large-scale (low-frequency) shelf circulation and its climatology
   b. Wave climatology, including seasonal changes in height, direction, and frequency
   c. Vertical variation in flow fields, internal motions and stratification are important to sediment and waste dispersal
   d. Formulation of momentum budget for shelf motions in order to predict short time-scale waste dispersal.

2. Near-bottom fluid motions must be known to predict suspended sediment transport and tractive forces acting on sediment particles on the bed. Information needed includes:
   a. Near-bottom flow fields, to define transport paths for suspended matter
   b. Near-bottom shear stress ("skin friction") to predict bedload transport and initiation of motion, especially needed for combined wave-current flows
   c. Effect of near-bottom shear stresses and form drag on regional circulation
   d. In areas of complex bottom topography, procedures are needed for spatial averaging to obtain a meaningful sediment transport relationship.

3. Sediment transport must be understood to define the transport paths and rates for various sediment types and to define the eventual dispersion of nuclear wastes. Information needed includes:
   a. Understanding of cohesive sediment transport, including the effects of organic materials
   b. Physics of non-cohesive sediment motion, including carbonates
   c. Bed-form genesis, migration rates, over a wide range of time scales with a distinction between active and relict bedforms
   d. The chemistry and physics of flocculation processes
   e. Chemical and biological modification of sediments.
   f. How to represent physical sediment properties in any sediment transport or emplacement model
   g. Understanding of forcing function for sediment transport--e.g., do we use significant wave height, rms wave height, or maximum wave height?
   h. Animal-sediment interactions, effect of biological activity on the transport and especially the mixing of sediments within the water column and along the ocean floor
   i. Large-scale sediment transport--mass movements
      i) submarine landslides
      ii) slope stability
      iii) turbidity currents
   j. Storm climate--effect of catastrophic events on dispersal of nuclear wastes
   k. Relationships between space and time scales of motion for fluids and sediments. What part of the velocity spectrum do we need to know to predict sediment transport?
   l. Mobility of radionuclide species through host sediments
   m. Affinity of radionuclide species for clay or organic particles.

4. Sediment and water mass sources can be used as tracers for predicting nuclear waste dispersal. Information needed includes:
   a. Shelf-slope sediment interchanges; effects of submarine canyons
   b. Beach-shelf sediment interchanges
   c. Estuary-shelf sediment and water exchanges.
5. Shelf stratigraphy must be known to determine where and how deep to place wastes, as well as to predict the mixing (downward migration) of the wastes through the sediments. Information needed includes:
   a. Historical sedimentation rates on shelves (e.g., from biogeochemical studies)
   b. Sedimentation rates of special margins (e.g., deltas)
   c. Past sedimentary environments, paleobathymetry, shelf history
   d. Facies analysis
      i) sea-level facies relationships
      ii) seismic facies analysis including lateral continuity
      iii) biofacies and ichnofacies analysis including vertical and lateral continuity
   e. Geophysical exploration techniques, for facies analysis, sediment thickness, hydrocarbon potential (e.g., heat flow) and karst zones
   f. Bottom morphology: on scales from cm's to km's
   g. Internal sedimentary structures: their relationship to bedform migration rates and sedimentation rates.
6. Tectonic aspects of a region should be known to predict seismic stability of a waste site. This includes the local history of tectonic activity such as earthquakes, etc., and the neotectonics of active margins.
7. Man's future intervention into the environment should be known to predict the future disruption of waste disposal areas. Possible examples could include:
   a. Effects of dredging and drilling causing accidental recycling of wastes
   b. Probability that offshore mining of sand and gravel will return contaminants or spoils to land.
8. Effect of waste material on the bottom should be understood so the waste material does not significantly alter the disposal site.
9. Groundwater motions on shelves are important for prediction of waste dispersal within the sediment column. Information needed includes:
   a. Migration rates of groundwater at site specific locations
   b. Effect of groundwater flow on stratigraphic units (e.g. carbonates), specifically solution, cementation, crystallization.

10. Sediment consolidation and benthic boundary layer diagenesis are also important.
    a. Geological consolidation (overburden pressures)
    b. Consolidation changes induced by container loading: both total settlement plus time rate of settlement
    c. Consolidation effect on permeability of sediments
    d. Effect on excess pore pressure distribution
    e. Modification of diagenetic processes.

Technology needed

1. Specific instrumentation is needed for:
    a. Flow field studies (synoptic; small scales (mm))
    b. Sediment transport volume and rates
    c. Seismic investigations (multi-channel, multi-beam side scan).
2. *In situ* sediment testing (physical properties).
3. Undisturbed sediment sampling.
4. Drilling or emplacement of material.
5. Monitoring capabilities for waste disposal and dispersal (rates, concentrations and quantities of waste input).

ECONOMIC PROBLEMS - NUCLEAR WASTE DISPOSAL

One cannot avoid the political influence on economic aspects when considering nuclear waste disposal questions. Deep-water storage implies international or at least multinational scientific and technical cooperation. Shallower, nearer to shore (but not necessarily nearshore) sites could be controlled by the U.S. Government but might have to meet the same kind of international scrutiny as the deep disposal option, even if done within a U.S. economic zone.

Knowledge gaps

Selection of the optimum storage method requires knowledge of: (a) geological stability of site; (b) freedom from groundwater interference or significant leakage to ocean; (c) access, recoverability and repairability (this involves different assumptions than some current concepts, and also assumes that solidification (e.g., ceramic encapsulation) will be mandatory); and (d) security of the disposal site from geological hazards.

Both shallow and deep storage are candidates for nuclear waste disposal. Important knowledge gaps are:

1. What is the leakage potential (convective and diffusive) in storage systems?

2. What are the relative sizes of enclosure zones, and cost of retrieval systems at alternative sites?
3. What are probabilities of erosion and rates of change of geological and geochemical systems?

The most favorable site from a geologic standpoint may be too costly and hence economically unacceptable for disposal. Assessment of the dangers associated with alternative sites and the ability to make rational decisions on economic/environmental trade-offs require that gaps in our geologic knowledge be carefully filled. The economic feasibility of a site must be strongly tied to these geological and engineering considerations.

Technology needed

No new technology is required in addition to that mentioned in the previous section other than improved numerical and analytical models of the long-term fate of emplaced nuclear wastes.

ENGINEERING PROBLEMS - NUCLEAR WASTE DISPOSAL

Engineering problems concerning nuclear waste disposal in the ocean require the development of a reliable delivery system, emplacement techniques, assessment of sites, long-term evaluation of natural properties, and long-term environmental monitoring. Collection, storage and transportation of wastes to the site are likewise important engineering design considerations. The delivery system and emplacement techniques are being considered by the Department of Energy (DOE) and other organizations. Basically, they are not geologic concerns.

Knowledge gaps

Two are especially important:

1. Long-term behavior and response (both dynamic and static) of geologic containment media due to rupture, loading and heat caused by the waste container, including rate of migration of toxic substances and physicochemical alterations to containment material

2. Predictability of changes in geological/engineering characteristics of potential sites, including rate of water migration due to natural processes, erosion and deposition of sediment, etc.

Technology needed

Technology is needed to develop reliable delivery and emplacement technology. For high-level waste retrieval it will be necessary to develop methods for the recovery of a continuous undisturbed sample to the depth of emplacement. Likewise, it will be necessary to make *in situ* measurements of properties and processes in the sub-seafloor, such as permeability, pore pressure, water migration, thermal properties and response, etc. For any type of disposal it will be necessary to develop long-range *in situ* process monitoring systems.

ENVIRONMENTAL PROBLEMS - NUCLEAR WASTE DISPOSAL

The main environmental problem of nuclear waste disposal concerns the toxic effects of nuclear wastes if they were to escape into the marine environment from their containment (see scientific problem section for other comments on environmental aspects). Toxic effects could be both immediate and/or long term. Basic considerations associated with toxic effects are:

1) Site selection - should avoid areas of existing or potential resources; should be isolated from the biosphere as much as possible
2) Transportation - minimization of environmental exposure during transportation to final storage site
3) Monitoring for leakage at disposal sites.

Knowledge gaps

There are two important areas where knowledge is missing:

1. Short and long-term effects of containment, with respect to both the containment vessel and the host sediments, including:

    a) lack of knowledge of hazards associated with breakdown of containment vessel and,
    b) lack of knowledge of cummulative long-term environmental (principally biological) effects and relevant concentration/dilution processes

2. Assessment of stability of the physical environment of storage area, such as magnitude and frequency of geological processes, (e.g., seismic events, depositional and erosional activity or slope instabilities).

Technology needed

1. Geochemical and biological monitoring systems for the sediment as well as for the water column. These should be *in situ* devices with variable sampling intervals, that have adequate data storage and data transmission capabilities
2. *In situ* process monitoring systems for integrity of storage site. i.e., to measure current scour, seismicity, etc. This task is largely a synthesis of existing techniques into a single appropriate package.

REGULATORY AND POLITICAL PROBLEMS - NUCLEAR WASTE DISPOSAL

Regulatory and political problems are immediate, vast, and poorly defined. Because of the potential of long-term toxic effects, site selection will have local, national and international ramifications. The same is true for transportation mechanisms (on land, through ports and at sea). In the international arena the Law of the Sea Conference has essentially avoided the question of nuclear waste disposal although the London Dumping Convention has addressed ocean bottom disposal. There is some debate as to whether the Dumping Convention would cover subsurface disposal. In the United States, policies of individual states and the federal government are often in contradiction. The recent closing of U.S. land-based, low-level disposal sites has had considerable impact on our awareness of the waste disposal dilemma, and has suggested to some the marine environment, perhaps the shelf, should be considered as a disposal area. In any event, the geologic profession has an obligation to provide geologic knowledge bearing on national political decisions.

Knowledge gaps

Final regulatory and political decisions should benefit from critically needed environmental and engineering information concerning safety of the plan, especially in comparison to other disposal schemes. This information is not available now. Legally there are variable state regulations within coastal waters (essentially out to 3 nautical miles) and no formal policy out to 200 nautical miles. The London Dumping Convention allows nations to issue special permits for low-level nuclear waste dumping after consideration of several factors. Permission for dumping of high-level wastes are essentially prohibited, but there are some loopholes.

Technology needed

None, but problems considered elsewhere in the nuclear waste section should be answered.

NUCLEAR WASTE DISPOSAL - Comments about type, amount, time frame of funding; priorities and responsibilities:

Since the problems of ocean nuclear waste disposal and the dispersal of accidental nuclear waste leakage into the oceans is immediate, funding of projects addressing these various questions should continue with dramatic increases in funding levels. The participation and cooperation between the various funding agencies responsible for nuclear waste problems (Department of Energy, NOAA, USGS, and NSF, for instance) are essential to formulate an effective and efficient mechanism for distributing funds and overseeing the massive effort required to resolve these problems of nuclear waste disposal and dispersal. In order to adequately resolve some of the basic questions raised in this report, both large scale coordinated programs (time scales 5-10 years), as well as some smaller scale, single principal investigator projects are necessary to address individual aspects of the problem.

A major priority for funding should be to develop instrumentation for both the scientific and engineering geological aspects. Advancement in our understanding of the basic scientific and engineering questions rely, in part, on the development of sensors to measure fluid and sediment properties as indicated in earlier sections. This funding impetus may be in part in the form of equipment grants, and grants aimed at merging scientific ideas with good engineering technical insight. The sensor development could coincide with the development of well-planned field experiments and the improvement of analytical models for predicting dispersal phenomena.

Further priorities should include the selection and assessment of potential disposal sites. Pilot studies should be initiated to evaluate some of the analytical prediction models and the monitoring capabilities, prior to full-scale implementation of the disposal option.

The funding level required for these programs is difficult to assess, in part because it is hard to provide estimates of funding levels of government participation. For research and development outside of the federal government, an estimated $10 million should be allotted per year for geological studies of this particular use of the marine environment.

There was little agreement on the relative roles of academia, government and industry for attacking these problems. The consensus was that these three groups should work closely together to solve this common problem, with the funding burden necessarily shared by government and industry. Actual planning, development, modeling, and deployment should take place with the cooperation of all three groups. Monitoring duties should be shared by the three groups as well.

Current public debate about the future of nuclear power indicates lack of credibility of the present federal development and regulatory agencies, the utility companies, and equipment vendors. Such a lack of credibility could well carry over to the research and assessment phase concerning the suitability of the ocean option for nuclear waste disposal. In such a situation the university research community, which traditionally has provided new knowledge and information to decision makers irrespective of a particular viewpoint, can play the crucial non-advocate role.

SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

Due to the increasing industrialization and housing development in U.S. coastal regions there has been a corresponding increase in pressure to utilize the marine environment for disposal of waste materials. The problem is complicated by the scheduled 1981 U.S. Environmental Protection Agency's moritorium on ocean sludge disposal and other aspects associated with the Clean Water Act. However, sites for land-based disposal are rapidly diminishing and use of the marine environment for disposal is clearly a reality, if not a necessity. The now concluded major study conducted by the Corps of Engineers through the Waterways Experiment Station has provided an excellent scientific and technological base for dealing with the problem of disposal of dredged material. Nevertheless, prior to establishing the efficacy of marine disposal of any wastes, numerous additional scientific, engineering, environmental, economic and socio-political problems should be further addressed and solved.

Principal among the scientific problems are compatibility of solid wastes with sediments, toxicity evaluations, and long-term effects. In order to help solve these problems, research efforts are needed in water column movements, seafloor fluid motion, sediment transport and exchanges, shelf and near-shore stratigraphy and tectonics, and the development of technology in instrumentation for sampling and monitoring.

Similar investigations need to be conducted with regard to the engineering aspects, but with additional research on sea-floor stability and interactions, with man-made structures such as sewer outfalls and pipelines. Sampling and monitoring instruments must be in situ in nature.

The environmental aspects of waste disposal are extremely important and will require a multi-disciplinary approach, involving biological, chemical, geochemical, geological and other marine-oriented expertise. All of the data obtained in the scientific and engineering phases will be applicable to specific investigations into long-term material behavior, toxic effects and exchange mechanisms.

The political, socio-economic and regulatory aspects of marine waste disposal present many problems, both now and in the future. In summary, however, it will be the data collected in the investigative phases which will become the critieria upon which to base coherent and viable regulatory judgements.

SCIENTIFIC PROBLEMS-SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

The basic problems are:

1. Determination of the final resting place for dredge spoils dumped either on the water surface or on the seafloor
2. Evaluation of the effect of these wastes on biota
3. Compatibility of wastes with bottom material, for example, will these materials affect the transport or dispersion of natural materials in a deleterious fashion?
4. How long will it be before the effects of dumping (accidental or otherwise) disappear from a particular area?

Knowledge gaps

1. Water column motions studies are needed to predict dispersal of suspended waste material. Information needed includes:
    a. Large scale (low-frequency) shelf circulation (climatology)
    b. Wave climatology for particular dump sites
    c. Intermediate time-scale flows (periods from 20 seconds to 1 day) should be emphasized
    d. Vertical variation in flow fields, internal motions and stratification are important to sediment and waste dispersal
    e. Formulation of a momentum budget for shelf motions to predict short-time scale waste dispersal.
2. Near-bottom fluid motions information is needed to predict near-bottom sediment transport. Information required includes:
    a. Near-bottom flow fields, to define transport paths for suspended matter
    b. Near-bottom shear stress ("skin friction") to predict bedload transport and initiation of motion, especially for combined wave-current flows
    c. Effect of near-bottom shear stresses on regional circulation
    d. In areas of complex bottom topography, procedures for spatial averaging to obtain a meaningful sediment transport relationship.

3. Sediment transport relations are required for defining waste pathways. Information required includes:
   a. An understanding of cohesive sediment transport
   b. Physics of non-cohesive sediment motion
   c. Bedform genesis and migration (over wide time scales). Also active vs. relict qualities of bedforms
   d. Transport of "non-conforming" sediments, e.g.
      i) Barium
      ii) Floccules
      iii) Fecal Pellets
      iv) Carbonate sediments
      v) Cohesive sediments
      vi) Nepheloid layer
   e. Understanding of flocculation processes
   f. Chemical and biological modification of sediments
   g. Physical sediment properties and how to represent these in any sediment transport model (e.g. sediment settling)
   h. Animal-sediment interactions including the effects of biological activity on the transport and mixing of sediments both within the water column and on the ocean floor. In addition, one should know the effect of waste material on the biota
   i. Large scale sediment transport--mass movements
      i) submarine landslides
      ii) slope stability
      iii) turbidity currents
   j. Catastrophism, including storm effects on sediment transport
   k. Relationships between space and time scales of fluids vs. sediment
   l. Mobility of disposed materials through host sediments
   m. Affinity of disposed materials for clay or organic particles.
4. Source of sediment and water masses should be known to define the fate of wastes. Specific information should include:
   a. Shelf-slope sediment exchanges including effects of submarine canyons
   b. Beach-shelf sediment interchanges
   c. Estuary-shelf sediment and water exchanges.
5. Shelf stratigraphy is required to evaluate the impact of wastes on the environment. Information required includes:
   a. Sedimentation rates
   b. Sedimentation rates of special areas (e.g. deltas)
   c. Pre-dumping sedimentary environments
   d. Facies analysis
      i) Sea-level facies relationships
      ii) Seismic facies analysis including lateral continuity of facies

iii) Biofacies and ichnofacies analysis including vertical and lateral continuity

e. Bottom morphology, at all scales (cms to 100's of kms)

f. Internal sedimentary structures and their relationship to bedform migration rates and sedimentation rates.

6. Tectonic aspects should be considered to assess the long-term fate of wastes. This includes the local history of tectonic movements (earthquake history) and neotectonics of active margins.
7. Man's future intervention into shelf environments, including:
   a. Effects of dredging and drilling on recycling contaminants
   b. Probability of offshore mining for sand and gravel on returning contaminants or spoils to the land areas.
8. Effect of waste material on bottom (e.g. on carbonate shelves).

9. Sediment consolidation and benthic boundary layer diagenesis. Information needed includes:
   a. Geological consolidation (overburden pressures)
   b. Consolidation changes induced by dumped material loading: both total settlement plus time rate of settlement
   c. Consolidation effect on permeability of sediments
   d. Effect on excess pore pressure distribution
   e. Modification of diagenetic processes.

Technology needed

1. Instrumentation is needed for
   a. Flow field (synoptic; small scales (mm)) measurements
   b. Sediment transport measurements (rates and scales)
   c. Seismic investigations (multi-channel, multi-beam, side-scan sonar)
2. *In situ* sediment sampling (physical properties)
3. Undisturbed sediment sampling.
4. Drilling capabilities
5. Monitoring capabilities for waste disposal and dispersal
6. *In situ* sea flumes to monitor erosion and resuspension potential.

ECONOMIC PROBLEMS - SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

From a geological perspective, it is difficult to define wastes since some utilization may be found which renders the substance a raw material (or resource) rather than a waste product. By-products of processes or activities which have been termed "transformable wastes" include:

a. electroplating wastes - compounds recovered and sold
b. sewage effluents - aquaculture applications with the removal of nutrients
c. sulfuric acid - neutralized with aragonite oolites and sold as high quality gypsum board
d. dredged materials - used as hydraulic fill, building aggregate or extruded ceramic products.

The term "terminal waste" has been employed for those by-products which cannot be treated or otherwise transformed into a useful material.

In those cases where it is possible to associate waste disposal with other offshore developments ("co-development"), mutual benefit is derived from complementary activities. An example is the use of pits created by sand and gravel extraction as waste containment sites.

An additional problem arises from conflicts in use and the establishment of priorities which exclude disposal activities. On land, we do not hesitate to commit certain areas to an exclusive purpose. At sea, there has been reluctance on the part of a significant element of the public to accept this. We feel pilot studies will be required to evaluate the feasibility of exclusive ocean use.

Knowledge gaps

1. Options for transformation of dredge materials to usable products, or usable configurations (e.g., offshore islands).
2. Options for "co-development" of offshore disposal sites.

Technology needed

1. Capping technology (the burial of undesirable materials with a cap of clean sediment).
2. Transformational technology, and placement innovation.

ENGINEERING PROBLEMS - SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

The number and type of engineering problems depend on the type of disposal mechanisms and location. Among the more general problems are:

1. Pipeline stability
2. Construction techniques
3. Structural characteristics of the seafloor
4. Flow characteristics of dilute suspensions
5. Scour characteristics of the bottom
6. Resuspension of fines during storms
7. Stability of dredged materials and leaching of pollutants.

On a larger scale the problems involve the actual selection of a disposal site, and the method of disposal.

Knowledge gaps

1. Structural and geotechnical data on bottom materials is needed before burial operation can occur.
2. Dewatering techniques.
3. Low turbidity dredging of high water content materials.
4. Structural characteristics of the seafloor.
5. Information on anticipated depositional and erosional events.
6. Perturbation of bottom stability by the structure itself.
7. Liquefaction by earthquakes, waves, etc.
8. Motion in the near-bottom fluid that could cause resuspension.

For dredged materials it will be necessary to know:

1. Diagenesis of dredged material and underlying sediment
2. Mechanisms of erosion, transport and deposition of organic-rich cohesive sediment
3. Methods of containment
4. Effects of dredged material on bottom stability
5. Data base to prepare effective numerical and analytical models.

Technology needed

1. Effective and inexpensive means of interpreting structural characteristics of the seabed
2. Instrumentation for assessing stability of areas against slumping or other types of mass movement (this could include *in-situ* monitoring)

3. Large-scale, in-situ sea flumes or other types of equipment to make controlled field studies of resuspension, scour, and other sedimentation processes.

ENVIRONMENTAL PROBLEM - SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

These problems are major and raise basic questions in many aspects of marine science. There will be increasing use of the sea for solid and liquid waste disposal as land disposal is restricted. Environmental impacts of sea disposal could vary in space and time, depending on characteristics of sewage interaction. Environmental impact should be loosely used to mean not only changes evident in the biosphere but any reaction or sequence of reactions or diagenesis which follows disposal. Because of the increasing pressure for solid and liquid waste disposal sites, some of these questions are of extremely high priority, such as problems of toxicity, impact on bottom communities and conflicts between multiple uses of the seafloor. Some important problems are:

1. Waste products may include toxic substances such as metals, chlorinated hydrocarbons, oil, grease, etc. often incorporated into particulate fine-grained matter. The trajectories of these particles to the bottom and later during any resuspension is often uncertain. Thus the fate and even ultimate location of some of these pollutants are unknown.
2. Physical and chemical alterations of the bottom will occur because of the disposal of pollutants these in turn may have some effect on the benthic community and perhaps on the entire food chain.
3. There is a lack of control over composition, amount and frequency of dumping. Little coordination appears to exist concerning monitoring groups, standards and field techniques.
4. It is important to determine the specific circumstances under which effluent discharge actually is beneficial to marine organisms. This point becomes especially important if a "zero discharge" philosophy is utilized.

Knowledge gaps

1. Behavior of the material in the water column, on the seafloor and during resuspension events. In addition, what are the conditions whereby the deposits can be remobilized?

2. Bio-accumulation and bio-magnification aspects are poorly understood.
3. Are current "acceptable levels" of toxicity realistic?
4. What is the time-scale of toxic effects? Do they vary for different organisms and conditions?
5. Effects of organic material on deposition and erosional processes.
6. Effects of bioturbation on mixing rates.
7. Geochemical aspects such as the differences between unpolluted sediments and polluted sediments, exchange mechanisms between dissolved sewage constituents and natural sediments, diagenesis of contaminated sediments, and exchange mechanisms between infauna and porewater contaminants.
8. The circumstances which determine when sewage is beneficial to biota. Similarly, alternatives to ocean dumping, such as landfill and incineration should be considered for each case.

Technology needed

1. Acoustic and/or optical methods to determine trajectories of materials through water column and those occuring as a result of resuspension events.
2. Improved bio-assay techniques to understand bio-accumulation and bio-magnification aspects of benthos.
3. Interdisciplinary sampling devices, such as tripods with current meters, cameras, transmissometers, sample bottles.
4. Remote sensing by satellite and geophysical techniques, including acoustic profiling

POLITICAL AND REGULATORY PROBLEMS - SEWAGE, INDUSTRIAL AND DREDGE MATERIAL DISPOSAL

As the need for dump sites increase, the problems become inextricably interwoven with the economic future of the dumper and the legal, political and environmental pressures from the federal government (Clean Water Act, for example), states, institutions, groups and individuals.

Politically the present body of discharge regulation is a response to public concern against pollution and discharge abuses. In some instances, the philosophy that more treatment is always better and that no discharge is the best of all has been adopted. No assessment has been made of benefits to the marine environment that might be realized by proper treatment and introduction of organic waste materials. Obviously toxicants must be kept out of the effluent.

Sewage should be treated to the extent necessary to make it useful to marine life and not threatening to public health. It appears that present regulations address human concerns as much as they address environmental concerns.

Problems include:

1. What is the fate of particulate matter that may carry toxic materials?
2. What are the long term effects of existing dump sites and should activities (fisheries, etc.) be precluded from these areas? If so, for how long?
3. What is the appropriate level of treatment prior to the discharge of sewage effluent to the ocean, given the composition of the sewage and the ocean environment into which it is to be discharged?
4. How can the search for innovative uses of waste material be encouraged by policy or regulatory changes?

Related questions are:

1. What are the trade-offs between effective source control of toxicants and advanced levels of treatment?
2. If the "zero discharge" philosophy is implemented, will living marine resources suffer from the loss of this source of nutrients?
3. Should specification of acceptable effluent composition (and level of treatment) be tailored to each environment into which the effluent is to be discharged?

Knowledge Gaps:

1. The fate of particulate matter introduced into the oceans.
2. Long-term environmental effects of materials previously dumped.
3. Mechanisms for release of pollutants from particulate material.

Technology needed:

1. Long term monitoring systems.
2. Numerical and analytical models of waste dispersal.

SEWAGE, INDUSTRIAL, AND DREDGE MATERIAL DISPOSAL - Comments about type, amount, time frame of funding; priorities and responsibilities

The disposal of wastes into the ocean is a continuing problem; although legislation has been established to stop ocean dumping in the near future, ocean dumping will continue, with a mixture of beneficial and deleterious effects. The primary priorities for funding and research in this field are the determination of rates of movement of disposed material, its physical and chemical breakdown rates, and susceptibility to leaching and subsequent release from the dumpsite area (pesticides, for instance).

The funding levels for this research are uncertain, so no monetary estimate was attached to this task. However, the need for active and increasing research in these areas is clear, and should be considered immediately. A major task in the funding effort should be to coordinate research activities among those agencies responsible for waste disposal (e.g., U.S. Army Corps of Engineers, DOE, NOAA, and EPA), clarify their roles, and develop coherent guidelines for research and development.

Studies should include both coherent, long-term (3-5 years), multi-disciplinary approaches, as well as the single investigator research whch is so essential to scientific advancement. Emphasis should be attached to monitoring and evaluating spills of opportunity on a rapid response basis, for testing models and instrumentation of waste disposal effects. Specific priorities for research were suggested:

1) Development of instrumentation to monitor fluid and sediment priorities near dumpsites, for both short-term and long-term monitoring.

2) Development of *in situ* testing apparatus for geotechnical priorities as well as chemical breakdown of waste materials.

3) Numerical and analytical modeling of dispersal processes, with coordinated "sea truth" field experiments. This modeling process will be required to meet the time constraints that the regulatory apparatus will necessarily impose on the scientific studies.

4) Detailed monitoring of active and abandoned dump sites of various types on the shelf, for geotechnical, geochemical and other geological effects on the nearby environment.

There was no consensus on the relative roles of government, academia and industry, other than the requirement that the three groups work closely to solve these problems. Government and industry would again be responsible for funding these projects, with the planning, priority setting, coordination, and performance of these projects the joint responsibility of all three groups.

OFFSHORE STRUCTURES

The geological and physical boundary conditions involving offshore structures are highly site specific and in general will benefit by every advance in our basic understanding of the sea. The socio-economic boundary conditions tend to be much more stringent, involving cost, conflict of use and safety. Given these statements a plan or framework for marine geological research is almost case by case dependent.

SCIENTIFIC PROBLEM - OFFSHORE STRUCTURES

The primary scientific problems are centered around safety of the structures. Since each site carries its own environmental constraints, unique new scientific problems may be posed for each structure. The most important areas of scientific work involve the prediction of rare events and evaluating forces on non-uniform, structural configurations, although virtually any advance in understanding the marine environment will be useful to offshore structures at one place or another.

Knowledge gaps

1. Structural design--given a known forcing function what stresses does that induce on the structure itself and its ability to fulfill its primary mission? How do we monitor the condition of a structure through time to insure its structural integrity? How is the dynamic structural loading transmitted to the bottom sediments?
2. Water column motion information is needed to predict forces on structures and sediment motion which might influence the structure. Information needed includes:
   a. Large-scale shelf circulation
   b. Wave climatology, including seasonal changes in wave height, direction and frequency
   c. Vertical variation in flow fields for designing structures
   d. Momentum budget for shelf motions to forecast water motions for port and facilities operations.
3. Knowledge of near bottom fluid motions to predict or understand sediment motion along the bottom that might influence the structural stability.
4. Sediment transport studies to predict sediment motions that might affect the stability of structures on the ocean bottom. These include:
   a. Quantification of sediment transport parameters, both cohesive and non-cohesive, including organic material transport
   b. Bed-form genesis, migration rates over a wide span of space and time scales. Distinction between active and relict bedforms

c. Effects of structures on sediment dispersal
d. Physical properties of the sediment (geotechnical properties) to help evaluate the design and stability of structures, and to quantitatively define physical processes of sediment consolidation, erosion and deposition
e. Large scale sediment transport--mass movements
   i) submarine landslides
   ii) slope stability
   iii) turbidity currents
f. Storm climate such as the effect of catastrophic waves on sediment transport and on the structure itself.

5. Shelf stratigraphy-to determine stability of structures, site and design them properly (primarily shallow stratigraphy). Information needed includes:
   a. Historical sedimentation rates on shelves
   b. Sedimentation rates on slump-prone margins, e.g., deltas
   c. Past sedimentary environments
   d. Vertical and lateral relationships in facies analysis
   e. Bottom morphology--important for locating pipelines and towers. On carbonate margins, for karst topography, solution holes, lithoherms
   f. Distribution of hydrocarbons (specifically gases) that could affect foundation stability.
6. Tectonic aspects: determine local history of tectonism to evaluate earthquake risk.
7. Effect of structures on the environment, including:
   a. modification of the wave climate for onshore areas
   b. modification of sediment transport in nearby areas
   c. effect of structure on biota
   d. potential damaging effect of uses of these structures (e.g. oil-offloading, etc.).

Technology needed

1. Deep-water drilling capabilities for sampling foundation material.
2. Seismic and other geological tools for assessing shallow stratigraphy at sites.
3. Materials science, including corrosion technology.
4. *In situ* geotechnical measuring equipment.

ECONOMIC, ENGINEERING, ENVIRONMENTAL AND POLITICAL PROBLEMS - OFFSHORE STRUCTURES

Increased use of our offshore areas for oil and gas exploration, mineral extraction, offshore port development, power plant siting, etc. is presenting several interesting scientific, engineering and political problems and challenges. One important, but often neglected aspect, is just how much heat, pollution, etc., the coastal-estuarine environment can tolerate. More specific problems involve the character of the bottom in relation to structures. Among the important problems are:

1. Ability to predict (or define) geological, geophysical and geotechnical parameters for various sites and their relevance to design criteria
2. Forecasting seafloor stability and strength in a variety of settings over long (life of structure) and short (specific event) time periods
3. Ability to implement beneficial construction on, or modification of, coastal and offshore regions. Many significant marine building programs have died for varying reasons, but a direct or indirect role of political regulatory constraints is often involved
4. Ability to predict hazard potential and its impact on the environment for specific sites. Hazard potential should include magnitude, frequency and duration of natural events.

Knowledge gaps

Some important questions include:

1. Effects of cyclic loading.
2. Empirical history from which to predict behavior.
3. Lack of sufficient data from undisturbed sediment samples.
4. Detailed knowledge of benthic boundary layer structure and related sediment transport mechanics.
5. Identification of important processes and effects such as soil-structure interactions and relationship between geological and geotechnical properties.
6. Structure-specific questions, such as knowledge of probable ambient depositional/erosional events (for example, burial of pipelines is currently required by law in water depths less than 200 feet; is this really necessary?), perturbations of bottom stability by structure, liquefaction due to waves and earthquakes, and motion in near-fluid bottoms.

Technology needed

1. Techniques for in situ testing of sediment strength and other geotechnical properties.
2. Continued development of remote sensing techniques, particularly for better resolution and capacity to operate in deep water.
3. Development of devices for detection and monitoring of bottom sediment properties, dynamics, stresses, forcing functions and structural effects and responses. Such systems should have the capacity for self activation (or for predetermined input levels of selected data) and operation over widely varying time scales (seconds to years).
4. More effective and less costly means of interpreting seabed structural characteristics.
5. Testing of inherent stability of slopes against slumps.

OFFSHORE STRUCTURES - Comments about type, amount, time frame of funding; priorities and responsibilities

The funding mechanisms for these types of studies appear to be adequate, although the funding levels are too low, particularly for ship time and instrumentation. More coordination between government agencies could eliminate duplication of efforts, and perhaps provide more funds for a rapid response evaluation of specific events. the time frame for these studies is variable, since the studies are highly site dependent.

Priorities for funding should include:

1) Development and improvement of in situ instrumentation for geotechnical monitoring

2) Site evaluation studies on a thorough, comprehensive level, covering various geological hazards as stressed in this report

3) The study of the effects of structures on specific geologic substrates (including creep, fluidization, etc.)

4) Increased capability to fund projects of opportunity to monitor specific events.

The funding for this effort needs to incorporate both large scale, cooperative projects as well as individual investigator research to examine a particular geological hazard influencing offshore structures.

MARINE MINING

In the near future there will be increased interest in exploiting marine mineral resources, including such deposits as sand and gravel from shallow-water sites and manganese nodules from deep-water localities. The workshop participants noted numerous problems, gaps in our current knowledge, and necessary new technologies relative to marine mining in the next decade.

The scientific problems that must be approached include environmental effects of marine mining, accurate assays of marine minerals, recovery and treatment methods, rates of mineral production and natural replenishment, and the origin and age of particular deposits. Economic problems include the discovery and recovery of new minerals within the "exclusive economic zone", cost of supplies and equipment, recovery of mined areas, and mineral import costs. The engineering problems focus on the effects and fate of submarine excavations and holes in the sea bottom. The regulatory and political problems deal with possible multiple uses of offshore areas.

Our knowledge gaps are numerous. In scientific areas, we need to increase our knowledge of water movements both near the bottom and in the water column, the geochemistry of submarine minerals, sediment transport mechanisms and rates, sediment and water mass exchange mechanisms, stratigraphy and structure of shelf areas, tectonic setting and history of mineral deposits, and the effects of mineral by-products on the sea floor. Gaps in our knowledge of economic aspects include regional geology of continental shelves and slopes, genesis of ore deposits, exploration and processing methods, high-resolution seismic stratigraphy, origin and composition of manganese nodules, and new and innovative uses of marine minerals. Engineering knowledge gaps include the effects of mining activities on sediment, suspended material, wave refraction and reflection, sediment transport processes, accumulation of various pollutants, fresh water aquifers, and benthic communities.

New and improved technology is required in several areas, such as instrumentation for submarine monitoring of flow fields, sediment transport, extraction activities, and changes in bottom conditions. Also needed are improved exploration methods, including in situ sampling devices, gamma ray and seismic tools, and geochemical sensors. Improved and innovative production technology, including floating platforms, slurry pipelines, walking structures, precision location systems, and increased drilling capabilities, likewise is needed. Finally, we need to develop technology to model, monitor and predict catastrophic geologic events at mining sites.

SCIENTIFIC PROBLEMS - MARINE MINING

1. What is the effect of mining on the environment? Such as:
   a) Effects on marine communities within the water column and/or on the seafloor
   b) Modification on wave climate and subsequent sediment transport
   c) Effects of increased turbidity on the environment?
2. How does one adequately assay the shelf for mining purposes?
3. What are the recovery and treatment methods for marine mining for a specific site?
4. What are the rates of production of these materials and how long will it be before the mined objects replenish themselves or are depleted?
5. What is the age, origin, and history of the mineral deposits?

Knowledge gaps

1. Water column motions must be known to determine conditions during mining operations and eventual dispersal of any suspended sediment resulting from mining operations. This information also will be useful in estimating replenishment rates for sand and gravel mining. Knowledge required includes:
   a. Large-scale (low frequency) shelf circulation and its climatology
   b. Wave climatology, including seasonal changes in wave direction, height, and frequency
   c. Vertical variation in flow fields (internal motions and stratification are important)
   d. Momentum budget for shelf motions in order to predict short-time scale sediment dispersal.
2. Near-bottom fluid motions must be known to better predict transport of sediment in mining region. It will be important in marine sand and gravel mining operations to determine replenishment rates.
3. Geochemistry of ores and minerals must be studied in order to understand the genesis, history and production rates of various minerals. Work is required on the geochemistry of:
   a. Placer deposits
   b. Authigenic minerals
   c. Hydrothermal deposits
4. Sediment transport studies are necessary to predict dispersal and replenishment of bottom material; they are also important to determine bottom conditions during mining (e.g., bedform migration). Information needed includes:

a. Quantification of sediment transport, both cohesive and non-cohesive
b. Better understanding of wave shoaling, including refractive and diffractive effects. For example, what is the effect on wave shoaling when a large depression is made on the bottom, and how does this change sediment transport patterns, both on the beach and on the shelf?
c. Bed-form genesis, migration rates, over a wide span of time scales, distinction between active and relict bedforms
d. Transport of non-conforming sediments
   i) Barium
   ii) Floccules
   iii) Fecal Pellets
   iv) Carbonate sediments
   v) Cohesive sediments
e. Chemistry and physical processes of flocculation
f. Physical sediment properties
g. Chemical and biological modification of sediments
h. Statistics of fluid motion necessary to model sediment transport
i. Animal-sediment interactions, especially the effects of biota on replenishing sand and gravel deposits at a mining site
j. Large scale sediment transport(i.e., mass movements)
   i) submarine landslides
   ii) slope stability
   iii) turbidity currents
k. Storm climate and the effect of catastrophic events on mining operations and mineral replenishment.

5. Sediment and water-mass sources and sinks are important for dispersal and replenishment. Information on the following will be needed:.
   a. Shelf-slope sediment exchanges; effects of submarine canyons
   b. Beach-shelf sediment interchanges
   c. Estuary shelf sediment and water exchanges.
6. Shelf stratigraphy is required to properly assess mineral deposits, particular information includes:
   a. Historical sedimentation rates on shelves (e.g. from biogeochemical studies), especially for slowly accreting deposits, such as phosphorites, etc.
   b. Past sedimentary environments, paleo-bathymetry, shelf history
   c. Facies analysis:
      i) sea-level facies relationships
      ii) seismic facies analysis
      iii) biofacies analysis; vertical and lateral continuity of facies.

d. Geophysical exploration techniques, for facies analysis (especially shallow), sediment thicknesses, and mineral potential
e. Bottom morphology over wide range of spatial scales.

7. Tectonic history of vertical and lateral movement of mineral materials, and the depth history of mineral genesis for a particular area are required.
   a. History of tectonic movements
   b. Neotectonics of active margins
   c. Tectonic response to glaciation, sea-floor motions.
8. Effects of mineral exploration by-products on the bottom such as on biological communities in the water column and at the seafloor and modification to circulation and sediment transport.
9. Sediment consolidation and benthic boundary layer diagenesis are important considerations, these include:
   a. Geological consolidation (overburden pressures)
   b. Consolidation changes induced by container loading: both total settlement plus time rate of settlement
   c. Consolidation effect on permeabijlity of sediments
   d. Effect on excess pore pressure distribution
   e. Modification of diagenetic processes.

Technology needed

1. Instrumentation:
   a. flow field monitors
   b. sediment transport monitors
   c. improved seismic tools
2. *In situ* sediment sampling devices for obtaining undisturbed material, and testing for geotechnical properties
3. Drilling and coring capabilities, for evaluating deposits and retrieving mineral products.
4. Monitoring capability for mineral exploration and extraction in general. (This includes the instrumentation cited above, as well as efficient planning of monitoring procedures to minimize cost and maximize information acquisition. This is a major gap in available technology. The answers may be available, but the application to oceanic monitoring problems has been minimal.)

ECONOMICS PROBLEMS - MARINE MINING

Economic problems include the need to discover, recover and process minerals occurring in the U.S. exclusive economic zone (EEZ) which extends out to 200 nautical miles and beyond, to increase the reliability and lower the cost of supplies, lower the environmental impact of land recovery, and reduce mineral import costs. Currently identified marine minerals include limestone, sand and gravel, phosphorite, manganese nodules (including those nodules within the U.S. EEZ on the Blake Plateau), placer minerals (gold, platinum, titanium minerals, and chromite sands), sandblasting minerals (garnet, staurolite, and kyanite), authigenic and hydrothermal sulfides, base metal deposits, and rock salt. Economic needs are urgent in several areas (e.g., sand and gravel for New York metropolitan area).

Cross-fertilization of knowledge in the areas of economic geology, ocean mineral studies, ocean engineering and marine policy is needed. Industrial exploration and technological development currently are at very low levels (though interest is strong), as a consequence of absence of mineral leasing policy for federal outer continental shelf (OCS).

Knowledge gaps

1. Better knowledge of regional geology and shallow structure of shelf/slope regions.
2. Need for models for genesis of ore deposits to improve exploration/development strategies (recent Pacific hydrothermal discoveries were made largely by accident).
3. Improved exploration techniques.
4. High resolution seismic stratigraphy.
5. Innovative processing techniques and applications.
6. Knowledge of metal distribution in marine manganese nodules, and understanding their origin.
7. New and innovative uses of marine materials.

Technology Needed

1. Geophysical and geochemical exploration tools.
2. Urgent need for more efficient and lower-cost shallow coring/drilling technology (10-100m)
3. In situ exploration systems (towed gamma emitters, seismic, geochemical sensors for surficial deposits, such as placers and phosphorites).
4. Innovative technology for mining on the continental shelf (e.g., floating platforms, slurry pipelines, walking structures).
5. Design of mining structures for stability in various environments, and innovation in restoration of the sea floor to a pre-mining state.

ENGINEERING PROBLEMS - MARINE MINING

Among the major engineering problems associated with mining minerals like sand and gravel is what happens when a hole is produced on the sea floor and how does that hole affect other marine aspects of the region. Marine mining operations will be affected by sub-bottom or bottom conditions which are often hard to ascertain. This will be especially evident with more deep-water operations such as nodule mining.

Knowledge gaps

1. Post-mining effects
   a. Effect of hole shape on wave refraction and reflection
   b. Effect of hole on bottom sediment transport (hole infilling with sand from beach or offshore)
   c. Effect of hole as a trap for pollutants
   d. Effect of possible groundwater-aquifer puncture.
2. Mining effects
   a. Effect on benthic communities
   b. Production of suspended material (e.g., turbid sediment plumes).
3. Importance of shelf as source or sink for coastal sands.

Technology needed

1. Increased ability to sense bottom changes.
2. Methods to forecast changes caused by catastrophic events.
3. Techniques to improve knowledge of bottom circulation and sediment transport.
4. Continuous monitoring of bottom conditions.

ENVIRONMENTAL PROBLEMS - MARINE MINING

Environmental problems associated with marine mining are considerable and can be divided into two categories:

1. Effects of mining, such as introduction of suspended material into the water, re-introduction of pollutants that were buried in the sediments, damage of benthic community, and problems associated with disposal of tailings.

2. Effects after mining, including changes in the shape of the bottom that can affect wave refraction, cause mud and pollution accumulation and change the bottom habitat. The mining operation can also interfere with ground water systems and the replenishment of coastal sand supplies and thus may damage local beaches.

Knowledge gaps

1. Effect of hole or change in bottom topography on wave climate
2. Is the shelf area a source of beach sand? If so, we need to understand the beach sand cycle and net sediment transport direction.
3. Dispersal paths of bed load, suspended material and tailings

Technology needed

Technology is needed to continuously monitor bottom conditions, sediment dispersal, waves, etc. Especially important is the ability to predict or model effects of catastrophic events.

REGULATORY AND POLITICAL PROBLEMS - MARINE MINING

Regulatory and political problems principally concern how mining operation will affect other uses of the environment. For example, changes in wave patterns that might result from bottom topographic changes could affect replenishment of beach sand or harbor shoaling. Mining operations and resulting sediment plumes, if any, can affect fisheries (especially shelf fisheries). Politically it might be appropriate to set aside certain areas as offshore parks and other areas as mining sites. This might help resolve conflicts between mining activities and environmental concerns without having to consider legal recourse.

Political decisions should be made indicating whether or not marine minerals mining can be allowed and what restraints, if any, are necessary.

MARINE MINING - Comments about type, amount, time frame of funding; priorities and responsibilities

Many of the problems associated with marine mining are in the category of scientific concerns; these must be resolved in order to effectively mine in the oceans. The workshop participants encouraged the coordination of research within government, and also outside of government. Increased cooperative meetings and research projects should be encouraged to provide the multi-disciplinary flavor to marine mining studies (such as is occurring through the Underwater Mining Institute).

Priorities for research should include:

1) Improved knowledge of basic scientific questions affecting mineral genesis, distribution and accessibility

2) Geological/geophysical exploration techniques could be improved

3) Encourage pilot studies to examine the feasibility of mining specific minerals, and the effect of the mining on the environment.

HYDROCARBON EXPLORATION AND EXTRACTION

America's energy needs are the concern of all citizens. Finding, extracting and transporting fossil fuels in order to help meet our present energy shortage should receive maximum assistance from the scientific community. Academic, industry and government working cooperatively can make a significant contribution toward this end. Further, it is essential that our efforts are carried out with minimal damage to the environment.

SCIENTIFIC PROBLEMS - HYDROCARBON EXPLORATION AND EXTRACTION

Geological problems associated with hydrocarbon exploration and extraction can be considered at 3 different levels. First would be those problems whose solution yields critical and general background information concerning broad areas of continental margin for the identification of new frontier areas for hydrocarbon exploration, and for the general effects of hydrocarbon exploration and exploitation on the environment. These types of studies have long-range practical goals and should be long term in nature. The importance of broad area questions is critical especially to those making decisions about exploitation of the U.S. continental margin. Often it is these types of questions which have received the least amount of attention from the funding agencies..

The second level of problems are those that relate to specific sites and need intense studies within geographically-limited areas. Often this type of research is made in conjunction with site selection for drilling and production. Considerable funding is now concentrated in site specific studies, involving academic, industry and government research groups. This type of mix is healthy and should probably continue on about the same style.

The third level of studies concerns the monitoring of the effects of hydrocarbon exploration, exploitation, and transportation on the marine environment. Like the second level, monitoring studies have to be designed with location and knowledge of the effects of a specific activity. The purpose of the monitoring studies should be two-fold: (1) to make further exploitation more efficient both technically and with regard to adverse effects on the environment and (2) to assure the safety of the surrounding area and the facility itself. Monitoring studies need to be relatively long term but should not go on forever.

Major scientific problems to be answered include:

1. How are hydrocarbons generated and accumulated?
2. How does one effectively and efficiently explore for hydrocarbons and find frontier areas?
3. What are clathrates, how are they formed, what is their distribution and are they economically valuable?
4. In case of spills or leakage, how fast do the hydrocarbons disperse, and what effect do they have on sediment transport?
5. In case of spills or leakage, how can the effects of the spill on the environment be minimized?
6. What are the effects of drilling by-products (e.g., drilling muds, barium, etc.)?

<u>Knowledge gaps</u>

1. Water column motions; information is needed to predict dispersal of hydrocarbons after spillage or leakage. Need to estimate wind, wave and current forces on drilling platforms and transportation systems. Data required includes:
   a. large-scale (low frequency) shelf circulation and its climatology
   b. wave climatology, including height, direction and frequency
   c. need to know vertical variation in flow fields--internal motions and stratification are important to hydrocarbon mixing
   d. need to formulate momentum budget for shelf motions in order to predict short-time scale hydrocarbon dispersal.
2. Near-bottom fluid motions studies are needed to predict hydrocarbon dispersal along the bottom.
3. Sediment transport: studies necessary to predict hydrocarbon dispersal along the bottom and transport of hydrocarbon-saturated sediments. Important aspects include:
   a. Quantification of cohesive sediment transport, including effects of organic materials
   b. Physics of non-cohesive sediment motion
   c. Bed-form genesis and migration rates through time scales
   d. Distinction between active and relict bedforms
   e. Transport of non-conforming sediments
      i) Barium
      ii) Floccules
      iii) Nepheloid layer
   f. Chemistry and physics of flocculation processes

g. Chemical and biological modification (e.g. breakdown) of sediments
h. Physical sediment properties in a complex environment (e.g., hydrocarbon covered, etc.)
i. Determination of forcing function and fluid flow parameters for sediment transport
j. Animal-sediment interactions (effect of biological activity on mixing and breakdown of hydrocarbons)
k. Mass movements of sediment
   i) submarine landslides
   ii) slope stability
   iii) turbidity currents
l. Storm climate--effect of catastrophic events on hydrocarbon exploration and transportation
m. Relationships between time and space scales of motion for fluids and sediments.

4. Sediment and watermass sources and sinks-water quality parameters and sediment characteristics can be used as tracers for predicting hydrocarbon fates. Important aspects are:
   a. Shelf-slope sediment exchanges; effects of submarine canyons
   b. Beach-shelf sediment interchanges
   c. Estuary-shelf sediment and water exchanges.
5. Shelf stratigraphy--important to determine hydrocarbon potential and cost-effectiveness. History of margins important to assess source rock potential. Knowledge needed:
   a. Historical sedimentation rates of shelves (e.g., from biogeochemical studies)
   b. Sedimentation rates on special margins (e.g., deltas)
   c. Past sedimentary environments, paleo-bathymetry, shelf history (e.g., CO_2, T, O_2)
   d. Facies analysis--
      i) sea level facies relationships
      ii) seismic facies analysis--techniques
      iii) Vertical and lateral continuity of biofacies
   e. Geophysical exploration techniques, for facies analysis, sediment thicknesses, and hydrocarbon potential (e.g. heat flow, high resolution seismics)
   f. Bottom morphology over wide range of spatial scales
   g. Source rocks for organic material.
6. Tectonic aspects: to determine structural traps, heat flow and hydrocarbon maturation rates, including:
   a. History of vertical movements
   b. Neotectonics of active margins.

7. Groundwater distribution under shelves should be known to evaluate potential contamination of groundwater at any site due to drilling or storage programs, thus affecting groundwater quality in other locations.

Technology needed

1. Instrumentation for:
   a. flow field studies (synoptic; small scale (mm), Lagrangian and Eulerian)
   b. sediment transport
   c. seismic investigations (multi-channel, multi-beam)
2. Undisturbed sampling and testing for geotechnical properties
3. *In situ* geochemical testing
4. Drilling capabilities
5. *In situ* monitoring capabilities for hydrocarbon dispersal, including instrumentation and field experiments to monitor dispersal.

ECONOMIC PROBLEMS - HYDROCARBON EXPLORATION AND EXTRACTION

The basic problem is to obtain an adequate supply of hydrocarbons to meet immediate U.S. needs. A considerable amount of the new supply will come from source rocks underlying present-day marine environments.

Knowledge gaps

1. Character of potential source and reservoir rocks in undrilled areas.
2. Geotechnical character of sediments in areas of potential slope instability and where gases are present in continental margin sediments.
3. Possibility of clathrates as resources or as sealing beds and their environmental risks.
4. Distribution of shallow freshwater aquifers in U.S. shelf area.
5. Establishing best use of a particular lease site - and possibilities for multiple uses.

Technology needed

1. Improvements in interpreting seismic stratigraphy.
2. Geotechnical measurements at depth in the sediment column.
3. Techniques for taking and analyzing pressurized cores.
4. Inexpensive shallow 30 - 100m coring technology.

ENGINEERING PROBLEMS - HYDROCARBON EXPLORATION AND EXTRACTION

The discussion of engineering aspects related to hydrocarbon activities are presented in the offshore structures section (pages 29-32)

ENVIRONMENTAL PROBLEMS - HYDROCARBON EXPLORATION AND EXTRACTION

1. Geological hazards - bottom sediment stability and sediment transport.
2. Incorporation of hydrocarbons into bottom sediments.
3. Identification of natural hydrocarbons seeps.
4. Drilling mud disposal - how and where?
5. Background hydrocarbon conditions of the environment.

Knowledge gaps

1. Identification of geological hazards.
2. Slump movement rates?
3. Distribution and sources of hydrocarbons in sediments? Mechanisms for dispersal of hydrocarbons in sediments?
4. Where are natural hydrocarbon seeps?
5. Locations for drilling mud disposal?

Technology needed

1. Bottom sensors to measure triggering mechanisms for mass movements.
2. Techniques to rapidly analyze hydrocarbons and satisfactorily fingerprint oil to determine sources.
3. Sediment transport sensors.

POLITICAL PROBLEMS - HYDROCARBON EXPLORATION AND EXTRACTION

Basic problems include background information prior to tract evaluation and leasing. This information will allow a better evaluation of priorities for the use of an area. Likewise public education should be established to adequately present various alternatives.

Knowledge gaps

1. The environmental impact of oil in different environments and using different techniques.
2. Background level of pollution and the effects it might have had.
3. The mechanisms of movement of hydrocarbons once it enters the water.

Technology needed

1. Rapid methods of hydrocarbon analysis.
2. In situ experiments on the biological effects and movement of hydrocarbons (i.e., an experimental spill or "spill-of-opportunity").

HYDROCARBON EXPLORATION AND EXTRACTION - Comments about type, amount, time frame of funding; priorities and responsibilities

The participants uniformly agreed that the funding levels and mechanisms were inadequate for this geological use of the ocean. An increase in funding appears necessary, as well as increased coordination among the responsible government agencies (USGS, BLM, NOAA, EPA, U.S. Coast Guard) to better define the (apparently) diffuse responsibilities of the government. The suggestion was discussed that a lead agency is required, with a clear charter for addressing this problem; this situation would help academia and industry clarify the government agencies with which they should be strongly interacting.

An increased need for international cooperation on the hydrocarbon problem became apparent during the meeting. Coordination of regulatory and clean up operations is clearly lacking, as was evidenced in the recent Gulf of Mexico oil spill. This cooperation could span scientific, engineering, economic and regulatory aspects and might be a possibility for the International Sea Grant Program.

Funding should be jointly shared by government and industry, since both groups play major roles in the hydrocarbon problem. Lines of communication between government, industry and academia should be opened to reduce duplication of effort, and create a more cooperative environment for resolving these problems. Industry has clear supremacy in certain aspects of hydrocarbon development; academia should not duplicate these, but add their own expertise to different aspects of the problem. Emphasis should be placed on future government funding of:

1) Mapping (over large scales) geotechnical properties of the ocean bottom, and stability parameters for exploration and extraction activities

2) Detailed studies of shelf hydrodynamics and sediment dynamics, including both kinematical descriptions of flow as well as dynamical interrelationships

3) Increased emphasis on the geological/geophysical exploration of virgin or poorly explored regions for their hydrocarbon potential.

MILITARY RELATED PROBLEMS

There was some hesitation among the scientific aspect group to discuss military activities that relate to marine geology. Part was probably due to lack of knowledge of military activities, part to a feeling that much military related research was classified. The economic aspect group felt they lacked military expertise and that time did not allow an attempt to develop a detailed answer, but the group recognized the importance of this category. In addition to direct military activity, the economic group noted that conflicting uses involving the military have had direct impact on economically important geologically-related offshore programs. Examples include restricting petroleum lease sites in the Destin Dome region (Florida) and on the Blake Plateau with potential conflict with manganese nodule mining, owing to presence of submarine lanes and rocket ranges. It was suggested that better coordination among federal agencies, especially the Department of Defense, could result in strategies to resolve conflicts and permit multiple activities to develop.

The engineering, environmental, political aspect group spent some time on this category and identified several specific problems:

ENGINEERING PROBLEMS - MILITARY

1. Prior to putting "items" on the seafloor, knowledge of the *in situ* physical properties of the sediment including bearing strength should be known. Some of the properties have been studied and published by Navy scientists, in particular those from the Naval Electronic Laboratory (now called Naval Undersea Center) in San Diego. If the items are to be left there for any period of time information concerning sediment deposition, scour, sand waves, sediment stability, etc., should be available.

2. Anti-submarine warfare work requires information concerning acoustic and geotechnical characteristics of the sediment, in both the dynamic and static sense.

3. Information as required in #1 and #2 above are also pertinent to salvage operations, both on or in the seafloor, offshore military structures, and ordinance disposal.

Knowledge gaps

1. The interactions between bottom sediment and structures.

2. Dynamic properties of the sediment, especially on the continental shelf.
3. *In situ* sediment stress tensors.
4. An understanding of sedimentary processes acting in the benthic boundary layer including deposition, erosion, transportation and diagenesis.
5. Sediment or soil property maps showing average properties, anomalies, etc.

Technology needed

1. Improved sampling devices to better obtain representative samples, and improved *in situ* and laboratory testing equipment.
2. Development of better techniques for remote sensing of geological, geophysical and geotechnical properties.
3. Development of sampling theory to meet space and time considerations.

ENVIRONMENTAL PROBLEMS - MILITARY

1. Disposal of unused or still dangerous military ordnance material can present environmental problems.
2. Establishment of marine training areas can lead to conflict in usage for parts of the seafloor.

Knowledge gaps

1. For ordnance disposal the following items are important: burial rates, transportation and disposal, rates of degradation of material on the seafloor, up-to-date inventory of existing ordnance disposal areas, and techniques or methods of "cleaning up the area" for later mineral mining or fishing activities.
2. For training areas the following are pertinent: explosive activities that damage the sea floor, type of substrate, cable and sensor laying, suspended sediment, excavation and effects of the resulting depression.

Technology needed

1. Techniques for monitoring long-term currents and mass movements and their effects in the disposal area.

2. Knowledge of ocean bottom seismic activity and its effects on items being disposed.

3. Establishment of experimental areas, for nuclear and non-nuclear activity.

REGULATORY AND POLITICAL PROBLEMS - MILITARY

There are several political or policy matters which, although not of direct geological importance, can have a strong influence on marine geology. The first item concerns the development and establishment of U.S. marine policy. In some areas, such as the Law of the Sea negotiations, the military has had a very strong input. For example, the question of freedom of passage of military ships through straits probably was one of the more important positions of the United States in its negotiations, whereas the character of the marine scientific regime within the new extended jurisdiction zones (at least out to 200 nautical miles) was not a major item in the negotiations. The U.S. was more successful in obtaining, through negotiations, those items perceived by others a being of primary importance. Stronger emphasis by either the U.S. State Department or the U.S. Navy (and probably by the marine science community) in the earlier stage of negotiations might have produced a more favorable regime for marine science in the extended jurisdiction zone than the presently negotiated consent regime. Alternatively, the consent regime that essentially now covers about 37% of the ocean and all of its coastal regions could increase the opportunities for cooperative geological work with foreign countries especially for those types of research activities described in this report.

A second point is that the degree of funding by the military, in particular the Office of Naval Research, has strongly influenced the direction and general health of marine scientific research. The decrease in ONR funding over the past few years has, in part, contributed to some of the ship-funding problems now found facing the academic community.

MILITARY RELATED PROBLEMS - Comments about type, amount, time frame of funding; priorities and responsibilities

ONR is the primary funding agency for military related marine problems; its level of funding must increase in future years to maintain the research effort historically needed by the Navy. Better communication between the government, industry and academia could improve the response of the research community to Navy needs, and clarify the applied aspects of much research which may appear unrelated to military problems. A tendency to internalize research has been observed in some government agencies (e.g., U.S. Army Corps of Engineers, U.S. Coast Guard), removing the research and funding possibilities from the civilian research community. This tendency should be tempered, in order to increase the interaction between military and civilian researchers, to the benefit of both groups. Unsolicited proposals should be more encouraged to allow industry and academia to suggest research which they feel may benefit the military; this approach could complement the research priorities established by the military themselves.

SPECIFIC GEOLOGICAL PROBLEMS

After spending about a day on the (1) scientific, (2) economic, and (3) engineering, environmental, regulatory and political aspects of the afore-mentioned geological uses, the workshop effort turned towards four more specific geologic problems: catastrophic events, slope stability, shelf morphology, and sediment characteristics. The same questions posed earlier were considered (What are the problems, knowledge gaps, technology needed, funding, etc.?) but no focus was made toward specific uses. However, the remarks of the four groups generally apply to all the uses described in this report.

CATASTROPHIC EVENTS

A catastrophic event was defined as a low-frequency, high-energy event of short duration that affects natural systems, structures and operations. The effects differ as a result of spatial and temporal (frequency and duration) factors. Sources of energy for these events include earthquakes, tsunamis, turbidity currents, high velocity currents of short duration, and major slope failure. Because of variability, various means of sampling, analyzing and detecting are required; some need to be developed.

The term "catastrophic" is subjective and refers primarily to adverse impacts on human activity. Many natural geologic processes are driven by random "catastrophic" events whose effects become predictable when integrated over a sufficient time interval; uniformitarian processes tend to have a catastrophic fine structure (for instance, shoreline retreat during the postglacial transgression has been driven by countless catastrophic storm surges).

PROBLEMS - CATASTROPHIC EVENTS

Catastrophic events are known to be major elements in coastal and inner-shelf evolution. Development of a capability to predict them is of high priority but is difficult because: (1) The physics of processes leading to a probability of an event are not known; (2) Low frequency of past large-scale events makes measurement of effects difficult except for extrapolation from historical and geological records. There are probably many catastrophic events for which traces are not recognized. More attention is needed for such events as oxygen depletion, atmospheric effects on sediments, etc., which may leave geological records.

Knowledge gaps

1. How may the magnitude of the causal event be assessed?
2. What records of the event and its impacts are there and how are they to be interpreted?
3. Can predictive models be developed?
4. Knowledge of the consequences of the event on natural systems and on structures.

Technology needed

Studies of geologic processes as now conducted could permit observation of the effects of catastrophic events. The better the detail of the investigation the greater will be the possibility of recognition of these events. When frequency and/or impact of events is such that direct observations and measurements are possible, they should be attempted using existing or specially developed equipment.

Experience shows that catastrophic processes are best studied by systematic observations with in situ recording sensors, which are in place for sufficiently long periods of time to give the probability of an event occurring a high value. The advent of microprocessors means that "smart" systems can sample lightly for very long periods of time, then switch to an intensive sampling mode when an event occurs and the parameter being sensed exceeds a threshold value (conditional sampling).

Contingency observations (by "quick-response teams," etc.) are usually far more expensive than in situ monitoring. They are useful, however, for supplementary qualitative descriptions.

Catastrophic events should be studied by:

1. Development of a coastal benchmark system for shelf modification and bedform movement. The National Ocean Survey should be encouraged to process its coastal current-meter data to provide a mean flow climatology, and its bathymetric data to evaluate the seafloor response to flow-rates of erosion and shoaling.
2. Development of standard wave measurement systems in offshore areas. A program such as that initiated in California by the Department of Navigation and Ocean Development should be expanded.
3. Development of a system to monitor rapid slumps, possibly by means of accelerometer probes.
4. An increase in the number of seafloor seismic stations to complement the terrestrial net.
5. Develop a capability to measure ground response movements to seismic events.

Also needed is better planning of routine monitoring to permit recording of severe events. For example, extending the height of tide gauges to record unusually high tides and the development of smart systems with long-term survival for sensing catastrophic events.

Comments about type, amount, time frame of funding, priorities and responsibilities

Long-term support for monitoring and detection of events would be valuable, as will be funds for a flexible response to individual events. Neither type of support is adequately available at present. Some Sea Grant Programs have quick-response funds, but sometimes it still is difficult to mobilize for studies of catastrophic events. Coordination of such activities is a very important factor. The amount of funds needed is hard to define, but monitoring is expensive.

Government agencies should probably play a prime role in monitoring while academics can best help in designing experiments and equipment. Military support with data and funding could be valuable. Research in the area of catastrophic events could be an important aspect towards developing high-level technology. Industry can play an important role in determining which catastrophic events are of priority importance. Their experience and facilities could be critical to the definition of a program and subsequent direction of research.

SHELF MORPHOLOGY AND BEDFORMS

The seafloor of the shelf is the equivalent of a terrestrial desert, an alternation of erosional and depositional surfaces and bedform arrays shaped by sandstorms and duststorms. Shelf sediment transport affects almost all uses of the continental shelf.

PROBLEMS - SHELF MORPHOLOGY AND BEDFORMS

Horizontal transport patterns define pollutant dispersal patterns since most pollutants travel attached to sediment particles. Patterns of erosion and deposition determine the locations of seafloor structures and should influence the location of dumpsites, as well as fishing grounds and areas of sand and gravel deposits.

Morphological features of the continental shelf occur over a wide range of size scales. Large-scale elements (cuestas, terraces, shelf valleys, shoal retreat massifs) are relict from terrestrial or (more commonly) nearshore marine environments.

Their distribution strongly affects human usages such as mining (sand and gravel, alluvial gold, tin), and structures and sites for oil platforms and dumpsites. Meso-scale and small-scale elements (sand ridges, sand waves) are more likely to be equilibrium responses to flow (bedforms); as such they tend to migrate and are therefore of even more concern to environmental and resource engineers.

The problem is that the formative and maintenance mechanisms of shelf bedforms are not understood to a degree that permits predictions of future behavior to be made, because the velocity field is not known with sufficient detail over large enough areas.

Knowledge Gaps

Suspended fine sediments are chemically active and carry pollutants. Regional fine sediment budgets on the continental shelf are poorly known. Transport from rivers, through deltas, estuaries and lagoons, across the shelf, and on the slope is complex, with many pathways and feedback loops. On both tide and storm-dominated shelves, transport has a complex time structure. Particles are entrained into the mean flow (windor tide-driven flow) by high-frequency motions associated with surface and internal waves. Transport is thus intermittent at both the surface-wave scale and the event (storm) or tidal scale. These processes are poorly understood.

Sand transport shapes the surfaces of shelves with low mud budgets and controls the coastlines and shorefaces of nearly all shelves; understanding the sand budget of the inner shelf is required for solving beach erosion problems, and for siting sewage outfalls and pipeline corridors.

The processes of sediment transport and its relation to the driving forces are not well known for shelf areas. Storm-related events are possibly dominant and require long-term monitoring to compile statistically significant data (the transport climate) on the characteristics of these transients. Characteristics of the seabed materials must be mapped. The third dimension, particularly as regards bedding structure, stratigraphy and age, needs extensive exploration and explication. The rheology of cohesive sediments on the shelf requires an even larger amount of study.

Specific problems include:

1. Characterization of the flow field at various time and space scales and the interaction between scales (wave-wave and wave-current interactions)
2. The nature of wave energy dissipation on the shelf
3. Characterization of time and space scales of sediment transport (transport climatology)
4. What are the boundary layer processes responsible for sediment entrainment into flow?
5. What is the relationship between the time and space scales of fluid motion and the time and space scales of bedform arrays?
6. What boundary layer processes create and maintain bedforms?

Technology needed

A larger number of time-coordinated instrumented tripods with even more complete inventories of sensors need to be deployed in patterns that sample regional phenomena, subregional processes and local events. Waves, tides, currents, light, sediment strength, grain translation speeds, boundary layer thickness, turbulence (3-D) spectra, thickness of the traction carpet, suspended sediment concentration, and the particle size frequency distribution at various levels all require measurement at data rates up to sixteen samples per second.

Specific technologies needed include:

1. The simultaneous measurement of highand low-frequency fluid motions
2. The measurement of the size distribution and concentration of fine sediment
3. *In situ* observations of transport processes (both Eularian and Lagrangian)
4. The measurement of the settling velocity of fine sediments
5. The measurement of cohesive sediment properties, specifically, surface areas and surface charges.

Comments about type, amount and time frame of funding, priorities and responsibilities

The principal problem as regards funding mechanisms is that associated with the wide dissemination of expertise. In the Federal Government the U.S. Navy including ONR, U.S. Army Corps of Engineers, Waterways Experiment Station and Coastal Engineering Research Center, DOE, NOAA (in several different departments), Coast Guard, USGS, and NASA, all have competence in essential elements of the needed program. So do numerous universities and research institutions. A mechanism is needed to bring these forces to bear collectively and effectively on the task.

SLOPE STABILITY

The stability of the continental slope and areas having high sedimentation rates, such as deltas, is critical for many structures and seafloor activities in these regions. Incomplete knowledge of the seafloor properties and processes often results in overdesign and an unnecessarily high cost of man-emplaced structures (pipelines, platforms and temporary expooration equipment). Loss of life and pollution can result from our inability to adequately predict environmental stresses that are placed on offshore areas.

PROBLEMS - SLOPE STABILITY

1. Deltaic Environment

   a. At present, the factors leading to failure through increasing instability are not adequately quantified.
   b. Realistic factors of safety for facilities are not established.
   c. There are inadequate sampling techniques to deal with ambient sediment conditions (pore pressure, gas content, etc.).
   d. Lateral and vertical variability of sediment deposits in terms of their physical and mechanical properties is poorly known.
   e. There is a great need for reliable soil properties data and especially for *in situ* data on the geotechnical properties under ambient and dynamic conditions. Time-dependent changes in soil properties under dynamic environmental stresses is severely lacking.

2. Outer Continental Shelf - Upper Continental Slope

   a. Age of upper slope slumps is uncertain.
   b. Distance from shore and water depth make work difficult.
   c. Heterogeneity of materials.
   d. There are no major research programs addressing the continental slope.
   e. Lack of quantification of sediment parameters.

Knowledge gaps

1. How do we characterize the mechanics of deformation?
2. Uncertainty regarding triggering mechanisms, magnitudes and frequency of occurrence.

3. Lack of quantification of parameters which are factors in failure (gas, sediment loading, wave loading).
4. Choice of appropriate testing program and analytical models to obtain realistic data is important; however, obtaining quality data is at present among the greatest deficiencies.
5. The importance of creep processes is poorly known and understood.
6. What are the effects of cumulative, small-magnitude seismic events on slope deposits?
7. Rates of motion and forces developed in slides are virtually unknown.
8. What are effects of internal waves at the shelf break?
9. General delineation of important forcing functions is poorly known (magnitudes, rates, frequency of occurrence).
10. Lack of sufficient _in situ_ soils properties data makes predictions uncertain.
11. Lack of reliable environmental data for prediction of design criteria.

Technology needed

1. _In situ_ long-and short-term geotechnical probe for soil properties monitoring.
2. Suitable testing facilities to maintain ambient conditions of soil parameters.
3. Sampling devices to measure ambient conditions.
4. Ability to monitor areas of high instability.
5. Deep-towed surveillance system to establish meso-and microscale topography.
6. If possible, declassify or make available existing Navy acoustic systems.
7. _In situ_ geotechnical probes for submersible use.
8. Precision bathymetric and slope maps are required for nearly all areas of the continental slope, rise and shelf.

Comments about type, amount, time frame of funding; priorities and responsibilities

Funding levels should be sufficient to provide for detailed research efforts in critical areas of national interest, for long-term monitoring of selected areas, and for seasonal monitoring. The potential of opportunistic research must be encouraged--for example, work after a hurricane or earthquake. Some research should address lease sales and other sensitive areas. Instrumentation, including mapping techniques, need increased support or else allow researchers more opportunities to use military equipment (for example, multi-channel bathymetry devices). R&D is needed to provide adequate numbers of in situ geotechnical probes for both shallowand deep-water environments.

Priorities: A means to recover samples at ambient conditions and methods to monitor actual deformation rates and forces are high priority. Also important are techniques to map, in detail, small areas of the outer shelf and upper slope and rise at a small scale, and to establish a survey scheme to sample and monitor certain areas--one with slumps/one without slumps, and in various geotechnical environments. A greater research effort should be devoted to assessing the importance of creep processes in selected offshore areas. Integrated, multidisciplinary research studies should be encouraged. Deep drilling through selected geological deposits and formations associated with areas of seafloor slides should be undertaken. Long, high-quality core samples are required for adequately assessing potential movements in major slump areas.

SEDIMENT CHARACTERISTICS

Many of the physical, biological and chemical properties of marine sediments and their interactions are really not well known, but their importance to the various geological uses described in this report is obvious.

PROBLEMS - SEDIMENT CHARACTERISTICS - BIOTURBATION

What is the relationship of chemical, biological and physical characteristics of sediment, and how are they influenced by man's activities in the benthic boundary layer?

Knowledge gaps

Infauna activity can change sediment characteristics with respect to: porosity and permeability, grain-size, pH-Eh, pore-water chemistry, addition of fecal material, effects of mucous and other organic compounds, burrow formation in uncemented sediments, effect on shear strength and other physical properties, seasonal variations in shallow-water sediments and mixing of surface contaminants. None of these are well understood.

Technology needed

1. Box cores frozen *in situ* to preserve structures.
2. CAT-type scanner to detect *in situ* fabric, organisms, etc. in different geological environments.
3. Improved signal processing for better surface and substrate penetration and resolution.
4. X-ray electronic image intensifier for lab and *in situ* examination of sediments.
5. Improved remote, unmanned tools to measure seafloor properties.
6. Improved *in situ* geotechnical tools.
7. Improved surface chemistry measurement techniques.
8. Develop a biologically sterilized test site that can be monitored over extended time periods.

Comments about type, amount, time frame of funding, priorities, and responsibilities

Present funding mechanisms might be adequate, but there should be more support for basic research in this area. One priority should be to quantify measurements made of sediment characteristics.

PROBLEMS - SEDIMENT CHARACTERISTICS - MASS PHYSICAL PROPERTIES

We need better instruments to evaluate the biological, geochemical and physical characteristics of continental margin and ocean basin sediments, and the effect of man's activities on these materials.

Knowledge gaps

1. How does one accurately forecast strength from in situ measurements, and how are these related to laboratory tests?
2. What is the short-and long-term behavior of sediments under environmental loads - especially dynamic loading of sediments?
3. Soil characterization and variability is largely unknown for the principal soil types on the margin and deep basins.
4. Effect of gas on physical properties of sediments.
5. The effects of man's activities (e.g., dumping and mining) on shelf sediments are relatively unknown.
6. The in situ sediment geotechnical properties are largely unknown.

Technology needed

Standardization of tests between different laboratories.
Development of in situ geotechnical probes.

Comments about type, amount, time frame of funding, priorities and responsibilities

Coordination between industry and academia is very poor. Industry is providing minimal funding for its needs. Some money is available for instrumentation, but not for well-planned scientific-engineering investigations at sea and so subsequent data analysis and synthesis is poorly funded at present.

Priorities should include:

1) technology transfer between industry, military, government and academia for improved biological and geochemical studies
2) long-term monitoring of margin and deep sea for all sediment properties and changes with time
3) standardization of techniques among labs
4) comparison of in-situ and laboratory measurements
5) detailed precision bathymetric and slope mapping.

We could study foreign analogs of U.S. environments and problems to best make use of the money we have.

PROBLEMS - SEDIMENT CHARACTERISTICS - GEOCHEMISTRY

What are the biological, chemical and geotechnical inter-relationships within bottom sediments and how does man impact these relationships?

Knowledge gaps

More study is needed on the processes of absorption and adsorption of small particles onto larger ones and on the transport, deposition and release of toxic materials. Little is known of the flocculation history of particles -- the chemical nature of flocculation is poorly known.

Comments on type, amount, time frame of funding, priorities and responsibilities

NSF's Geochemistry Program, according to some, doesn't cover the entire area of geochemistry and no other agencies fill in this gap. Priorities should be to quantify some chemical measurements, e.g., porewater geochemistry.

APPENDICES

APPENDIX I

Dear :

On October 10, 11 and 12, 1979, the National Sea Grant College Program is sponsoring a Workshop on Marine Geology in the Next Decade to be held at the Woods Hole Oceanographic Institution in Massachusetts. Because of your active involvement in either research or management aspects of marine geology, you are asked to participate in this workshop. The primary objective of this workshop is to discuss possible future uses of U.S. bounding waters in order to develop a plan, or framework, for marine geological research in the next decade. The plan should include the knowledge gaps (questions which need answering), equipment and facilities needed, the accuracy or precision required of the answers, time scales involved, and probable costs.

The workshop was motivated by the increasing need for the U.S. to use the varied aspects of its offshore region, primarily through exploration for resources, increased shipping, offshore facilities, etc. This utilization places increasing emphasis on expanding our knowledge of marine geology in these bounding waters.

Enclosed are a prospectus for the workshop, outlining the objectives, organization and final products desired, and a tentative agenda. In addition, a workshop questionnaire is provided to be returned by August 15, 1979, so we can make some final arrangements. After that date the final workshop agenda and other information will be provided.

We will make lodging reservations for those who desire it at a local motel. If a need is indicated on the questionnaire, a bus will be made available to shuttle participants between Woods Hole and Boston. We have an extremely small amount of travel funds available and will try to help those with special needs. For many, your friendly local Sea Grant Program should be helpful in this regard.

We hope you will be able to participate in this workshop and, in any case, we welcome comments or suggestions for its improvement.

Sincerely,

WORKSHOP COORDINATING COMMITTEE
David A. Ross
David G. Aubrey
Donald F. Squires

PROSPECTUS

MARINE GEOLOGY IN THE NEXT DECADE
A Discussion and Workshop

Premise

In the approaching decade there will be an increased need for the U.S. to use the varied aspects of its offshore region, primarily through exploration for resources, increased shipping, offshore facilities, etc. Such utilization will require an understanding of many topics of marine geology (including biology and engineering aspects) to a degree greater than is now often possible. This need for increased understanding presents new challenges and opportunities for the university research community. We propose a workshop to define some of the future problems and the mechanisms for their solution.

A 2-1/2 day meeting (October 10, 11, 12, 1979) is proposed to identify and discuss the nature of geological and geologically-related problems in need of solution to permit improved utilization of U.S. marine resources in the coming decade. In keeping with National Sea Grant objectives, "... to increase the understanding, assessment, development, utilization, and conservation of the Nation's ocean and coastal resources ... " (P.L. 94-461), the meeting is sponsored by the National Sea Grant College Program at the Woods Hole Oceanographic Institution.

Objectives

Objectives of the workshop are to develop a plan, or framework, for marine geological research based upon more effective utilization by the U.S. of its offshore regions. The plan, or framework, will include: the knowledge gaps (questions which need answering), equipment and facilities needed, the accuracy or precision required of the answers, the time scales involved, and probable costs. It should be noted that most marine geologic research previously supported by Sea Grant has emphasized coastal zone erosion and estuarine problems. This workshop plans to focus on future problems and opportunities in the more offshore areas.

This plan, or framework, should primarily identify that research most suited for universities to pursue. Secondly it should identify what problems are most amenable to solution by a university-industry research partnership. Because of the Sea Grant orientation, a tertiary objective will be identification of means of raising at the local program level, the priorities of marine geological research and improving the quality of those proposals.

Organization and Mechanics

On the premise that small groups are more productive than large ones, the workshop will be numerically limited and aimed towards a few selected subject areas directed toward prospective uses likely during the decade of the 80's. We hope to have approximately 40 participants. Subject areas will tentatively be: shelf sediment transport (physically and biologically induced) and its possible effects on offshore activities; mineral resource assessment; and engineering geology. Historically, universities have been on the leading edge of scientific progress. Recognizing that possibility, a fourth section could address visionary uses and needs. These four categories are arbitrary and general and we look to the participants to sharpen our focus in these or other areas. Prospective uses or needs include (but are not limited to): marine phosphate mining, deepwater ports, and petroleum production in frontier regions.

We realize the difficulties of travel nowadays and feel that most people would find it easier to arrive in the late afternoon or evening. Thus, it seems best to start with a brief evening session on the 10th. This first session could be used to initially identify the critical problems and challenges that will be the focus of the next two days of discussion. Those that can't make this evening session can add their input on the following morning (or send it ahead). We anticipate dividing into several groups (with Chairmen and rapporteurs) to make a first draft of a plan for the evolving subject areas. This will be followed by open discussion among the entire group and reconsideration and further modification of the plans. We anticipate finishing by 5:00 P.M. on the 12th.

To develop our plans this far I have asked Dr. Don Squires, Director of the New York State Sea Grant Program, and Dr. David Aubrey of Woods Hole Oceanographic Institution to be initial members of a steering committee. Additional committee members will be added during the workshop.

We think it would also be valuable to have some participants who are knowledgeable in marine policy and will invite some people from this field.

Product

Workshop session chairmen, together with the Steering Committee will provide a final polish and collation of the individual reports, following the Workshop. This final document will be provided to the Director, National Sea Grant College Program, other appropriate groups and individuals and the participants.

Preparation

You are being invited because of your present management responsibilities or your research activities and interests. Therefore, we believe you are on top of the present level of knowledge and state-of-the-art. We anticipate participants to come mainly from the university research community but are also inviting representatives from industry and government laboratories and agencies such as NOAA, Interior, ONR and NSF. To make most efficient use of your time at this workshop, you probably should have some familiarity with several recent reports addressing research needs concerning use of U.S. waters (a short list is attached). For university personnel, travel support should be available through your Sea Grant Program. We will have limited funds available. A subsequent mailing will provide a final agenda, a list of participants and logistic matters.

While the organization and mechanics described above sound locked in concrete, they are not, especially if there are better alternatives. Consequently, we ask several questions: 1) Can you participate and to what extent? 2) Do you have suggestions to make to our plan? 3) What are the priorities for the subject areas (or prospective use areas) you wish to discuss? We would like your response by 15 August 1979.

Sincerely,

David A. Ross

18 June 1979

WORKSHOP ON MARINE GEOLOGY IN THE NEXT DECADE
QUESTIONNAIRE

(Please Return by 15 August 1979)

Name:

Address:

Will you be able to attend the workshop on October 10, 11 & 12, 1979? YES____ NO_____

Do you want us to make lodging reservations for you? (The available rooms are doubles.) YES ___ NO ___ We definitely need your response by 15 August for room reservations.

Would you make use of a special bus shuttle between Boston and Woods Hole before and after the workshop? YES ___ NO ___

Any specific comments on areas suggested for discussion or alternative recommendations?

Suggestions for other workshop participants:

General Comments and Suggestions:

APPENDIX II

August, 1979

Dear :

We are pleased that you will be able to attend the Workshop on Marine Geology in the Next Decade to be held at the Woods Hole Oceanographic Institution on October 10, 11 and 12, 1979. The response to the workshop has been favorable; we hope the enthusiasm will make this a successful gathering.

To freshen your memory, the primary objective of the workshop is to discuss possible future uses of the U.S. marine environment* in order to develop a plan, or framework, for marine geological research in the coming decade. The plan should include the questions which need answering, equipment and facilities needed, the accuracy or precision required of the answers, time scales involved, and probable costs. The research may be either basic or applied and may involve industry and/or the academic community. The motivation for the workshop came from the increasing need for the U.S. to use the varied aspects of its offshore region, primarily through exploration for resources, increased shipping, offshore facilities, etc. This utilization places increasing emphasis on expanding our knowledge of marine geology in our offshore waters.

Enclosed are several items of interest, including a list of workshop participants. We have tried to incorporate suggestions for additional participants, which some people have provided. In addition, a revised workshop agenda is included, along with tentative working groups. Please call or mail in any additional suggestions or improvements you would like to see in the program.

We are soliciting written statements from the participants outlining, in advance, their input into the problems which this workshop is addressing (see the attached questionnaire). These advance statements,

---

*Marine environment, as defined by NOAA in the Federal Register (V. 44, N. 141, Friday, 20 July 1979, p.42709) means any or all of the following: the coastal zone ...; the seabed, subsoil and waters of the territorial sea of the United States, including the Great Lakes; the waters of any zone over which the United States asserts exclusive fishery management authority; the waters of the high seas; and the seabed and subsoil of and beyond the Outer Continental Shelf.

which we would like to receive by September 15, will help us organize the working groups more effectively, and insure that everyone's interests are covered as far as possible. If you are unable to mail your ideas, please call them in to us (Ross: 617-548-1400, ext. 2398; Aubrey: 617-548-1400, ext. 2852; Squires: 518-474-5787) so that we can draw on your ideas.

We will be sending you, in a few weeks, some excerpts from recent reports and documents that should provide a good background for your participation at the meeting.

A logistics letter will be mailed in September detailing tentative working group assignments, information on shuttle bus schedules, lodging arrangements, and other last minute items. We have arranged lodging for those who indicated an interest in their previous questionnaire. If your lodging requirements should change, please let us know as soon as possible.

Thank you for your interest in the workshop. We hope to make it a productive and worthwhile affair.

Sincerely,

WORKSHOP COORDINATING COMMITTEE
David A. Ross
David G. Aubrey
Donald F. Squires

QUESTIONNAIRE

(To be returned by 15 September 1979)

1. In your opinion, what are the major broad topics which must be researched in the following ten years in order to better define the marine geology of U.S. marine environments?

2. What are the specific experiments or theoretical work which you envision in order to resolve the above problems?

3. Other comments or suggestions:

Name:

Address:

August, 1979

Dear :

This letter is a follow up to an invitation for a Workshop on Marine Geology in the Next Decade which was mailed to you in June of this year. The workshop, which is to be held at the Woods Hole Oceanographic Institution on October 10, 11 and 12, 1979, would benefit from your participation. We are writing to you since we have not received any response to our first letter. In case you did not receive the invitation, please let us know and we will send you another as soon as possible. If you have received the invitation and have been unable to respond, we hope this letter will serve to renew your interest in the workshop.

To freshen your memory, the primary objective of the workshop is to discuss possible future uses of the U.S. marine envirnment* in order to develop a plan, or framework, for marine geological research in the coming decade. The plan should include the questions which need answering, equipment and facilities needed, the accuracy or precision required of the answers, time scales involved, and probable costs. The research may be either basic or applied and may involve industry and/or the academic community. The motivation for the workshop came from the increasing need for the U.S. to use the varied aspects of its offshore region, primarily through exploration for resources, increased shipping, offshore facilities, etc. This utilization places increasing emphasis on expanding our knowledge of marine geology in our offshore waters.

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WORKSHOP COORDINATING COMMITTEE
David A. Ross
David G. Aubrey
Donald F. Squires

MARINE GEOLOGY
IN THE NEXT DECADE WORKSHOP

Woods Hole Oceanographic Institution
Woods Hole, MA 02543
October 10-12, 1979

SELECTED READINGS

Table of Contents

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March 1979

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50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-80-19	2.	3. Recipient's Accession No.
4. Title and Subtitle THE USE OF THE COASTAL OCEANS IN THE 80'S: OPPORTUNITIES FOR MARINE GEOLOGY			5. Report Date April 1980 6.
7. Author(s) David A. Ross and David G. Aubrey			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Woods Hole Oceanographic Institution Woods Hole, MA 02543			10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G) #NA-79AA-D-00102
12. Sponsoring Organization Name and Address Department of Commerce, NOAA Office of Sea Grant			13. Type of Report & Period Covered Technical 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

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17. Document Analysis a. Descriptors

1. Marine Geology Research Prospects
2. Oceanographic Research - United States
3. Marine Geological Resources

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 64
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

Woods Hole Oceanographic Institution
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I. Ross, David A.
II. Aubrey, David G.
III. #NA-79AA-D-00102

This card is UNCLASSIFIED