Proceedings of the Marine Minerals Workshop

March 23-25, 1976
Silver Spring, Md.

Sponsored by:
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

September 1976
Rockville, Md.

U.S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary

National Oceanic and Atmospheric Administration
Robert M. White, Administrator

PREFACE

The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) established an Office of Marine Minerals (OMM) in September 1975 as a focal point for NOAA's expanding programs in marine minerals. One of the first tasks which OMM set out to achieve was to determine and summarize all of the major marine mineral activities sponsored by NOAA to date in a logical array of categories. Summaries of these activities and a brief description of the individual projects upon which these summaries are based are found in these proceedings.

Another task was to elicit from those highly involved in marine mineral activities throughout the U.S. their concerns about obstacles to marine mineral development and recommendations for facilitating the development of a marine mining industry. A description of these concerns and recommendations is also contained in these proceedings.

Accordingly about 80 experts from industry, government, academia, and the public were invited to a Marine Minerals Workshop, which was held during March 1976 in Silver Spring, Maryland. This is perhaps the first time such a large distinguished group ever assembled for the primary purpose of addressing marine mineral problems covering such a wide spectrum of mineral commodities.

The resources addressed included manganese nodules; sand, gravel, and shell; placers; and phosphorite and hard rock. The problems and needs of each resource were examined from four points of view: environmental assessment; economic and legal assessment; resource research and assessment; and technology development.

The time scale of expected development by U.S. industry of each of these commodities is different. Commercial production of manganese nodules is expected to occur in the early 1980's. The commercial production of offshore sand and gravel will probably take place off the U.S. before placer mining but after the commencement of manganese nodule mining. The mining of marine phosphorite and oceanic crust metallic deposits is expected to take place after placers.

While the problems slowing down the development of each of the commodities differ from one commodity to another because of the nature and location of the resource, there are various commonalities to the problems, when examined from a broad perspective. For example, two major problems facing the miner for both deep ocean and offshore minerals pertain to the environment and to the need to establish a proper legal/investment climate. In addition, reconnaissance survey information has been cited by the offshore minerals industry as having a high priority.

It is the intention of NOAA to implement as many of these recommendations as possible within reasonable budgetary constraints. It is our hope that the material contained herein will also provide useful information to Government agencies, the Congress, industry, academia and the public in general.

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I

Objectives of the Marine Minerals Workshop

Amor L. Lane
Acting Director
Office of Marine Minerals

1. Welcome

May I take this opportunity to welcome all of you to this Marine Minerals Workshop. Many of you have traveled far and wide to come here, thereby giving up several days of your precious time to participate in the deliberations of this important subject.

Those of us involved in marine minerals affairs know that our nation is on the threshold of significant actual ocean mining in certain areas and that discussions which not too long ago were very much academic and speculative are now becoming more definite and are, accordingly, provoking serious consideration by Government administrators.

My opening remarks today will be directed towards four subjects:

- The Need for Marine Mineral Development
- Objectives of NOAA in Marine Minerals
- The New NOAA Office of Marine Minerals
- The Nature of This Workshop

2. The Need for Marine Mineral Development in the United States

I am confident that I do not have to tell this group the potential importance of marine minerals to the economy and welfare of our nation. The entire U.S. economy is based on minerals. According to the Bureau of Mines in 1975, the value of the metals and non-metallic raw materials produced in the U.S. (not including fuel) were valued at the mine site at about $13.5 billion. These materials provide the support for our Nation's Gross National Product of $1.5 trillion. So one can readily detect the catalytic effect of minerals on our economy.

But what is the supply problem existing today? A Geological Survey paper entitled, Mineral Resources Perspective 1975, summarized today's outlook as follows:

> "Our problem is simply that the United States does not have an adequate known domestic supply of all the minerals needed to maintain our society for the foreseeable future. We never have had all we needed, but in the past we could easily obtain materials from abroad. Today we meet a smaller percentage of our needs from domestic supplies, and minerals from overseas are increasingly costly and, in some cases, of uncertain availability."

In fact, foreign sources cannot contribute as readily as before. Again quoting statistics from the Geological Survey,

> "Patterns in world mineral supply and demand which had persisted for some four decades began to change radically after World War II. Between 1945 and 1972, world consumption of 18 basic mineral commodities increased about six times, whereas U.S. consumption less than doubled. Starting from a far lower per capita base, both the other developed countries and the more advanced developing countries are catching up in industrial production. Furthermore, world population is multiplying more rapidly than the U.S., placing even more demands on limited mineral supply."

And what is our outlook for the future? According to a 1974 Report of the Council on International Economic Policy, the United States continues to be ever more dependent on foreign sources of supply for essential mineral raw materials. In 1974, the Nation was more than 90 percent dependent on foreign sources for its consumption of seven commodities. Based on trends of the last decade, forecasts for the year 2000 indicate that we shall then be completely dependent on imports for significantly more than seven commodities.

These are the types of predictions that compel Government policy makers and industry to look to the oceans for alternate sources of supply. In fact, in contemplating the international political trends of our times the wise course of our nation is to have as many options as possible.

Up until now I have been talking about the total mineral picture, but with most of my remarks having been directed to metals in particular.

However, our non-metallic minerals also occupy a very important part of the economy. For example, sand and gravel production throughout the U.S. amounted to 979 million tons in 1974 with a mined value of $1.5 billion. The value of the finished products making use of sand and gravel amounted to about $9 billion (finished products including sidewalks, highways, etc.) To indicate the magnitude of annual production of sand and gravel one could, using this annual output, build a wall 3 feet wide by 6 feet high which would extend from the earth to the moon. Another way of looking at this annual amount of production is that this could also be used to build 2,300 Washington Monuments.

The importance of sand and gravel to the group here is the fact that offshore sand and gravel may soon be economically attractive in certain localized metropolitan centers around the U.S. where nearby land sources are becoming scarcer and the more remote potentially available land locations for sand and gravel are becoming too costly due to the transportation costs.

But in stating the importance of fostering the development of marine minerals, it is generally understood that it is equally as important to produce minerals in such a manner as to be compatible to the maximum extent possible with our environment. Indeed we have the rare opportunity at this moment in our history to achieve this goal without the necessity for costly retrofit programs, because unlike most activities, ocean mining in this country has effectively not yet begun.

3. Objectives of NOAA in Marine Minerals

Last September the Commerce Department established an Office of Marine Minerals in NOAA to serve as a focal point for NOAA's new and expanding programs in marine minerals.

One of the first tasks facing this Office was to reexamine objectives for the Commerce Department in this area.

We see the objective of Commerce is to foster the balanced development, conservation and management of marine mineral resources. But this encompasses such widely diversified subjects as industry assistance, environmental quality, and resource research and assessment, not necessarily in that order.

We see Commerce's role in industry assistance as including the promotion of a favorable investment climate for the U.S. marine mining industry, providing for technical services, and promoting technological advances. In environmental quality it is to evaluate and predict the potential environmental impact of marine mining systems and operations and to develop adequate environmental safeguards. In resource research and assessment, it is to provide a better understanding to aid in locating and developing marine mineral resources and in selective areas to provide support for the inventory and assessment of the potential of such resources. (In this latter subject of resource assessment, we do look to the USGS as being the primary Federal organization to be concerned with assessments.) We are hopeful that the results of this workshop will help us to sharpen the statement of objectives.

4. Twin Challenges Facing the New Office of Marine Minerals

Of course, we have never entertained any thoughts to try to cover all minerals in all aspects of our first year of operation, but rather to concentrate our efforts. In fact, when our new Office was created, we were immediately confronted with two tasks:

- Attending to certain immediate needs.

- Starting to plan ahead for future years.

a. Attending to Certain Immediate Needs

Attending to certain immediate needs involved (among other things): (a) examining how and what Commerce could contribute towards the solution to the uncertain investment climate currently facing the U.S. deep ocean mining industry; and (b) helping to get our environmental assessment programs underway.

With respect to the immediate need encompassing the subject of environmental quality, this has been an exceedingly important area. I am specifically referring to three aspects:

- The DOMES[1] program itself which is being carried out by the Environmental Research Laboratories.

- The development of preliminary environmental guidelines based on the results of DOMES I plus inputs from other sources.

- The evaluation of the effects of onshore processing of manganese nodules in the Coastal Zone.

On the subject of our onshore processing effects study, this will be done under contract. The assessment will be done in three phases. The first phase requires the characterization of onshore processing plants and their outputs including the associated required transportation and waste disposal systems. The second phase involves the selection of several representative sites where it would appear locating a processing plant would be logical. And the third phase consists of environmental and socio-economic studies for each specific site. Ocean disposal of wastes will be considered as an alternative to land disposal. Similarly, at-sea processing will be considered as an alternative to onshore processing. This three phase approach is necessary because actual environmental and socio-economic effects from development depend considerably on the specific site or geographical area. It is anticipated that request for proposals for Phase I will be made in the next few weeks.

b. Starting to Plan Ahead for Future Years

In carrying out the responsibilities of a new Office it is clear that a major portion of one's efforts should be addressed to advanced planning for FY'77 and FY'78 and beyond. Where should we focus our efforts, our funds? How should we go about stimulating interest and activities by our nation's universities, our oceanographic institutions, and industry at large. Obviously, extreme care should be taken to develop programs which are responsive to the nation's needs. But to do this properly, we need a handle on just what has been done in the past. And so we have convened this Workshop of distinguished participants all of whom are here by invitation. This is the most significant gathering ever assembled for the sole purpose of examining NOAA's marine minerals programs, and to look ahead for our nation's needs.

5. Nature of the Conference

a. Objectives

The three major objectives of this workshop include the following:

- To provide an information base of past and present marine mineral-related activities sponsored by NOAA

- To encourage better communications among the principal investigators conducting marine mineral-related activities

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[1] DOMES-Deep Ocean Mining Environmental Study. Current planning is to split it into two parts: Phase I (DOMES I) and Phase II (DOMES II).

- to develop information regarding the future direction of existing programs and activities needed to further develop marine mineral resources in an environmentally safe manner.

b. NOAA's Capabilities

All of the marine mineral activities to be reported here today have resided in the Sea Grant or Environmental Research Laboratories (ERL) components of NOAA. The major new program launched in FY 1976 is the Deep Ocean Mining Environmental Study (DOMES) for which $3 million was appropriated for Phase I. This is being done by our ERL component. This study will assess the pre-mining environment of selected areas in order to be able to predict the impact of mining and also to provide sufficient information to be able to write preliminary environmental guidelines for at-sea mining.

In addition, in FY 1976 mineral resource-related programs will be sponsored by NOAA's Office of Sea Grant at a level of approximately $550,000 (with matching funds included).

However, other components in NOAA have important contributing roles to play. These include the National Marine Fisheries Service, the National Ocean Survey, the Environmental Data Center, the National Weather Service, the Office of Coastal Zone Management, the National Environmental Satellite Service, the Manned Undersea Science and Technology Program, and the Data Buoy Program.

Agencies within the Commerce Department which have programs relevant to marine minerals include the Maritime Administration, the Domestic and International Business Administration, Economic Development Administration and the National Bureau of Standards.

The Secretary of Commerce also has an Advisory Committee on Marine Petroleum and Minerals made up of distinguished representatives from industry, academia and environmentalists. Committee liaison is also maintained with various interested Federal agencies. The Advisory Committee helps to assure information exchange with segments outside of Government, helps to take advantage of the best knowledge and judgement available, and helps to assure that Commerce research is relevant and responsive to the needs of the industry and the nation at large.

c. Modus Operandi

(1) Why focus on NOAA

The objectives of the Conference emphasize previous NOAA sponsored research and the desired directions for future NOAA's programs. This is not to say that we are not interested in what the rest of Government should sponsor. Indeed I would anticipate that this Workshop will have spillover. But we have to start somewhere and to get a handle on what needs doing, we thought the simplest way would be to focus on NOAA's programs and plans at this time.

(2) The Matrix Approach

As you know, the Conference is addressing four commodities; manganese nodules; sand and gravel; placers; phosphorite and hard rock minerals.

We are also examining each commodity from four points of view: environmental, legal/economic, resource research and assessment, and technology. This makes for a 4X4 matrix giving 16 elements; so we will have 16 summarizers today.

We could have invited all of our previous principal investigators to speak but this would have been unwieldy and would have required a much longer workshop. Instead, we asked all of the principal investigators for a particular matrix element to submit their material, reports, abstracts, and publications to the corresponding summarizer. I wish to note that many of these principal investigators are in the audience and participating in this Workshop.

(3) Today's Plans

We recognize that some of the matrix elements will have many projects which NOAA sponsored while others will be sparse. The reason they are sparse may be there is no need for many programs or that required programs were not sponsored or proposed. We deliberately built into today's presentations this probability of an unbalance. Some summarizers may have much to say; others will have little to say, but we wanted to find out where we stood. We wanted as accurate an inventory of past and current NOAA sponsored programs as possible. I wish to add that the summaries are not intended to be critiques, but rather to show what was done.

We will be passing out the summaries four at a time as we proceed into the day. Please note that the summarizer will not necessarily read his entire paper if the paper takes longer than 15 minutes. On the other hand, there may be some summarizers who have something to add or modify since submitting his paper to us. Please consider these papers as preprints. The final version will be printed in a Conference Proceedings, but we did want at least the preprints to be available and in your hands for use to facilitate more intelligent discussions today and for use in tomorrow's panel meetings.

You should also note that some projects that are being summarized have broad applicability to several different commodities, particularly some of the technology projects. In addition, some projects had multiple objectives. We have, accordingly, in some instances, asked more than one summarizer to review a given project which might be relative to his commodity assignment. This will lead to some duplication, but I leave it to the summarizers to take note of this in order to adjust their verbal presentation, if need be, and thereby minimize unnecessary duplication in the verbal presentations.

Tonight we have a dinner preceded by a reception. I'll tell you more about this later.

(4) Plans for Tomorrow and Thursday

About tomorrow and Thursday. . . as you should know by now, we are splitting into the four commodity panels tomorrow, and into a separate room for each. You should have received by now an indication of which panel you will be expected to participate in.

Please note also that we have invited a few representatives from each of three sister agencies: The Department of Interior, Corps of Engineers, and the NSF (IDOE Program). As I just said, although it is NOAA sponsored programs that we are reviewing today and the thrust tomorrow is what programs should NOAA be focusing on in the future, nevertheless it is obvious that we are doing all of this in the context of what our nation needs to do. So it is obvious that we must have other agency representatives to help reduce unintentional duplication and to help maximize coordination.

We have also invited representatives from NOAA's major line components to be available at Wednesday's Commodity Panel meeting in order to help answer questions. We have asked industry people to be present at this workshop in order to help us match our programs with their efforts and help guide us as to what constitutes high priority programs.

Finally, in addition to current and past NOAA sponsored researchers, and government and industry representatives, we have also invited additional specialists to help round out the expertise we think is needed. This includes environmentalists (who in turn are comprised of scientists, lawyers, and public organization representatives in general).

We expect that your presence here these 2 1/2 days will provide enormous benefits to NOAA. We are hopeful that you will have found the time well worth it for yourselves.

Again, our appreciation for your taking out all of this time from your busy schedules to attend this workshop.

II

Reports of the Commodity Panel Sessions

On

- Manganese Nodules
- Sand, Gravel, and Shell
- Phosphorite and Hard Rock
- Marine Placers

These reports reflect the major findings of the Workshop Commodity Panel Sessions conducted March 24. The reports were prepared at the conclusion of the day's sessions and presented for comment to the Workshop as a whole on March 25. Panel members were given subsequent opportunity to present written comments on the report of their session. The final reports which follow reflect these comments.

SUMMARY

NOAA MARINE MINERALS WORKSHOP

MANGANESE NODULE COMMODITY SESSION

MARCH 23-25, 1976

INTRODUCTION

The development of the deep ocean manganese nodule resource is being advanced at a very rapid pace by various international industrial consortia. In most cases the programs are well beyond the stage of fundamental research and development and at present are in the engineering development phase leading to the verification of technical and economic feasibility prior to the start of construction of commercial systems. In the next two to three years, it is expected that up to four tests of mining systems at actual Pacific Ocean mine sites will be undertaken. The other principal area of technological development, the extractive metallurgical processing technology, has been proven at pilot scale and the next several years will see the operation of demonstration size plants for verification of processes and for production of products for market evaluation. In conjunction with these activities, industrial survey ships will explore mine sites to determine the reserves and confirm the sites as ore bodies.

In light of the above status, session participants examined the principal areas of Environmental Assessment, Resource Research and Assessment, Technology Development and Economic and Legal Assessment to identify and to assign priorities to federal research needs associated with fostering and encouraging the orderly and safe development of this resource. It is believed that the areas identified are important but may not be inclusive, since only a very short time was available for the exercise. However, a basis for discussions did emanate from various sources which do represent a vast storehouse of information and effort. The following previous presentations and reports assisted in providing a basis for the initial identification of activities:

- The recommendations by Summarizers of the NOAA Marine Minerals related activities.
- The information presented at NOAA's Oceans and National Economic Development Conference in Seattle in 1973.
- The National Academy of Engineering Report (1975) on "Mining in the Outer Continental Shelf and in the Deep Ocean".
- The National Academy of Engineering Committee on Sea Floor Engineering Background Paper (1975) "National Needs, Current Capabilities and Engineering Research Requirements - Offshore Mining Industry".

Although a primary objective of the deliberations was to suggest technical and other efforts to be undertaken either directly or indirectly by NOAA's Office of Marine Minerals, the session participants did not restrict or limit the discussions to only those topics that might come under NOAA's cognizance. Rather, the discussions were quite general in this regard, and identified areas of general government activity. The decision, as to which agency is the proper one to undertake the work, was left to the Office of Marine Minerals to pursue.

The session's modus operandi included a general discussion of the manganese nodule resource, the interrelationship between NOAA activities, particularly DOMES, and the NSF IDOE Sea Bed Assessment Ferro-Manganese Nodule Program, the identification of problems or gaps in existing research, and the preparation of a list of recommended research and other actions. The conclusions of the session have been summarized in a tabular format, Figure 1, in which the items are listed, classified as to near and long term projects, and identified as to importance or priority.

The program shown on this Summary represents, as best as can be expected of such a diverse group, a consensus of what types of programs should be undertaken or supported by government agencies. In many areas the selection of an activity and its classification was recommended unanimously. In other cases the inclusion of an activity and its priority was decided by marginal majority opinion and is so noted.

ENVIRONMENTAL ASSESSMENT

The subject of environmental assessment centered around the NOAA Deep Ocean Mining Environmental Study (DOMES)

Phase I, presently in progress. Further important work on the subject is needed to go beyond the base line and predictive work of DOMES I. These will involve the monitoring of the planned pilot mining tests and the subsequent commercial operations. In addition, the panel identified the need for environmental impact assessment work related to possible at-sea disposal of solid wastes from nodule processing and for studies and research to develop possible beneficial uses of the solid wastes. Also, it was recommended that NOAA work should interface with the activities of the NSF IDOE program and with the programs of other government agencies responsible for environmental impact work associated with the land based nodule processing plant operations.

- <u>DOMES II</u>

  This project should include the government/industry cooperative effort to acquire and evaluate data on the changes and disturbances of the deep ocean marine environment, caused by pilot nodule mining operations. The monitoring of such mining tests will commence in the first half of 1977 and, therefore, planning for the activity should commence now.

- <u>DOMES III</u>

  Since the pilot mining tests will be of relatively short duration, the long term effects of nodule mining will only become evident when the first commercial mining operations begin. As these operations are expected to begin as early as 1981-82, the appropriate NOAA efforts to monitor commercial mining should be programed at this time.

- <u>At-Sea Disposal of Solid Wastes of Nodule Processing Plants</u>

Some of the planned nodule processing technology will produce clean, inert solid wastes which can be disposed of at sea as well as on shore. A typical one million (dry) ton per year plant, processing nodules for manganese, copper, nickel, and cobalt could produce between 500-600 thousand tons per year of such residue. Some other operations, which will not produce a manganese product at first, probably will decide to set the tailings aside as a potential reserve for manganese. Although the disposal of wastes at sea is covered under the existing Ocean Dumping Act, it was decided, by a close majority, that it would be appropriate for NOAA to study the effects of dumping the on-shore processed nodule residue at sea, but on a low priority basis.

- <u>Beneficial Uses of Solid Wastes from Processing Plants</u>

A potential for converting a liability into an asset exists if the solid, disposable nodule residues can be utilized for beneficial purposes. It was recommended that NOAA undertake such studies, although some work in this area is already being sponsored by the Industry at several Universities. The potential applications include: Clean land fill, agricultural top soil, high density construction aggretates, etc. This work was classified as a long range, low priority item.

- <u>IDOE/DOMES Interface</u>

In many areas, such as data collection, equipment, ship tracks, etc., the work of the NSF, Seabed Assessment activities and the DOMES scientific programs overlap. Principal investigators of both programs also have been maintaining close contact. It was, therefore, suggested that a formal, long range contact and information exchange arrangement be set up by NOAA. This could include the appointment of a staff member of the IDOE, Ferro-Manganese Nodule Program to NOAA's DOMES Advisory Panel.

- <u>Land Based Environmental Impact Statement - Liaison</u>

To meet the requirements necessary for the preparation of the overall manganese nodule environmental impact statement (in conformance with the National Environmental Protection Act), NOAA should establish liaison and interfacing with other government agencies charged with the responsibility for the preparation of the EIS for the land processing plants. This will be very helpful during the course of the NOAA project recommended for the study of the land based impact of ocean nodule mining.

RESOURCE RESEARCH AND ASSESSMENT

Only a very small area of the world's oceans have been sampled to determine the world wide abundance and distribution of manganese nodules. Most industry survey activity has centered in the North-East Central Pacific, in order to be in close proximity to the continental United States, where the initial metallurgical processing plants will be located. Due to the high cost of ocean transportation and the need to bring all dredged nodules ashore, it becomes imperative to locate the mine sites as close to the processing plants as possible, if meaningful investment returns are to be achieved. Nevertheless, should deposits be located that have appreciably higher assays than those presently known, they may become economically attractive targets, despite increased transportation distances. In addition, factual information on the world wide distribution of potential nodule deposits is needed if valid and meaningful estimates of world wide reserves and numbers of mine sites are to be determined for use in long term planning and orderly international development of the nodule resource. In light of the above, three specific areas of Federal involvement in resource research and assessment were identified.

- Reconnaissance Surveys

  Surveys should be conducted to determine, on a broad area basis, the nature and extent of manganese nodule deposits in all oceans. Instrumentation development may be needed to enhance the effectiveness and speed of these surveys. The new instrumentation capability developed in connection with this activity might be utilized also in the (future) assessments of resource depletion of specific mine sites.

- Mine Site Sizing Criteria

It was agreed that there is not time available for the Federal government to obtain new field data for making an independent judgment on appropriate mine site sizes, before this information is needed for use by Law of the Sea and domestic legislation planners. However, the factors involved in this decision include nodule concentration and grade, topography, and seafloor engineering properties, some of which are being examined at the three DOMES I sites. Therefore, the panel recommends that NOAA use these data, as well as other data in the public domain, to make its own estimate of the area likely to be required to support a long term, commercial, first generation mining operation.

- International Cooperation

It was generally agreed that International Cooperation and information exchange on an equitable basis is desirable. However, the panel recognized an inherent difficulty in this regard. Many foreign governments support* their deep ocean mining industries, which have acquired considerable data but will not release them by the order of their own government(s). On the other hand, U. S. data obtained by Federal support can be obtained without formal cooperation, under the Freedom of Information Act. Nevertheless, the panel urged NOAA and other agencies to be alert to the potential for trading ship time, loan instrumentation, etc., for selected foreign data.

TECHNOLOGY DEVELOPMENT

The general feeling of the group was that in most instances the development of mining and metallurgical processing engineering and technology is the responsibility of industry. However, there are certain areas of technology which are sufficiently broad in scope and time required for performance, which suggest a government supported program.

- Environmental Loads

  Depending on the type of deposit and its geographic location, a set of environmental parameters (such as wind, waves, currents, etc.) exist which must be determined to establish the interactions between the environment and the mining system. The acquisition of oceanographic and

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* Due to stated urgent National objectives to obtain new and independent sources of depleted mineral reserves.

meteorological data for the determination of key environmentally induced loads in the areas where nodule mining is likely to occur is of great importance. The availability of such data will permit the design of safer and more effective nodule mining systems.

- Materials for Use in Sea Water Environment

As the mining industry and others move their operations into greater ocean depths, the selection of proper high strength materials capable of survival in this very hostile sea water environment for long periods of time becomes vital.

Areas which require a considerable amount of improvement include: Fatigue life of materials in sea water; fracture mechanics of materials exposed to sea water at high stress levels; the effects of residual stresses due to welding; the effects of erosion and corrosion of various materials when subjected to slurries containing nodules and sediments moving at high velocities in oxygen rich conditions; etc. With regard to corrosion and erosion, the development program should also include the identification of durable protective coatings.

- Mapping Systems for Sea Floor Micro-Topography

Micro-topographical maps are needed for detail resource assessment and mine development. The capability to produce these maps rapidly, accurately and automatically is a need of the deep ocean miner and others. The basic components required to assemble such a system exists, but what is needed is a system integration effort to produce a commercial version of the Scripps "deep tow". Component sub-systems include a narrow beam echo sounder for topographic measurements, a side-scan sonar to determine bottom roughness, location and shape of features such as rock outcrops and small scarps, stero photography, and an acoustic navigation system to provide accurate location. The system can include real time TV and should include a shipboard mounted automatic contour map plotting system.

- <u>Engineering Properties of Sea Floor Sediments</u>

The knowledge of the geotechnical properties of the sea floor sediments contribute to the design of the dredge head which has to survive on the ocean bottom and collect nodules. Although industry has already made studies in this area, much more information should be obtained. A better understanding of the sediments of the equatorial Pacific will permit the design of improved second and third generation mining systems. This work should be undertaken on a low priority basis by NOAA and would be of great use to industry and others.

- <u>Process Development - Fundamental Research</u>

Although the primary responsibility for the development of nodule processing resides with industry, it is nevertheless useful and constructive to conduct some basic, "bench scale", research work to identify possible new approaches and developments. This kind of activity has been traditional and successful in the development of land mineral processes and, therefore, suggests that such an effort might be fruitful for the new and unique nodule resource as well.

Work in this area might very well be coordinated with the fundamental mineralogical research of the IDOE, Ferro-Manganese program.

- <u>Process Development - Environmental Impact</u>

An area of concern to those watching the development of the nodule resource is the possible harmful effects which may occur as a result of the shore based processing activity. Although the industry has indicated that all processing presently under consideration will be designed to satisfy existing environmental guide lines, it is important to have a full understanding of these proposed processes to be in a strong position to evaluate the effects prior to the completion of the commercial plants. Accordingly, it is recommended that some effort be undertaken to study such proposed processes and their basic reagents and effluents for use in the evaluation of environmental impacts.

- Mass Physical Properties

The panel considered the possibility that certain mass physical properties (e.g., porosity, bulk density, permeability, etc.) of the sea floor sediments may influence the benthic species which live there. If such a correlation can be established, then studies of the mass physical properties at a given mine site, before and after mining, may increase the confidence of the estimates of the post-mining repopulation of the benthos - at least with respect to the species, if not with respect to the rate of repopulation. The panel recommends a high priority, long term investigation into this matter.

- Navy Technology - Transfer

The panel discussed the utility of the non-classified technology developed by the U. S. Navy in a variety of categories (e.g., acoustic sounding bottom loss, materials performance, etc.) to the developing deep ocean mining industry. If this technology could be made available and catalogued, it would be of great use to industry. In addition, panel members opined that a vast amount of classified data probably still exists in Navy archives which, if released, would be very beneficial in the early commercialization of deep ocean mining and other offshore activities. Therefore, the panel recommended the establishment of an interface in NOAA to serve as a liaison between industry and the U. S. Navy, and to insure the orderly transfer of as much of this technology as national security will permit.

- Alternate Nodule Uses

With a view toward the ever-pressing need to increase the Nation's mineral resource base, consideration was given to the potential new uses of the nodule deposits commonly found in the world's oceans and many lakes. It was reported by one panel member that nodules can absorb from 25% to 200% of their weight in SO_2; hence, the nodules might find applications as exhaust gas scrubbers in industrial and power plant stacks. Other potential uses for the nodules as catalysts were considered as well. The panel therefore recommends a long range, low priority investigation into this potential.

- Alternative Applications for Manganese and Cobalt

The panel discussed the likelihood that much of the deep ocean manganese nodule production will be geared to markets for nickel and copper. That being the case, considerable tonnages of manganese and cobalt will accumulate during processing. While the metals can be stockpiled in tailings ponds, and can be considered a resource for the future, new uses for them would increase their economic value, and would reduce the land areas needed for stockpiles. The demand for these materials for which they substitute would also be reduced. The panel recommends a long range, low priority investigation into this potential.

ECONOMIC AND LEGAL ASSESSMENT

Apart from industrial needs for activity in this area, a discussion revealed the need for the Federal government to conduct specific legal studies in order to plan better for the development of deep ocean mining on the part of U. S. citizens. Three legal and one economic short term studies were recommended:

- Alternative Law of the Sea (LOS) Arrangements

  In anticipation of a possible failure of the Law of the Sea Conference, it would be appropriate to research and analyze alternatives to a global law of the sea treaty governing deep sea mining. Each alternative should be evaluated in terms of national ocean policy as well as industrial and consumer interests. These might include bilateral and multilateral treaties.

- Alternative U. S. Laws

  Again, should International actions fail or be delayed, it would be appropriate to research issues involved in enacting domestic legislation which provides for the licensing and regulation of the U. S. citizens engaged in deep ocean mining activities. Among the problems to be addressed are: Base term and area; operating procedures; royalties and fees; work requirements; risk insurance; and, claim recognition reciprocity with other nations.

- <u>Applicability of Existing Laws</u>

  A study to identify and assemble presently applicable domestic and international law, regulations, and procedures affecting deep ocean mining would be exceedingly valuable for both Government and Industry. Among the subject matter areas which should be investigated are: Environmental protection; financing and taxation; safety at sea; labor standards; civil and criminal laws; and liability and responsibility.

- <u>Economic Impacts of Alternatives</u>

  As a means of evaluating and comparing alternative legal regimes it was recommended to research the economic impacts of the various regimes proposed to regulate the exploitation of deep ocean manganese nodules.

FIGURE 1

Manganese Nodule Recommendations
(for NOAA and other Federal Agencies)

	PRIORITIES					
	Short Term			Long Term		
	A	B	C	A	B	C
Envir. Ass.						
DOMES II	X					
DOMES III				X		
IDOE-DOMES Interface				X		
At-Sea Disposal of Process Plant Residues *						X
Beneficial Uses of Process Plant Solid Wastes						X
Land Based EIS Liaison	(X)					
Resource Research & Ass.						
Reconnaissance Surveys				X		
Mine Site Sizing Criteria	X					
International Cooperation	(X)					
Technology						
Environmental Loads				X		
Materials for Use in Sea Water *				X		
Mapping Systems	X					
Engineering Properties of Sediments			X			
Process Development - Fundamental *					X	
Processing Development - Environmental Impact					X	
Mass Physical Properties				X		
Navy Technology Transfer	(X)					
Alternate Nodule Uses						X
Mn/Co Alternative Applications						X
Economic & Legal Ass.						
Alternative LOS Arrangements	X					
Alternative U.S. Laws	X					
Existing Law, Applicability	X					
Economic Impacts of Alternatives	X					

(X) = In House, Low Cost

* = Recommended by Marginal Majority

MANGANESE NODULE COMMODITY SESSION

SESSION PARTICIPANTS

Raymond Kaufman, Chairman	Deepsea Ventures, Inc.
John Padan	NOAA - DOMES
Guenter Reichert	Lockheed Missiles-Space Co.
Frank T. Manheim	Dept. Marine Science, Univ. S. Fla.
James L. Bischoff	U. S. Geol. Survey, Menlo Park
John D. Corrick	U. S. Bu. Mines, Washington, D.C.
Murray L. Hayes	NOAA/Nat. Mar. Fisheries Service
George Peter	NOAA/ERL, MESA Program Office
John L. Mero	Ocean Resources, Inc.
Glenn Flittner	NOAA/National Weather Service
Bob Burns	NOAA/PMEL/Seattle
Jim Andrews	Univ. of Hawaii, Honolulu
Edwin M. Davin	IDOE/NSF
Thomas W. Chapman	Univ. Wisconsin
Roger G. Burns	M.I.T.
B. J. Livesay	Kennecott Exploration Inc.
H. Gary Knight	L.S.U. Law Center
George H. Keller	Oregon State - School of Oceanography
David Halpern	PMEL-NOAA, Seattle
G. W. Sheary	INCO-OMD
Adrian Richards	Lehigh University
R. J. Willard	U. S. Bureau of Mines
D. F. MacInnes	Sierra Club
Edgar L. Newhouse	OMM-NOAA
Tony Amos	LDGO
Alex Holser	Ocean Mining Administration - Interior

NOAA MARINE MINERALS WORKSHOP

Commodity Panel Report

Sand, Gravel and Shell

INTRODUCTION

The Sand, Gravel and Shell Commodity Panel met in an all day session on March 24, 1976 and reported its initial finding to the Workshop on March 25, 1976. Approximately twenty-five Commodity Panel members contributed to the discussions and written materials which resulted in the findings. This report summarizes these discussions and recommendations.

The Panel and the Workshop were guided by the three major objectives of the Minerals Workshop, placing major emphasis on a single overall objective, which summarily stated was:

> To identify problems, develop recommendations and suggest priorities for existing and future government programs and activities for development and conservation of marine sand, gravel, and shell resources. This objective was considered from the perspective of four points of view, i.e.
>
> A. Environmental Assessment
> B. Resource Research and Assessment
> C. Technology Research and Development
> D. Economic and Legal Assessment.

This report provides background as to why sand, gravel, and shell is a marine mineral of substantial importance to the nation. More importantly, the report summarizes the results of the discussions at the Workshop by suggesting the key problems from each of the four perspectives and recommends programs or activities which the Panel feels are important to the future development of marine sand, gravel, and shell resources. It should be noted that the Panel placed primary but not exclusive emphasis on sand and gravel.

BACKGROUND ON SAND, GRAVEL AND SHELL AS A MARINE MINERAL COMMODITY

Construction aggregrates are a vital part of the U. S. economy. In 1974 there were about 5600 commercial sand and gravel operations producing over 900 million tons of sand and gravel annually valued at $1.6 billion. Virtually no sand and gravel aggregate is obtained for commercial purposes from seafloor deposits, although there are notable exceptions in the New York/New Jersey area and in San Francisco Bay where sand is dredged for nearby bay fill operations. Sanko (1975) has estimated the value of sand mined in New York Harbor alone was $30 million in 1975. Further, in several coastal areas, offshore sand has been used for federal beach nourishment projects. The seafloor on the continental shelf surrounding the U. S. and its territories provides a potential alternative source for sand, gravel and shell. A modest shell industry already exists in some areas of the U. S., particularly along the Gulf of Mexico.

The U. S. Bureau of Mines expects the demand for sand and gravel to grow at a rate of about 3% per year through the year of 2000, representing nearly a two-fold increase over present production. In many areas of the country, terrestial deposits

75%

are either being depleted, made inaccessable by urban expansion, are too expensive because of increased land values, are being restricted from use by recent legislation or are not economical due to current transportation costs from increasingly remote areas. Further, as a consequence of terrestrial resources depletion and increasingly higher costs for transportation, prices for sand and gravel have been increasing at a substantial rate in recent years. Higher land values, urbanization, zoning, and environmental restrictions are all contributing factors in magnifying the problem. Hess and Cruickshank (1975) suggest that new sources of supply which are economically competitive and can be mined with minimal impact on the environment must soon be developed in order to circumvent serious shortages which are otherwise certain to come by the year 2000.

Engineering News (May 6, 1976) data indicate that carload prices of sand in 20 cities averaged $4.12 per ton (with a range of $1.35 to $5.55) (f.o.b. plant) while 3/4" to 1 1/2" gravels ranges from $2.15 to $7.50 per ton all in carlots. Based upon Bureau of Mines data supplied to the Workshop, the average value of processed sand and gravel sold or used by producers, f.o.b. plant, was $1.64 per ton; unprocessed sand and gravel was $0.54 per ton; industrial sand and gravel was $4.77 per ton. The average 1975 price (f.o.b. plant) for all U. S. sand and gravel production combined was $1.50 per ton using Bureau of Mines data by Pajalich(1975). Between 1972 and 1974, production prices have increased by about 16%, while transportation costs have increased even more. Sand and gravel is a commodity highly sensitive to transportation costs (the price of sand and gravel generally doubles for each 20 to 25 miles of truck haulage). Barging costs are approximately 5% of trucking costs to move sand and gravel, providing a part of the incentive to consider mining sand and gravel offshore. Hence, utilization of marine sand and gravel is becoming increasingly attractive, particularly in the coastal metropolitan areas, such as New York, Los Angeles, Boston, Washington, D. C., San Francisco, and San Diego.

Economic pressures combined with predicted growth demands make it prudent to seek new sources of sand and gravel that are economically competitive and sources where the mining will have an acceptable impact on the environment and be aesthetically appropriate. It is from this context that marine sand and gravel resources are being considered. Hess and Cruickshank (1975) report that U. S. reserves of sand and gravel might be increased by a factor of up to 25 if seafloor deposits are considered.

The foreign marine sand and gravel industry is highly developed in some parts of the world, such as the United Kingdom (20 million tons/year), Holland (10 million tons/year) and Japan (19% of the country's needs). An indication of the economic factors comes from U. K. dredge operations in 1970 which show capital costs of between 80¢ and $2.68 per ton of annual production capacity and operating costs (including capital pay back) of between 35¢ and 49¢ per ton. By comparison, product value for inland sand and gravel delivered to the Los Angeles Harbor area in 1968 was $2.69 per ton and is expected to exceed $6.00 per ton by 1980. Using reported costs from these operations, it is clear that marine aggregates in the U. S. are likely to be competitive with terrestrial sources in the near future, if not already.

The resource reserve in the U. S. continental margin has been estimated by various individuals as shown in the Table I and Figure I. Hess and Cruickshank (1975) suggest the apparent resource may be as great as 1400 billion tons, although this figure does not take into account the economic factors essential to supplying markets.

The existence of a technology in the United Kingdom and the Netherlands as well as the experience of U. S. dredge operators and the U. S. Corp of Engineers suggests that the capability exists to mine deposits in water depths to about 30 meters with conventional suction equipment and to 45 meters with jet-assist boosters (Hess, 1971).

Table I. Resources of Sand and Gravel in Selected Areas of the U. S. Continental Terrace as Estimated by Various Workers. (Prepared for this report by S. J. Williams, Coastal Engineering Research Center, U. S. Army)

Location	Quantity Estimated*
Maine	94 million cubic meters[a]
Massachusetts Bay	44 million cubic meters[b]
Rhode Island	108 million cubic meters[a]
Long Island Sound	100 million cubic meters[c]
Long Island South Shore	5254 million cubic meters[d]
New Jersey	2730 million cubic meters[a,e]
Delaware-Maryland	168 million cubic meters[f]
Virginia	15 million cubic meters[g]
North Carolina	172 million cubic meters[h]
Florida East Coast	2271 million cubic meters[i,j,k,l]
Southern California	458 million cubic meters[m]
Eastern Lake Michigan	"Large Quantities[n]
New Jersey (gravel)	10-30 billion cubic yards[o]
New England (sand)	450 billion metric tons[p]
New England (gravel)	31 billion metric tons[p]
California, Russian River	100 million metric tons[q]
California, Redondo Beach	5 million metric tons[r]
California, total	"Considerably less than Atlantic"[o]
Alaska, southeast	"Large Quantities"[o]
Hawaii, Oahu	370 million metric tons[s]

[a] Duane, 1968
[b] Meisburger, 1976
[c] Williams, 1977
[d] Williams, 1976
[e] Williams and Duane, 1974
[f] Field, 1977
[g] Meisburger, 1972
[h] Meisburger, 1977
[i] Meisburger and Duane, 1971
[j] Duane and Meisburger, 1969
[k] Field and Duane, 1974
[l] Meisburger and Field, 1975
[m] Field, 1974
[n] Meisburger and Williams, 1978
[o] McKelvey et al, 1969
[p] Manheim, 1972
[q] Marine Minerals Technology Ctr., Tiburon California, unpublished data
[r] Fisher, 1969
[s] Campbell et al, 1970

Note: * Some of the estimates are in nature of reserves; some are in nature of resources.

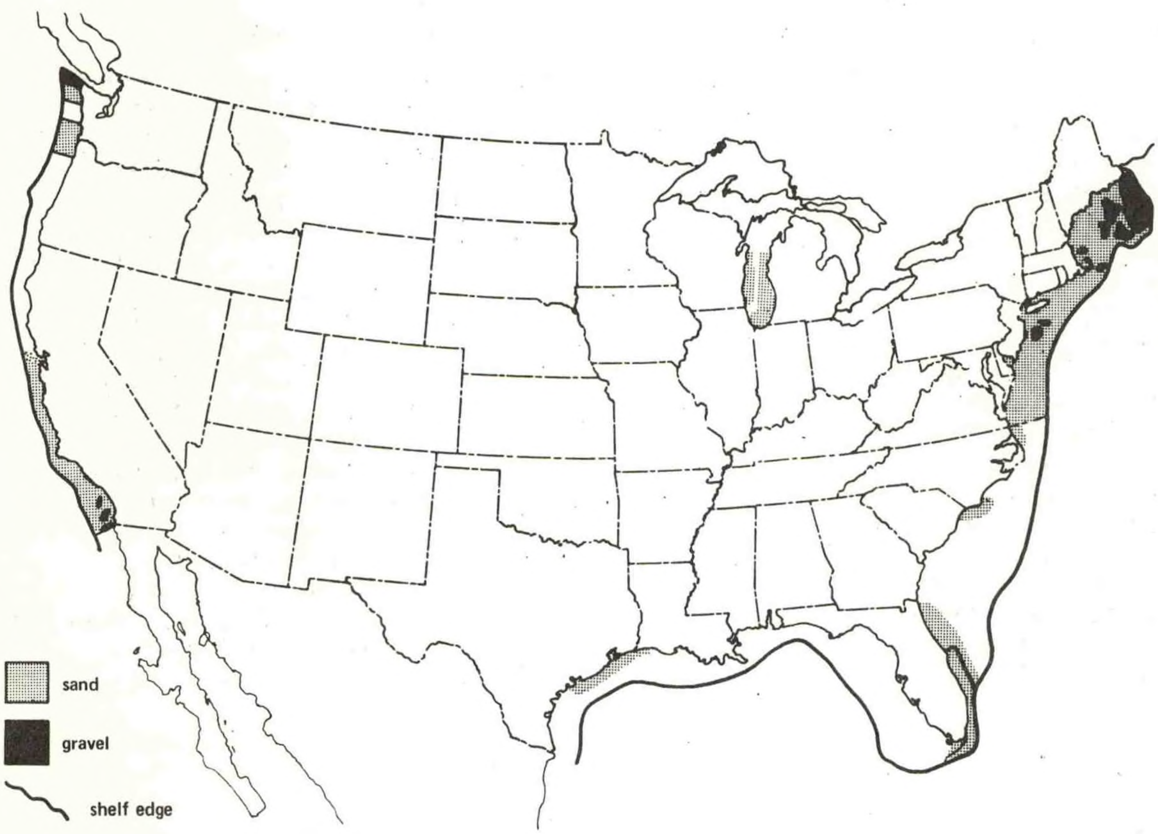

Figure 1 - Known distribution of promising areas for marine sand and gravel mining on the continental shelf.

Source: Michael J. Cruickshank and Harold D. Hess, "Marine Sand and Gravel Mining," Oceanus, Vol 19 (Fall, 1975), p.43 as modified by S. Jeffress Williams.

Alterations and disturbances to the environment associated with offshore sand and gravel mining are generally not well understood. Environmental disturbances can be classified into three categories; those associated with changes in marine ecosystems, those connected with interferences with other users of coastal waters, and of course, those which develop as a consequence of the change in the bottom topography created by resource removal. No comprehensive study has been conducted to assess the environmental impacts of marine sand and gravel mining. Some aspects of this problem are beginning to be evaluated. For example, the Ecology Branch of the Coastal Engineering Research Center (U. S. Army) is sponsoring research in several U. S. coastal areas to determine certain ecological effects of beach nourishment and of offshore dredging. Some of these results are presently available and other results are scheduled to be published in the near future. This report makes several recommendations designed to overcome deficiencies in evaluating ecologic effects.

Most U. S. coastal states have established moratoria on offshore sand and gravel mining, largely because of unknown environmental and legal problems. There presently is no Federal leasing program for development of offshore hard-mineral deposits on Federally-controlled outer continental shelf (OCS) lands (seaward of the 3 mile limit of state jurisdiction). It appears that commercial development, if it occurs, will be on Federal submerged lands (OCS), with coastal states maintaining moratoria within their 3 mile jurisdictional limit until environmental and legal issues can be satisfactorily resolved.

This brief background review is intended to set the frame of reference for the recommendations which are discussed in the several following sections.

A. ENVIRONMENTAL ASSESSMENT

Key Problem: Problems related to the environment were considered by the Panel to be the major issues limiting the growth and development of an offshore sand and gravel industry. The Panel felt that there is a lack of understanding of biological and physical characteristics and processes in the marine environment which will be affected by sand and gravel mining. Further, the environmentally related dredging permit processes and regulations are judged to be too complex, not well enough defined and so filled with uncertainties that industry finds the risks are too great for the capital investment programs necessary to develop the systems and equipment for mining. Finally, the public is aware of potential environmental issues and exerts its influence through legislation such as the National Environmental Protection Act of 1969. These three interrelated factors make the uncertainties associated with environmentally related issues so great that industry has been reluctant to commit the large capital investment necessary to develop the systems and equipment for offshore mining without some form of government assurances. Solution of the above environmental problems, coupled with creation of a favorable legal climate and workable leasing/permit provisions, must take place if a marine sand and gravel (or shell) industry is to develop.

RECOMMENDATIONS

A-1. It is recommended that the U. S. Government immediately undertake to develop prototype leasing mechanisms which will permit the establishment of commercial-scale pilot dredging operations for marine sand and gravel mining of the OCS, the purpose of which is to provide a setting in which environmental questions can be answered. These should be long-term (several years of continuous operations) and should be conducted in carefully selected offshore sites which are representative of pertinent environmental issues and which have profit potential for industry. These industry operated pilot operations should be closely monitored and be used as a means to resolve the technical, legal, environmental, economic, industrial, socio-political, and legislative problems associated with commercial sand and gravel mining in the offshore regions of the U. S. Although such pilot operations would be created largely as a cooperative effort between industry and Government, the monitoring of such operations should be designed so that both Federal and state agencies can obtain answers and guidelines to environmental questions and related legal issues. The plan should include adequate incentives so that industry is sufficiently attracted to the project that they will be willing to invest the necessary capital to establish pilot commercial-scale operations. These commercial operations likely will be for dredge and fill projects (such as beach replenishment); however, the operation should be designed to encourage operations which also supply sand and gravel aggregate to the construction industry. This recommendation is posed as a "learning by doing experiment", hence it must be a carefully planned, monitored and executed program.

The Federal Government in the course of these pilot operations and corresponding environmental studies, should evaluate alternatives which could mitigate significant environmental damage should any such environmental damage occur from these prototype leasing operations.

A-2. There is substantial experience with large-scale commercial marine sand and gravel operations in several foreign countries such as the United Kingdom and the Netherlands. The U. S. Government should sponsor and encourage programs of international cooperation to assist the U. S. in answering the many environmental questions viewed as important percusors to the establishment of an offshore U. S. sand and gravel mining industry.

A-3. There are increasingly valuable information sources within the Environmental Data Service of NOAA, the U. S. Geological Survey, Bureau of Land Management, and other public and private agencies or institutions. In the conduct of research programs or activities, the Government should encourage the use of and contribution to these data sources.

B. RESOURCE RESEARCH AND ASSESSMENT

Key Problem: A complete inventory of continental shelf sand, gravel, and shell deposits for the United States and its territories does not presently exist.

RECOMMENDATIONS

B-1. It is recommended that the government continue to completion the general reconnaissance surveys for all coasts of the United States, Great Lakes, and possessions now under way by USGS, Corps of Engineers, and NOAA. For example, the Conservation Division of the U. S. Geological Survey should be encouraged to complete its resource inventory, including the plotting on maps of potential commercial deposits and resource boundaries. All such studies should include the lateral and vertical magnitude of deposits, and their basic quality and characteristics.

B-2. Efforts should be increased to ensure that all available data (from the reconnaissance surveys, industry data, academic research, and state government surveys) are integrated to develop composite assessments of the sand and gravel resources. These composite assessments can assist state coastal zone management plans and programs, help in the preparation of environmental impact statement documents, assist government and industry in locating suitable sites for development, and identify areas for conservation. Development of a composite assessment of sand and gravel resources is an essential precursor to OCS prototype leasing of this commodity.

B-3. It is recommended that fine scale detailed survey work not be undertaken by the Federal Government except for specific government projects for which it is absolutely mandatory. As a policy, the Federal Government should limit its survey work to general reconnaissance surveys. Industry is willing to conduct those fine scale surveys associated with the commercial development of any specific site or area, but it is not likely to contribute to the development of the general inventory suggested in Recommendations B-1 and B-2.

C. TECHNOLOGY RESEARCH AND DEVELOPMENT

Key Problems: The problems associated with the technology associated with sand and gravel mining are not serious when compared with the other obstacles which must be overcome before any such mining will begin. The Panel felt that sand and gravel mining in the marine environment is not technology-limited although there are many technical problems that need attention, particularly with respect to improving operating efficiencies at greater depths. Industry appears to be willing to develop the requisite new technology as it has done in the oil and gas industry and in the mining of hard minerals such as tin, but will only do so if it can be certain of a reasonable stable socio-economic, political and legal climate, including assurances of lease tenure.

Three general recommendations can be made regarding the needs for future work.

RECOMMENDATIONS

C-1. Initiate and continue to conduct research and development to make improved tools and methods available for exploration. These should include work on:

a. Techniques to improve the acquisition of both disturbed and undisturbed samples which are truly representative and which will provide valuable assistance in arriving at an accurate three-dimensional characterization of deposits.

b. Improved methods of remote sensing by acoustic or other means to aid in resource assessment.

c. Develop improved methodologies for exploration of resource deposits.

d. Industrial Research & Development should be encouraged.

C-2. Encourage continued research and development to improve forecasting for site specific wave (with wave height and period forecasts) and weather conditions on both the continental shelf and in coastal waters. These forecasts should make note of the fact that distant weather conditions can pose serious local problems.

C-3. Studies might be conducted with American Bureau of Shipping and other classification and standards institutions to improve certification for dredges and to relate these standards with those of foreign countries so that dredges and their associated water borne systems can be designed and constructed according to certification requirements appropriate to a sand and gravel mining industry.

D. ECONOMIC AND LEGAL ASSESSMENT

Key Problems: The central legal problems relate to regulatory and permit processes associated with current interpretation of federal and state laws and statutes. The uncertainties in environmental controls and regulations are sufficiently high that industry considers marine mining a high-risk venture and is reluctant to capitalize for a marine sand and gravel industry in the offshore region without some form of government insurance or protection against lease termination. The primary economic problems relate to the high cost of meeting environmental standards, the economic risk involved, and to certain problems of onshore product handling and distribution. The present environmentally-related dredging permit process, requiring approvals of numerous Federal and state agencies, is complex and time consuming - taking up to 2 to 3 years to obtain permit approval.

RECOMMENDATIONS

D-1. It is recommended that the U. S. Government immediately undertake development of OCS prototype leasing to provide for the pilot dredging operations recommended in the environmental section of this report.

D-2. It is recommended that economic studies be made to evaluate the costs associated with the various aspects of environmental control and regulation.

D-3. It is recommended that the government should provide, in the form of guidelines to coastal states and industries, a clear statement of its position on offshore sand and gravel mining. This statement of position should be constantly reviewed to reflect any changes in technology, environmental considerations (either regional or national), and economic climate or regulatory requirements that affect the government's policy position relative to offshore sand and gravel mining.

D-4. A thorough study of the dredging permit process should be made so that federal-state procedure can be streamlined and applications can be executed within a reasonable period of time.

D-5. It is recommended that studies be made of the problems and costs associated with onshore land acquisition for product discharge, handling, and distribution of offshore aggregate.

PRIORITIES

The fourteen recommendations are all of considerable importance. However, those recommendations associated with conducting closely monitored commercial-scale pilot sand and gravel mining operations at carefully selected sites is of the highest priority. Correspondingly, the following is a priority listing of the recommendations.

Highest Priority	Very Important Priority		
A-1	A-3	C-1	D-2
A-2	B-1	C-2	D-4
B-2	B-3	C-3	D-5
D-1			
D-3			

ADDITIONAL SUGGESTIONS

1. The Panel generally defined the term "marine" to be those parts of rivers, bays estuaries, and open sea subject to tidal influence seaward of the normal baseline of mean low water. Hence, "marine" covers those salt waters or tidally influenced waters contiguous to the U. S. coast.
2. Because of the substantial interplay between the respective interests and disciplines associated with marine sand and gravel mining, programs and activities recommended above should utilize interdisciplinary teams in all cases judged appropriate.
3. In planning programs and activities associated with the recommendations in this commodity report, the Panel recommends that the beneficiaries (the end-users of data and information) of all efforts be established prior to instituting the program or activity.
4. It is suggested that NOAA and other Federal agencies concerned continue to employ the concept of utilizing mechanisms for advice and counsel inherent in this workshop.

It appears to the Panel to be a healthy and desirable function in that it provides a forum for information exchange and deliberation of key issues among concerned multidisciplinary interests of government, academia, and industry. Thus, it provides a sound basis for making rational judgements essential to formulation and execution of a coherent national marine hard-minerals program.

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Sand & Gravel
Participants List

NAME	AGENCY
Dr. Robert W. Corell (Chairman)	University of New Hampshire
James Gillespie	North American Trailing Company
Dr. Thomas A. Grigalunas	University of Rhode Island
Dr. Larry C. Harris	Hopkins Marine Station
Dr. John B. Herbich	Texas A&M University
Dr. Harold D. Hess	U.S. Geological Survey
Dr. Donald Keene	Bureau of Land Management
Mike D. McKenzie	Office of Sea Grant - NOAA
Walter Pajaclich	Bureau of Mines
Dr. Bryan Pearch	Ralph M. Parsons Laboratory
Dr. Roger Saucier	Army Engineering Waterways Experimental Station
E. F. Shiels	Zapata Corporation
Capt. J.S. St. John	Erie Sand and Gravel Company
August G. Stoeffler	Construction Aggregates Corporation
S. Jeffress Williams	Army - Coastal Engineer Resource Center
James D. Eger	University of Rhode Island
Kent Hughes	Environmental Data Service - NOAA
Dr. Thomas Austin	Environmental Data Service - NOAA
Gordon Lill	National Ocean Survey - NOAA
Paul Stang	Coastal Zone Management - NOAA
Denzil Pauli	Marine Board - National Academy of Science
Karl Jugel	Office of Marine Minerals - NOAA
Glenn Flittner	National Weather Service - NOAA
Dr. F. T. Manhein	University of S. Florida

SUMMARY

NOAA Marine Minerals Workshop
Marine Phosphorite and Hard Rock Minerals
Commodity Panel Reports

Marine Phosphorite

INTRODUCTION AND BACKGROUND

The United States is now a major exporter of phosphate, the source of which are terrestrial deposits; at this time there is no marine production. The land resources appear to be vast and to represent a virtually inexhaustable resource, but for the present this first view should be corrected due to many reservations. The known reserves are also large and if they could be produced under existing methods and mores, they would serve the United States for at least another twenty years. However, over the past five to six years, these land reserves have been steadily reduced as the nation reassesses its land use policy as society applies environmental constraints on land use, and as more detailed analyses of the resource occurs. The production of phosphatic rocks is often associated with ground water problems. Urban sprawl has moved people into areas that were originally thought to have producible reserves. This has resulted in a complete reassessment of land use by most local governments. New regulations placing environmental constraints on open cut mining have reduced the overall size of reserves diminishing what we thought were producible five to six years ago. Because of this, the twenty or more year supply may not be a truly meaningful concept.

Another important limiting aspect to our assessment of land deposits is quality of the resource. As mineralogists look more closely into the quality of deposits prior to mining, they are finding less material which is useable at the grades needed for the industry as presently structured. Another important aspect of the long term picture of phosphate supply is that at the present time approximately three-quarters of all phosphate reserves are controlled by African and Arab nations. Perturbations caused by the policies of the Organization of Petroleum Exporting Countries (OPEC) are an indication of potential geopolitical problems which could evolve around control of phosphate, and world food production.

At the present rate of use, the U.S. will become an importer of phosphate by about 1995 unless new domestic reserves and resources are discovered. Present U.S. agricultural exports, which are actually dependent upon phosphate production, have a value of about 23 billion dollars per year; of this about one billion dollars is phosphate. This agricultural portion of our foreign trade just about pays for the total amount of oil we currently import in order for our nation to maintain its present standard of living. It is an economic reality that the phosphate produced to support the U.S. agricultural output is an important part of the U.S. economy, and without it the balance of payments would shift. The consensus of this panel is that the U.S. needs to develop alternate sources for our presently known terrestrial deposits of phosphatic minerals. Because of the growing environmental constraints and competing uses for land, ". . . that phosphate we think we have now, may not be available at the time we need it".

Main areas where land production is currently taking place are the northwest interior and the southeast sections of the United States: Idaho, Montana, Wyoming, and Utah; and North Carolina, Florida, and Tennessee. The deposits of phosphate rich-rock in these areas constitute a very large resource. However, the panel found that, based on information shown it by members, the closer the resource was scrutinized, the smaller the reserves became. In the face of diminishing domestic terrestrial reserves, one is moved to ask, are there potential marine phosphate resources and where are they? The area off Georgia and adjacent South Carolina has a fairly good potential. This deposit has been explored on Sea Grant funded projects with support by industry. The deposits appear to be stratified deposits cropping out on the continental shelf in depths of water approximating 30 meters. Analogous deposits are assumed to exist seaward of the land deposits known in North Carolina. Off of Florida phosphorite nodules have been found but resource potential is unknown. Another major potential source for phosphate production is in the Southern California borderland on ridge-tops where water depths are between 120 and 300 meters. Of the offshore areas mentioned, only Georgia and Southern California are currently considered as possible regions where the U.S., both government and industry, should be carrying out surveys and studies to assess the resource.

It takes approximately five years to bring a land mine into production once the deposits have been found to be extractable in an economically and environmentally sound manner and after the necessary developmental capital has been obtained. It could take longer to do this for an offshore deposit because there is no active technology producing offshore phosphorite, nor is there an atmosphere for investment in developing offshore production; it could be as long as ten or more years. Therefore, if the U.S. is to utilize its offshore deposits it should initiate at this time (and in sequence) exploration and initial assessment programs of the resource and the environment. The consensus of the panel was that if government provides private industry the proper background information and legal atmosphere for developing offshore mining, there would be pioneer entrepreneurs who would go out and start mining, realizing that some might make it and some might not. It was a majority opinion that it was in the national interest for government to encourage and not discourage such economic adventurers.

The minority view of the Panel is as follows: because the availability of land reserves and resources in the U.S. are so much larger on a comparative scale with marine deposits, and because the cost of recovering phosphate is apparently much less with proven technology on land, it is not likely that there will be any serious interest in marine phosphorites in this century.

We will be mining phosphate rock in Florida at least through the balance of this century, and in fact will probably supply rock to maintain the electric furnaces in Tennessee from Florida after 1985 or perhaps before. World competition for phosphate rock markets will probably lessen the demand for Florida rock in the export market and this will have the effect of extending domestic supplies. Our understandings of the reserves in Florida are not complete and, although we view the life of Florida mines to be no more than 25 to 35 years, depending on one's optimism or pessimism, there is a large tonnage minable at today's cost and selling prices and as these numbers increase in the future so well may the reserve.

It is probable that our reserves in North Carolina have been grossly underestimated. The combined reserves of Texasgulf, Inc., and North Carolina Phosphate Corporation are of the order of 1.5 billion tons and recent studies indicate that the mining rate can be substantially increased without causing a problem in the Castle Haynes aquifer. North of the Pamlico River an unknown, but very large, resource may well become an economically attractive reserve if FMC Corporation continues to successfully develop a slurry mining process. These land-based reserves and resources will very likely become important after the lower cost Florida reserves are depleted.

It is also very likely that reserves in the Western United States are more than adequate to supply the western agricultural markets and U.S. industrial market well into the next century.

ENVIRONMENTAL ASSESSMENT

Recognizing the similarity between environmental baseline studies needed prior to oil and gas development and construction of deep water ports to those needed prior to offshore mining, the panel felt that it would be quite proper for NOAA to develop environmental study guidelines which could be used in-house or passed on to other agencies such as the Bureau of Land Management. Those guidelines should be such that the environmental baseline and monitoring programs for oil and gas or deep water ports could also serve to help meet the environmental requirements attendant to ocean mining. We felt that NOAA or BLM should initiate a program to determine what information is needed additional to (or in place of) that for oil and gas in order to serve for environmental baseline studies related to ocean mining. Such criteria would make collection of (additional as warranted) information useful to an ocean mining program as part of existing data collection programs which are related to oil and gas developments. While such add-ons would not be necessary in all instances, they could be implemented in those instances where oil and gas or deep water port studies occurred where there was also a high potential for future phosphorite development.

In order to facilitate the development of a marine phosphorite industry, the panel identified the following items or needs as critical:

High Priority

- Information developed from New England Offshore Mining Environmental Study (NOMES) and Deep Ocean Mining Environmental Study (DOMES), and the University of Wisconsin Sea Grant Project should go a long way toward assessing the state-of-the-art and further needs. All projects should be supported in conclusion and the early preparation and dissemination of reports should be encouraged.

- Marine areas to be investigated, in order or priority are Southern California and Georgia; later to be followed by South Carolina and North Carolina.

Medium Priority

- Baseline studies at likely production sites should be designated to determine natural variabilities; one year baseline with a few stations selected for follow-on long term monitoring. Funds and support of environmental baseline studies should not be expended in large quantities in areas where there is a minimal potential for phosphorite development in the next ten years.

RESOURCE RESEARCH AND ASSESSMENT

Continued exploration for deposits of potential resource character are a requirement of any industrialized nation. Initial assessments are required for long-term planning (by both government and industry). Reassessment is required as exploration and assay technologies improve and user requirements change. Assessments of the resource and development of reserves made possible through exploration programs are important, but research on genesis of deposits also plays an important role in these matters, particularly as they provide clues to likely areas to conduct exploration programs. The importance of reassessment is exemplified by a recent study of a phosphorite deposit (reserve) in the western part of the U.S. That study showed that only one sixth of what originally was anticipated as a phosphorite reserve is now available for extraction. Overall reassessment has reduced the U.S. national reserve picture to about one fourth of that originally thought to have existed five to six years ago. To provide some idea of the volume of material being discussed, about 3 billion tons of reserves are now estimated versus a perviously predicted 11 billion tons. A few years ago, people would have said that the North Carolina deposits themselves were providing reserves on the order of two to three billion tons. However, reassessment of this particular eastern U.S. terrestrial deposit has shown that two to three billion ton reserves may be reduced to one tenth that amount or approximately 250 million tons. In this instance, it was environmental constraints which caused a reassessment and consequent reduction in the calculated reserves while in the instance of the western interior it was a more detailed analysis of both the amenability of the phosphate to treatment using existing technology and associated impurities which caused the reduction in reserve figures.

If properly implemented, conventional methods of exploration can go a long way toward improving our present knowledge of resources and of evaluating reserves. However, other additional needs are identified as:

High Priority

- o Better (greater detail and improved precision) bathymetric maps at a number of scales
- o Improvement in the delineation of deposits in both a lateral and vertical sense using existing technology (including use of submersibles and towed instrumented sleds)

Medium Priority

- o Implementation of precision navigation networks
- o Under government sponsorship establishment of research programs to determine the origin of marine phosphorites (particularly nodular deposits) by making comparative studies of terrestrial-marine deposits, paragenesis, and geochronological studies of the deposits

Low Priority

- Involvement of agronomists and other users into the program to provide guidelines as to the suitability of deposits

TECHNOLOGY DEVELOPMENT

While it is recognized that conventional positioning, exploration and assaying techniques can be better utilized to improve assessment of deposits, there is ample room for technological improvement in these methods. This is particularly so for speeding up the time to make assays (sample analysis cost) and delineation of sub-marine deposits. The nature of the deposit (nodule or lithified strata) as well as characteristics of any one accumulation will dictate the mining method employed. The technology of mining may well experience rapid change and growth once extraction were to begin. In the case of phosphatic nodules, the required technology may be easily derived from the state-of-the-art of dredging and deepsea mining technologies. In the case of strataform deposits, a new technology, undefined by our group, may be required.

Priority needs are seen as follows:

High Priority

- Improve sampling and exploration assessment capabilities for determining both lateral and vertical boundaries and concentrations of the deposits and the phosphatic material

Medium Priority

- More rapid methods for *in situ* mineralogic/elemental analyses
- More rapid methods for ship-board mineralogic/elemental analyses
- System to obtain and analyze large bulk samples of nodules and strata-form deposits
- Improved precision and accuracy of locating (in a cartesian and geodetic sense) the point sampled
- NOAA sponsorship of a multidisciplinary interagency study program to develop a strategy to create a technology for adequately assessing marine mineral deposits

Low Priority

- A place for archiving information on offshore minerals should be established by the National Oceanic Data Center (NODC); industry should be involved in helping establish the form and content of the data stored.

ECONOMIC AND LEGAL STUDIES

No one in the panel disagreed with the idea that marine phosphate deposits needed to be economically competitive with land sources. When that occurred utilization would being, or once begun, would continue. Based upon our discussions, we concluded that present knowledge of the offshore phosphorite deposits is so small (or of questionable value) that a firm assessment of their grade and extent, and hence their net worth in the present as well as future - markets is impossible to make. Perhaps illustrative of the equivocal nature of the information presently available is the fact that there were panelists who looked at the available data and said: (a) there is no economic use for the phosphorite deposits found off Southern California; and (b) yet another panelist equally expert in the field, said he was ready to go out and start mining the same deposit tomorrow if he could get a lease to do so.

Clearly, improved technology and assessment will improve the forecast of the net worth of marine phosphate deposits, permit predictability of cash flow, and the profitability of working these deposits. Nevertheless, it appears that a fledgling business would start, if the extant legal constraints would be withdrawn. In such a milieux, needs are identified as:

High Priority

- o More (or continuing) precise and accurate resource assessments of both marine and land deposits as a necessary base for economic and political forecasts, both domestic and foreign

- o Clear tabulation of governing bodies and their specific missions/ responsibilities regarding leases and leasing activities in state and federal waters

- o A statutory requirement for each cognizant agency to take definite action within a specific time after an application for lease is filed.

Conclusions

Much needs to be done before a healthy marine phosphate mining and processing industry develops. However, in the context of world politics and declining domestic land reserves, the time required to develop a mine requires the U.S. to act now in order to establish a marine phosphate industry by the 1990's. A partnership of government, industry and academia is necessary in order to develop that industry. If government, (1) were to help sponsor and carry out programs to provide information on the resource potential and (2)could provide a legal framework permitting leasing, then private industry would apply for those leases and carry out a more thorough resource assessment and subsequently develop and produce reserves. What would be really helpful would be a partnership between government-industry-academia in an environmental assessment study and a trial - at prototype scale - mining operation.

Marine Hard Rock Minerals

INTRODUCTION AND BACKGROUND

Marine metallic minerals occur in continental crust that is submerged beneath continental shelves or in-land lakes and in oceanic crust underlying ocean basins. Marine metallic minerals submerged beneath continental shelves or in-land lakes are generally extensions of terrestrial deposits and are relatively accessible for exploration and exploitation. Marine metallic minerals in oceanic crusts underlying ocean basins are less accessible to exploration and exploitation. With the exception of manganese nodules which are nearly ready for exploitation, marine minerals in oceanic crusts are at the stage of early exploration and technological development.

Metallic minerals other than manganese nodules present in oceanic crust constitute a major potential resource. These marine metallic minerals commonly occur in three forms. The first form is metalliferous sediments that lie on oceanic crust. Metalliferous sediments occur in all the ocean basins, but the only known metalliferous sediments with sufficiently high metal concentrations and large volume to have possible economic potential occur in the Red Sea. The second form of marine metallic minerals is encrustations of metallic oxides that adhere to oceanic crust. Relatively thick encrustations (less than 1 meter) are so far only known from several locations on the Mid-Atlantic Ridge and one location on the East Pacific Rise system. The third form of marine metallic minerals is massive sulfide deposits that occur within the oceanic crust. These massive metallic sulfide deposits are so far only known from slices of oceanic crust exposed in certain islands and on continents where they constitute an economically important class of ore deposits. The presence of massive metallic sulfide deposits in ocean basins is inferred but not yet demonstrated due to the problem of sampling the oceanic crust.

Exploration and assessment of massive metallic minerals in submerged continental crust may extend known resources. Exploration and assessment of marine metallic minerals in oceanic crust may discover new resources.

OBSERVATIONS

The approach to environmental assessment of massive metallic minerals in submerged continental crust is basically different from the approach to oceanic crust.

Submerged Continental Crust

- o Environmental assessment of marine metallic minerals in submerged continental crust, should follow procedures developed from precedents established for sand, gravel and placer deposits as well as marine phosphorites.

Oceanic Crust

- The NOAA Deep Ocean Mining Environmental Study (DOMES) concerned with manganese nodules should be regarded as a prototype for environmental assessment of other forms of mining marine metallic minerals in oceanic crust with appropriate modifications for different materials (unconsolidated sediment, encrustations on solid rock, and ore body within solid rock). The study should continue to early conclusions and preparation of reports.

RESOURCE RESEARCH AND ASSESSMENT

Submerged Continental Crust

- To determine the metallic mineral potential of submerged continental crust, resource research and assessment should follow directions already established for adjacent metallic mineral deposits on land but suitably modified for operations in the marine environment. In many instances, these would follow the same procedures used for exploring for stratiform deposits of phosphate.

Oceanic Crust

- To determine the metallic mineral potential of oceanic crust other than manganese nodules, resource research and assessment should be directed as follows:

  - The processes of metal concentration in oceanic crust (metallogenesis) should be studied where these processes occur at oceanic ridges where oceanic crust is created.

  - The processes of transfer of metals concentrated in oceanic crust to continents and islands should be studied where, in the general case, oceanic crust is destroyed at oceanic trenches and where, in the special case, oceanic crust is preserved by incorporation into islands and continents.

TECHNOLOGY DEVELOPMENT

Submerged Continental Crust

- The technology needed pertains to tracing offshore extensions of onshore metallic mineral deposits. The converse also holds, i.e. marine survey techniques may locate submarine ore bodies that could be traced onshore and developed initially on land.

- Existing shallow water (less than 100 meter water depth) geological, geophysical, and geochemical techniques need further development.

Oceanic Crust

- State-of-the-art oceanographic instrumentation is largely suited to regional survey-type investigations. A new generation of oceanographic instrumentation is needed to support the relatively detailed studies required to evaluate the metallic mineral potential of oceanic crust. Those developments are seen as:

- Deep towed instrument systems, presently in prototype stage, should be further developed to efficiently gather nearbottom geological, geophysical and geochemical data.

- Instrument systems for deployment on the deepsea floor should be developed to obtain time series measurements of relevant geological, geochemical and geophysical parameters.

- Submersibles with six kilometer depth capabilities supported by vessels with long range (3,000 nautical mile) cruising capability are needed for observations at oceanic ridges and in oceanic trenches.

- Sampling of the oceanic crust to assess metalliferous sediments and encrustaceans and to determine whether metallic sulfide deposits are present should be coordinated with the deepsea drilling project of the NSF. Deepsea drilling capabilities in solid rock without overlying sediment should be developed to sample for metallic mineral deposits in oceanic crusts.

ECONOMIC AND LEGAL ASSESSMENT

Marine metallic mineral deposits in submerged continental crust and in oceanic crust have different precedents to follow.

Submerged Continental Crust

- o Adjacent land deposits may aid in the economic assessment of marine metallic minerals in submerged continental crust. Legal assessment of metallic minerals in submerged continental crust may follow that of marine placer, phosphorite, and sand and gravel deposits.

Oceanic Crust

- o Marine metallic minerals other than manganese nodules in oceanic crust face many economic and legal problems similar to those attendent to manganese nodule mining. The economic and legal considerations being given to manganese nodules may be considered precedent to other marine metallic minerals in oceanic crust.

RECOMMENDATION

High Priority

Exploration and assessment of metallic mineral potential of continental and oceanic crust, in addition to manganese nodules should be a vital area of government activity and therefore should be supported because substantial evidence exists that the crust may be a new source for declining reserves of critical materials. However, great care must be given to the study of minerals that are truly needed.

Phosperite/Hard Rocks
Participants List

NAME	AGENCY
Robert Dill (Chairman)	Fairleigh Dickenson Univ.
Dave Duane	NOM/NSG
William R. Pickles	Lawrence Livermore Labs
John Noakes	Univ. of Georgia
Bill Gazdik	USDI/USGS -
Bill Stowasser	U.S. Bureau of Mines
Leonard Garrand	Garrand Company
Bob Meyer	Univ. of Wisconsin
Gordon Lill	NOAA/NOS
Glenn Flittner	NOAA/NWS
Burton Barnes	Federal Energy Administration
Pete Fischer	Cal State/Northridge
Andrew Carey	Oregon State University
Tony Inderbitzen	Univ. of Delaware
Andre Rossfelder	ECO Systems, Inc.
Peter Rona	NOAA/AOML
Joe Vadus	NOAA/MUS&T
John Mero	Ocean Resources

Report of the Marine Placers Session
NOAA Marine Minerals Workshop
State of the Art, Problems, and Recommendations

Background and State of the Art

Marine placer mining in the United States was first conducted on the beaches at Nome, Alaska, at the turn of this century. Indeed, some placer mining was conducted in waters up to about 10 feet deep off Nome, using large iron-wheeled wagons fitted with simple bucket recovery systems. (photographs of these machines are on display in the Nome City Library.) However, these early marine placer miners were unable to overcome the hazards and constraints of the high seas so common to the Bering Sea coastal waters and the thick winter ice cover. Nevertheless, some modest amounts of gold were recovered from these early offshore efforts, before the industry abandoned the machines and began to concentrate solely on the terrestrial placers in the Nome district. In the lower 48 States, little documentation exists to confirm some few tests, prior to World War II, in trying to mine underwater gold placers. Sporadic tests, none of economic viability, were made in San Francisco Bay, on a California beach, and on a protected beach in North Carolina. These early attempts were defeated before they began, through under-capitalization, lack of sound scientific knowledge of marine placer genesis - no exploration guides, aside from accidental discovery, were available - and the lack of mining equipment suitable to withstand the strong currents, storm waves, and pronounced corrosion common to high-energy marine placer sites.

The present period of renewed interest in marine placer exploration began in the early 1960's. This period was introduced by publication, in 1964, of John Mero's book, Mineral Resources of the Sea, wherein attention was called to the potential for finding and mining of gold and other heavy metals associated with buried beaches, modern beaches, and similar high-energy, nearshore sites. Contemporaneously, Raymond M. Thompson, Willard Bascom, J. R. Moore, Francois Lampietti, and several staff members of the U.S. Geological Survey and the Bureau of Mines, initiated exploration, or exploration research, directed toward locating economically viable marine placer deposits. Thompson and his Thompson Exploration Group, first brought attention to the potential for platinum, gold and tin placers offshore from known metal sources along the Alaska coast. Bascom conducted a world-wide exploration program, including Alaskan waters, while his associate, Francois Lampietti, focused attention on designing mining engineering systems and making realistic resource assessments. The Government sector early identified low-grade gold deposits off California and in Norton Sound, and conducted detailed coring tests in Alaskan waters. Academic research on marine placers was begun in the middle 1960's by J. R. Moore and his students at the University of Wisconsin, and further expanded by introduction of Sea Grant support in 1968. Since that time, the University of Wisconsin Marine Minerals Program has conducted an active, broad-based, applied research effort directed toward developing exploration guides for locating marine placer deposits, assessing both high-energy and low-energy placers, and determining the origin and distribution of placer deposits. This research has been jointly sponsored by Sea Grant and several American mining and petroleum firms.

Since 1969, a growing list of American companies and consortia have pursued marine placer exploration programs in American waters. The list includes, but is not restricted to, the following:

Callahan Mining Corp.
Inlet Oil Corp.
Thompson Exploration Group
Chandler Mining Operator
American Smelting and Refining Corp.
Shell Oil Co.
Marine Science Industries, Inc.
Andrau Enterprises
American Placer Gold
Amuedo & Ivey
Nome Ocean Mining & Engineering Co.
Engelhard Minerals & Chemicals Corp.

Of these several firms, the American Smelting-Shell Oil project at Nome has been the most rewarding to date, with gold recovered in their pilot mining tests in 1975. While still in development, marine placer properties held by Amuedo & Ivey and NOMECO along the Seward Peninsula coastline appear to have early, sustained production potential.

In considering the state-of-the-art for marine placer exploration and exploitation, including associated environmental monitoring and pre-mining surveys, as of 1976, we make the following observations.

(1) Most exploration is still guided by searching offshore from known mineral deposits on land, using, more or less, the same tools employed by marine geologists in their surveys of the past two decades. Some few operators, however, have, as of 1976, begun to use more sophisticated techniques involving geochemistry, dispersal (halo) tracking, high resolution acoustics, in-situ

metal sensing, and integrated exploration systems such as the "exploration window" concept recently developed at the University of Wisconsin.

(2) Actual recovery of marine placer ore has had only modest testing, largely through short-term pilot mining, and with conventional off-the-shelf dredges, drag lines, and sluices. Indeed, the design of special placer mining systems, compatible with profit, safety, and environmental protection, are yet to come from the drawing boards.

(3) Other than the study by R. M. Owen and J. R. Moore on the Chagvan Bay, Alaska, potential mining site, no detailed environmental assessments have been made. Writing impact statements for placer mining is still up to the individual operators and the agencies involved in regard to the specific details.

(4) Legal rules and regulations are as yet unresolved for the outer continental shelf Federal waters, although some states, notably Alaska, do have clearly defined rules and regulations for placer exploration and mining within the three-mile state-controlled waters.

(5) The problems of social and economic impacts, coastal zone facilities, taxes, capitalization, and the marketing of commodities are only now beginning to be considered.

In short, the infant marine placer mining industry is awakening, but it must make major accomplishments in overcoming technical and other problems by the end of this decade if it is to provide significant production of metals by the end of this century, a time of predicted exhaustion of several major mining districts in the United States.

Problems and Constraints in Environmental Assessment

In reviewing the status of marine placer exploration and exploitation activities, we have determined that there are several critical problems, which individually and collectively act to constrain timely and orderly development of this new industry. These several problems are presented and discussed below.

I. Environmental Assessment

In regard to environmental assessment, there is, as yet, no national base-line environmental inventory of potential placer mining areas of the inshore shelf or the outer continental shelf. Such an inventory could provide an environmental reference, or bench mark, for determining environmental change. Further, such data as will become available with the completion of the several current, or planned, USGS-BLM shelf surveys have not been routinely planned, reported, or advertised for the benefit of the hard minerals industrial sector, although such surveys could clearly provide a major part of the environmental inventory. The problem, then, is one of timely communication between agencies and users.

Considerable encouragement and interest have been expressed by government, industry and academia in determining which environmental parameters are the critical ones. Other than modest efforts to survey two placer mining sites in Alaskan waters, no comprehensive study has been made of a placer site, including evaluation of the importance of the several parameters in regard to their usefulness and importance. Indeed, such an investigation is needed for several marine placer mining test sites, in order to be meaningful, including "post-mortem" studies and surveys of mined-out sites.

Other than employment by the USGS of a few isolated, automatic, self-contained sensors in routine shelf surveys, no effort has been made to design, fabricate, and test electronic monitoring stations at specific placer mining sites. Clearly, there is much to be gained in pursuing such innovation, in terms of better data acquisition (continuous vs occasional), and less cost (instruments vs personnel). Further, continuously recorded data are amenable to meaningful statistical analysis, whereas spot data, or occasional data, are not.

II. Resource Research and Assessment

Of all problems considered by the Placer Panel, none received more discussion than that of the genesis and distribution of placer ore bodies. There has now been enough research on marine placers to allow us to recognize the existence of both conventional high-energy placers (swift current sorting and winnowing of larger heavy minerals) and, more importantly, low-energy placers (ultra-fine grained metal or mineral particles deposited in quiet bays or other protected sites). While Sea Grant supported research has defined some empirical relationships, chiefly between noble metals, transition metals, texture and mineralogy, other factors which undoubtedly influence placer ore deposition - critical wave and current energies, organic content, grain surface chemistry, geocatalysis, bathymetry of dispersal pathways, and processes active at the provenance (source) area - have not been studied. An understanding of these several variables is basic to establishing exploration guides for use by the industrial sector. Moreover, a full understanding of placer genesis in terms of source, transport in the natural dispersal conduit, and particularly the chemical/mineral/textural composition of the placer ore will allow process engineers to design specific recovery and beneficiation systems for specific placer deposits. Indeed, the viability (profitable recovery of both high- and low-grade deposits) of marine placer mining in America may prove to be mainly dependent on our knowledge of the details of placer genesis, and less so on regulations, capital, and environmental concern.

In considering placer research and assessment, we note with serious concern the lack of suitable vessels for offshore surveys. The problem is so acute that some placer investigations, while funded, must be postponed for periods up to 20 months in order to obtain adequate time on suitable vessels. One panel member succinctly stated the problem: "... there is no real lack of suitable vessels, but there is a very real lack of government vessels being made available to marine placer mineral researchers. It seems to me that with the many government vessels being utilized for other disciplines, more ship time could be made available to marine placer researchers. As an example, consider the Corps of Engineers with their many dredges." Furthermore, the need for new and more detailed nautical charts of placer exploration areas is obvious to all workers. This is particularly the case for potential OCS and coastal placer mining sites in Alaskan waters and some overseas insular territories. Lastly, in regard to placer research, there is a need to make available those samples collected in the course of routine agency surveys. Literally thousands of samples are collected each year by government agencies and universities, and many of these samples could be fruitfully analyzed for clues to possible placer deposits. At this time, most of these samples are either discarded, or used exclusively to meet other research and survey missions, notably navigational and environmental charting services. In conjunction with these problems is the need for some means of disseminating timely data, survey results, and associated information on OCS hard minerals.

III. Technology Development

The problems of placer mining that relate to technology and engineering development are most critical in the following problem areas.

Research and development of a reliable coring tool is wanting. At the present time, there is not an off-the-shelf coring tool that will penetrate 60 feet of coarse sediment and provide 90% recovery. All too many of the recent surveys have concentrated on surficial sediments, neglecting the in-depth (third)dimension, thus not confirming the full spatial extent and reserves of the deposit.

A second need is that of development of ore recovery and beneficiation systems specific to marine placers. Some conceptual research on ship-board separation systems has been made by the private sector, but, by and large, no new systems have been designed, fabricated and field tested. Clearly, the simple stringing together of bucket ladders, sluice boxes and jigs has not proven to be the answer. The hostile environment and diverse deposit types preclude such simplistic approaches.

Obviously, one of the serious problems to the industry as a whole is that of proprietary development in large companies and the lack of expertise and support in small companies. In order to move placer mining ahead, this disparity must be adjusted.

IV. Economic and Legal Assessment

The lack of an operating legal regime for OCS permits, leases, and monitoring rules on the part of the Federal agencies is a major roadblock to commercial exploration and mining on the outer continental shelf. Although this problem has been carefully reviewed by the National Academy of Engineering and its conclusions transmitted to the Department of Interior, no formal regulations have been promulgated, as of mid-1976.

In the economic realm, there is a lack of realistic, timely assessments and projections for the national and international commodity markets as they relate directly to placer mining. Furthermore, no up-to-date analysis of the potential United States marine placer industry is available. Thus, the factors of probable vs proven reserves, risks, costs, capital sources, markets, and international constraints or business are still unknowns to the would-be miner.

As a final problem, the firm or individual seeking to enter the marine placer business is currently faced with a bewildering and, at times,contradictory, series of approval hurdles. Not less than 10 agencies, offices, and/or regulatory bodies are concerned. The route through this red-tape maze is presently unknown - the very few who have ventured into it so far have done so with extreme wariness. Surely, a game plan and a road map to route the entrepreneur through the administrative and regulatory jungle are real needs,if early placer mining on the OCS is desired.

I. Environmental Assessment Recommendations

High Priority

1. A multi-disciplinary team should undertake an in-depth study to determine the critical parameters to be determined in preming environmental base-line surveys, and in monitoring during mining operations. Such a project must include team members in the physical and biological sciences, in engineering, and in statistics. Further, such concerns as the alternate uses of placer tailings should also be considered. Clearly, the study must differentiate between transient effects and irreversible effects, in regard to the environment.

2. Three marine placer sites, likely to be placed in production in the near future, should be investigated over an extended period (e.g.,three to five years) in order to establish variability of key, or critical, environmental parameters with time. Such results will provide a scale of limits to be expected under "normal" seasonal conditions.

Medium Priority

1. A basic base-line environmental inventory is considered a fundamental requisite for the industrial sector and for the several governmental agencies concerned with marine placers.

2. Early reports on OCS environmental and other data, including early lists of up-coming activities (cruises, etc.) should be made available on a timely basis to industry.

Low Priority

1. A special study of the impact of marine placer mining on the adjacent coastal zone should be conducted. It is noteworthy that placer mining is not amenable to corridor-concept regulations. Such a study should consider the on-land environmental aspects of processing plants, barge loading sites, passage of slurry pipelines across the beach, and socially related amenties.

2. An in-depth "post mortem" study should be made of a marine placer mining site after all mining has terminated. Such a study should include both technical and environmental reviews.

3. Electronic monitoring (sensor) stations should be developed. These systems should be designed for use either on buoys or on the seafloor, and should be given field trials at active or potential placer mining sites. Such monitors should include sensors for dissolved oxygen, temperature, suspended sediments, currents, and other variables as may be warranted. The design should incorporate those features of the USGS geoprobe that are, or may be, pertinent.

II. Resource Research and Assessment Recommendations

High Priority

1. Thorough and detailed investigations of the genesis of the several marine placer types should be conducted. This we consider a priority recommendation in that such research can assist in exploring for new placers as well as provide guides to designing beneficiation processes.

2. NOAA and other agency vessels should be made available to investigators studying marine placers, their origin, distribution, and environmental setting.

Medium Priority

1. New base nautical charts on the scale of 1:50,000 should be made for those coastal and OCS areas deemed most likely for placer exploration and development, e.g. Alaskan waters.

2. A "clearing house" should be established to provide and exchange information on marine minerals exploration and exploitation, data on relevant environmental studies, and timely notice of future surveys and associated activities, but not to duplicate the services already available through the Office of Environmental Data Services.

3. A mechanism should be established by which investigators can obtain access to bottom sediment samples collected by the National Ocean Survey.

4. A procedure should be identified by which marine minerals investigators can make known their needs and suggestions in regard to NOS ship and survey scheduling.

III. Technology Development Recommendations

High Priority

1. Research directed toward early and successful development of a coring tool, or system, which will penetrate 60 feet of sediment. This device must operate in mud, sand, gravel, or mixtures of these types, and it must not require large vessels or platforms for its use.

Medium Priority

1. Research on placer recovery and beneficiation systems should be supported in academic research centers.
(NOTE: Two members of our committee from industry felt that such research is more properly the role of the industrial sector. We quote from the written critique of one member: "In my opinion...private industry has the capability to develop the technology required to utilize placer resources lying on the OCS given an Econo - Legal framework that will allow that utilization to be made profitably.")

2. It is suggested that hardware development is warranted where such hardware is required in meeting specific project missions.

IV. Economic and Legal Assessment Recommendations

High Priority

1. A Federal permit and leasing policy for OCS hard minerals which clearly identifies prospecting, exploration, and mining rights and regulations should be promulgated without delay. As stated by one of our leading industry panelists: "...the major problem holding back development of the marine placer industry is the total lack of any official Federal policy on exploration and leasing. Industry needs to know the rules of the game, and the sooner the better."

2. A primer should be prepared that will provide guidance to those in the private sector seeking information on OCS permits and applications, on relevant legislation, and on those several agencies having jurisdiction over marine placer mining.

Medium Priority

1. An up-to-date study is needed of the economic structure of the marine placer industry (both active and potential), which stresses the investment differences between OCS placer mining and OCS petroleum exploitation.

Low Priority

1. A need exists for improved assessments of present conditions and future outlook of commodity markets of concern to marine placers miners.

NOAA MARINE MINERALS WORKSHOP
March 23 - 25, 1976

PLACERS
Participants List

NAME	AFFILIATION
Robby Moore (Chairman)	University of Wisconsin
Fritz Schuler	NOAA - Office of Marine Resources
Charles M. Hoskin	Inst. Marine Science; Univ. Alaska
James L. Harding	Skidaway Inst. Ocn, Savannah, Ga.
Frank E. Sentfle	U.S. Geological Survey, Reston,Va.
Anton Klaver	Mobil Oil Co., Dallas, Texas
Walter R. Courtenay, Jr.	Florida Atlantic Univ., Boca Raton, FL.
Leal W. Kimrey	NOAA-PMEL, Seattle, Wash.
Curt Amuedo	Amuedo & Ivey, Denver, Colo.
J. Wojcik	Asarco, Inc.
Robert W. Heins	University of Wisconsin
Hans Nelson	U.S.G.S., Menlo Park, Calif.
G. B. Tirey	Woodward-Clyde Consultants
Tom Ballentine	Conservation Foundation

III

Summary Reports of NOAA Sponsored Marine Mineral Research

In the sixteen papers that follow we have attempted to provide a complete summary of marine minerals research sponsored by the National Oceanic and Atmospheric Administration. Each paper is a summary of NOAA's research in an area defined by a combination of one of the following program elements:

Environmental Assessment
Resource Research and Assessment
Technology Development
Economic and Legal Assessment

and one of the following commodity groups:

Manganese Nodules
Sand and Gravel (and Shell)
Phosphorite and Hard Rock
Marine Placers

Abstracts of the NOAA research projects upon which these summaries are based are found in Appendix I. Project numbers[1], used in the text of the sixteen summary papers as well as in the abstracts, identify where the project originated by the prefix letter as follows:

S	Sea Grant Program
N	New England Offshore Mining Environmental Study (NOMES)
D	Deep Ocean Environmental Study (DOMES)
M	Marine Minerals Technology Center (MMTC)[2]
A	Atlantic Oceanographic and Meteorological Lab, NOAA

1/ These project numbers were assigned by the Office of Marine Minerals solely for the purpose of this Workshop.

2/ MMTC projects started prior to the establishment of NOAA are included.

Environmental Assessment of Manganese Nodule Mining*

Dr. George C. Anderson
Department of Oceanography
University of Washington

In this summary of NOAA-sponsored work on the assessment of manganese nodule mining on the marine environment, some material will be presented which will not have direct reference to manganese nodules per se, but the approach or thrust of each project is applicable to the subject. The discussion will begin with a literature search of marine mining environmental impact, followed by a study of the assessment of parameters of potential underwater mining sites. Reference will then be made to a particle dispersion study in Massachusetts Bay which was used to verify a numerical circulation model. The first NOAA-sponsored projects on environmental impact of manganese nodule mining began in 1972, and, for the sake of brevity, will hereafter be referred to as pre-DOMES (Deep Ocean Mining Environmental Study) projects. Finally, the presently ongoing DOMES project (which is a much more extensive and integrated approach to environmental assessment of manganese nodule mining than has been carried out heretofore) will be examined in some detail.

Literature Search

The objective of this project (Staff, Battelle Memorial Institute, 1971) was to search the literature and prepare a selected, annotated bibliography pertaining to environmental disturbances associated with marine mining. The published report contains over two hundred references. The references associated with mining impacts are presented by category of offshore industrial activity. In addition, a selected number of references are presented under a category "Directly Related References" but do not deal with impact. At the time of publication of the report, most of the available information was from fresh and brackish water studies, and no references were listed which dealt directly with manganese nodule mining.

Pre-Mining Survey

The objective of this project, supported by Sea Grant and directed by Dr. J. R. Moore, is to assess the critical chemical, biological, and geological parameters and coastal features of potential underwater mining sites and to develop a handbook to provide guidelines for environmental assessment.

An environmental analysis guideline model was prepared in anticipation of the need for environmental impact statements on ocean mining (Owen, 1973; Owen and Moore, 1974). The model incorporates four subject areas of concern. The geological portion includes an assessment of sediment texture, minerology, sedimentation rate, amount of impacted particulate matter, and bathymetry. Physical analysis consists of an hydrological and meteorological survey. Factors which characterize the chemical nature of the system both in the water column and sediment are included in the chemical analysis. Finally, biological analysis consists of primary production measurements and an assessment of organisms, particularly commercial and otherwise vulnerable species. Seven specific suggestions are offered as guidelines for impact assessment:

* Contribution No. 907 from the Department of Oceanography, University of Washington.

1. Define the physical boundaries of the mining site.

2. Conduct a literature survey and examine previous impact statements.

3. Review the legal situation regarding permits, claims, and environmental regulations pertaining to the mining site.

4. Apply the environmental analysis model to obtain the required baseline data.

5. Develop a systems model of the mining site based on data obtained from field studies.

6. Establish several observation stations at the mining site to monitor the environmental impact of the mining operations.

7. Select a control site that is geographically near the mining area and subject to the same meteorological and oceanographic conditions.

Particle Dispersion Study

As part of the project NOMES (New England Offshore Mining and Environmental Study) studies on impact of offshore mining sand and gravel, investigations were conducted in Massachusetts Bay (Hess and Nelson, 1975; Mayer, 1975).

Of significance to managanese nodule mining studies was the development and verification by NOMES of a predictive model to estimate the dispersion of fines in a dredge plume.

During June 1973, a study involving deployment of current meters and drogues was combined with a tracer experiment. The tracer experiment utilized 5 - 50 mμ diameter glass beads and 0.5 - 20 mμ diameter sphalerite particles introduced into the surface waters. Although the glass beads did not yield useful results, the sphalerite particles were successfully tracked for eight days. Meteorological, current, and tide data were collected for a 30 day-period whereas the tracer was introduced into the surface during the middle of this period. The plume was tracked utilizing fluorometric techniques. Sediment traps were deployed in an attempt to measure particles which settled out of the water column, but for various reasons yielded few results.

The mathematical models were conducted at M.I.T. under NOMES and consisted of both a two-dimensional finite element circulation model and a compatible finite element dispersion model. Results from the dispersion model, when applied to the results of the above-described experiment, compared favorably.

Pre-DOMES Studies

One of the preliminary investigations of the environmental effects of nodule mining has been conducted by the Lamont-Doherty Geological Observatory (Roels *et al*., 1973; and Amos *et al*., 1973). In the summer of 1970, the environmental impact of surface-discharged, sediment-laden bottom water on the water column was studied during a pilot "air-lift" mining test on the Blake Plateau in the North Atlantic Ocean. Both the fate of the bottom water discharged into the surface waters and its effects on oxygen concentration and phytoplankton growth were investigated.

The study suggested that it is most unlikely for surface discharged bottom water to produce anoxic conditions. Also, the effect that the bottom water had on phytoplankton growth suggests that significant growth increases would occur only if the concentration of the deep water, after mixing with surface water, was considerably greater than the 0.3 percent found during the monitored tests. Aerial photographs of dye-labeled discharge water showed deep water remaining in the upper water column for 3 hours after discharge.

In August and September 1972, a test at 10°N, 140°W of a Continuous Line Bucket (CLB) mining system aboard the Japanese mining vessel KYOKUYO MARU was monitored from the University of Hawaii's ship R/V KANA KEOKI. The physical, chemical, and biological conditions of the overlying water column were measured, and benthic fauna at the test site was sampled before, during, and after the mining operation. In addition, two cores of the bottom were taken and several thousand bottom photographs were obtained both before and during mining operations. Although there is uncertainty about whether the monitoring instruments penetrated the turbidity plume, no definite effects of the mining were observed.

In May 1974, an initial baseline study was conducted from the University of Hawaii's R/V MOANA WAVE at 8½°N, 151°W. Living organisms, sediments, currents, and water chemistry were sampled and studied in a 2° square around this site. (Data from this cruise are available from Amos et al., 1975; Roels et al., 1975a).

In April and May 1975, a similar baseline study at 15°N, 126°W was conducted by the NOAA R/V OCEANOGRAPHER. Data from this cruise have been analyzed (Roels et al., 1975b). This report contains the final, corrected data from all STD profiles, the dissolved oxygen, phosphate, silicate, nitrate, nitrite, ammonia, and turbidity data analyzed from samples collected at discrete depths; water column productivity and chlorophyll a data; the results of the enrichment experiments of bottom water and sediments on phytoplankton growth; the nephelometer profiles; the current meter data; and the complete analysis of ten 0.25 m^2 box cores for benthic organisms.

It should be noted that the locations where the 1974 and 1975 studies were carried out are the same as site areas A and C, respectively, of the DOMES studies to be discussed in the following section.

DOMES - Phase I

Project DOMES (Deep Ocean Mining Environmental Study), Phase I, is designed to identify potential marine environmental impact problems to be expected from the commercial-scale mining of deep ocean manganese nodules. The main goal of the DOMES project is to identify these environmental problems early enough to enable a timely response to the requirements of the National Environmental Policy Act of 1969, with respect to either "Law of the Sea" negotiations or domestic legislation.

The basic objective of Phase I is (1) to obtain sufficient baseline data to determine the range of natural variability of selected environmental parameters in the mining region, (2) to develop a preliminary predictive capability to assess the consequences of ocean mining on the marine environment, and (3) to allow the establishment of preliminary environmental guidelines for the mining of manganese nodules. In addition to establishing a quantitative, statistically defensible baseline, the goals also include the identification of the major processes that control the distribution and abundance of marine organisms. Environmental parameters sensitive to deep ocean mining will be identified.

The baseline study will yield the normal range of variations to be expected of physical, chemical, geological, and biological parameters within different regions of the mining area and seasons. The baseline study combined with a knowledge of the nature and fate of the discharge plume and the bottom disturbance will lead to an indication of the potential environmental impacts and provide the data base necessary for the formulation of an Environmental Impact Statement.

Phase II, on the other hand, is designed by extensive monitoring of prototype-mining-equipment tests to refine and/or modify the environmental guidelines established in Phase I. Predictive models developed during Phase I will be verified and modified as necessary as the test program proceeds. This schedule will support anticipated National Environmental Policy Act requirements and will permit final modifications of mining systems hardware and operations techniques, if required, in advance of commercial production.

It should be emphasized that Phase I studies will result in identification of "potential" impacts. Only after careful monitoring studies of the perturbations brought about by test mining operations can the impacts be verified. The baseline study assumes great importance since this provides the basis for measuring the impact.

Phase I officially began in FY 1976. Field operations will occur from August 1975 through early November 1976 in order to acquire baseline data at three sites in a 3.7 million square mile area of the North Pacific Ocean (5°N to 20°N and 110°W to 180°W), which is underlain by manganese nodules rich in copper, nickel, and cobalt. Data collection will be augmented by both shipboard and onshore investigations in order to develop a predictive capability which can be tested during the monitoring of either industrial prototype-mining-equipment tests (DOMES Phase II) or commercial mining operations.

A compilation and analysis of data is to be developed by August 1976, when a preliminary Phase I report will be issued. Interpretation of the Phase I studies will be completed by January 1978, when a final Phase I report will be published. Additionally, a series of data reports from each cruise will be issued as they become available.

Three sites selected by industry are being intensively investigated. The sites were selected to characterize the entire water column and to place specifically each site in or near the boundary of known surface and near-surface currents that cross within the 5° - 20°N and 110° - 180°W area that represents the area having the highest potential for future nodule mining. Site A (8°27'N, 150°47'W) serves as a representative site on the boundary of the North Equatorial Countercurrent. Site B (11°42'N, 138°24'W) was selected to cover the range of expected environmental changes both in a north-south and east-west direction. Site C (15°N, 126°W) is located in the North Equatorial Current.

Field operations are designed to provide the data needed to establish baseline information on existing environmental conditions, as well as supporting concurrent research and modeling efforts. Investigations at each site are designed to establish the nature of seasonal variations and, upon each visit, time-series measurements will be made to investigate diel variations of various parameters.

The field operations are planned to accomodate the requirements of the biological, chemical, physical, and geological investigations. Many measurements and samples will be used by several investigators; thus, the sampling program will be optimized to meet all needs.

Early in FY 1976, contracts were awarded to scientists from various parts of the country to carry out the work. Field work began aboard the R/V OCEANOGRAPHER on August 21, 1975, and continued through November 21, 1975. The second period of field work began February 11, 1976, and will continue through May 13, 1976. The field work will be concluded in the period late July to early November 1976.

An informal symposium of the DOMES Principal Investigators was held in Seattle, December 18, 1975, to present preliminary results. With the exception of some of the benthic work reported, all of the material resulted from contracts awarded since July 1975 and from field operations during the period mid-August to mid-November 1975. Since the meeting was held within a month of the end of the autumn field season, the material presented is of necessity preliminary in nature and full integration of the results is not yet possible. However, the emphasis of the symposium was directed towards a series of questions of concern regarding deep ocean mining, and the ultimate focus will be on an integrated program.

The symposium began with the biology of the sea bed followed by a discussion of sedimentology. Since the remaining bottom water programs were awarded only in early December 1975 (physical oceanography, chemistry, and plankton), a large subject area could not be covered.

After dealing with topics of the benthic biology and geology, the discussions turned to the upper water column where the emphasis of the program has been to date. It was decided that upper water column work should take precedence in starting dates--not necessarily for scientific reasons but because seasonal variations may be expected to occur in surface waters. Scheduling of the field work is, therefore, time-dependent for upper water column studies but is not considered time-dependent for the bottom water and benthic work. The upper water column discussions dealt first with the progress of the physical oceanography investigations and modeling of the surface discharge plume. This was followed by presentations on the chemistry programs and concluded with the biological studies of the regions including both the phytoplankton and zooplankton.

The following is a summary of the individual presentations.

Benthic Biology

Dr. Allen Paul, Columbia University: The benthic baseline study has utilized bottom photographs to enumerate the larger epifauna and intensive replicate box cores to determine quantitatively the bottom dwelling community. Over 8,000 photographs and 75 box cores have been taken, but more are required in 1976 to have enough samples to allow appropriate statistical treatment of the variability at each site.

Approximately 2200 photographs from site A have been analyzed. They show that tracks, trails, fecal casts, and nodules were common and that the large epibenthonónts were sparsely distributed (about 1 organism per 100 m^2 as compared to 8 - 16 organisms per 100 m^2 recorded from the floor of the oligotrophic Sargasso Sea). Elaziopod holothurians comprised 62% of the fauna.

Ten box cores from site C have been partially analyzed. The density of organisms ranges from 116 - 272 individuals per m^2 with an average biomass of 0.87 gm/m^2, not unusual values for the deep sea. Cnidaria make up customarily less than 2% numerically of deep sea fauna, but at site C they contributed over 23%. The nodules provided a firm substrate available for attachment of these sessile organisms, which probably accounts for their increased abundance in this area.

Dr. Peter Jumars, University of Washington: There are, in general, two ways to improve the statistical reliability of a baseline. Either a large number of samples can be processed, or more powerful statistics can be used to extract more information from the same number of samples. The time constraints of DOMES Phase I do not permit the former approach for the benthos. Hence, the latter method, cheaper both in time and in manpower requirements, is being pursued. Statistics capable of dealing with the low densities and high species diversities of deep-sea faunas are being developed or modified from existing procedures and tailored to the sample density and pattern achieved in the DOMES benthic baseline. When summarized, these baseline findings will be compared with the baseline and deep-sea community. This comparison will permit at least a limited predictive ability of the effects of nodule mining.

Sedimentology

Dr. James L. Bischoff, United States Geological Survey: The project involves about 12 geologists who are studying the geological and geochemical properties of the sea floor sediment in the DOMES sites. To date, all of their effort has focused on a single box core taken at site C during the spring of 1975. By concentrating the entire early effort on a single core, results are being inter-calibrated in such a way as to arrive at an optimum sampling plan for studies on all remaining cores.

The sediment is classified as a massive, mottled, siliceous, brown clay (manganese nodules cover about 25% of the sediment surface). Pleistocene to Recent age meiofossils were identified in the upper 4 centimeters of sediment. The clay minerology is mainly illite. Bulk chemical composition and interstitial water chemistry were found to be normal for the area.

Resuspension experiments with refrigerated bottom sediment and warm (surface) sea water revealed no significant release of heavy metals; toxic heavy metals were below the detection limits of 5 parts per billion.

Settling tests in seawater indicated that over half of the sediment will settle out of the photic zone (in upper 100 meters) within 140 days. Median grain sizes were found to be 4 microns or less, with no significant variation with depth in the core.

Although the mining system is not expected to excavate deeper than about 10 centimeters, it is interesting that the sediment characteristics changed somewhat below 20 centimeters in this 32 centimeter deep core. While no environmental problems were revealed by study of the deeper sediment, it is clear that the sediments at site C are neither as homogeneous nor as simple as earlier thought.

Physical Oceanography

Dr. David Halpern, Pacific Marine Environmental Laboratory, NOAA: During September 1975, vertical profiles of conductivity (i.e., salinity) and temperature were obtained from about 12°N to 18°N along 126°W. The depth of the upper mixed layer varied from 40 m to 10 m; a representative thickness of the mixed layer was 20 m.

A surface buoy mooring was deployed at DOMES Site C (15°N, 126°W) on 28 August. The wire cable between the two uppermost current meters broke on 28 October. During the 60.5-day period when upper ocean measurements were obtained, the vector-mean direction of the current within the upper 100 m was towards west and northwest (which was representative of the North Equatorial Current); whereas the vector-mean direction of the current between 200 m and 300 m depth was towards the east. The occurrence of the subsurface undercurrent was not expected. Daily vector-mean values of current speeds and directions were not steady and large fluctuations, especially at the inertial and semidiurnal periods, were observed.

Dr. Takashi Ichiye, Texas A & M University: Turbulent diffusion of sediments in the upper layer of the ocean is discussed from Eulerian and Lagrangian points of view. The latter model provides some simple estimation of width and depth of a plume of waste sediments discharged near the surface. A simplified version of the Eulerian model is the Fickian diffusion equation with eddy diffusivity variable with time and space. Analytical solutions of the Fickian equation are obtained for different boundary conditions in the interface (thermocline) with a steady state diffusion-advection of sediments discharged as a vertical line source. Vertical profiles of sediment concentration are plotted in the non-dimensional form for different current speed, discharge rate, vertical eddy diffusivity, and settling rate. The effect of the thermocline is that the sediment has a tendency to accumulate above the thermocline at a distance from the source if the thermocline inhibits the vertical diffusion due to its strong stability.

Chemistry

Mr. James Anderson, University of Washington: Features of thermocline depth were discussed in relation to the oxygen minimum zone and to nutrient distributions. A relatively shallow thermoridge is developed along 12°N and, in comparison with historical data, appears to be most evident during August and September. The oxygen minimum zone, beneath the thermocline, is most intense in the east and diminishes in development to 150°W at 15°N; a zone of extremely low oxygen concentration associated with relatively high concentrations of nitrite was present and is apparently a westward extension of the oxygen minimum zone developed along the coast of Central America. Microbial biomass in general was 100 times greater in the surface than at 1,000 m, was greater in surface layers along the thermoridge, and showed a small increase in the oxygen minimum zone compared to deeper waters. The structure of plant nutrient distributions in the upper 100 m showed significant variation over 24-hour periods. Variations may be due to biological activity or to patchiness or to a combination of both. Nitrate concentrations were low or not detectable above the thermocline.

Dr. Edward Baker, Pacific Marine Environmental Laboratory, NOAA: Examination of data from the fall 1975 cruise indicates that the highest concentrations of suspended particulate matter are found in the upper 100 m throughout the DOMES region, with the maximum concentrations occurring between 40 and 100 m. Only in the eastern portion of the mining area (at site C) were there any substantial particle accumulations below 200 m. These accumulations are apparently correlated with the most intense development of the regional oxygen minimum zone, between 180 and 350 m deep.

Simultaneous measurements of phytoplankton populations in the near-surface waters (< 150 m) suggest that most of the particulate mass is due to living phytoplankton. In the deeper waters, the suspended particulate matter is probably a combination of inorganic particles, mostly supplied by airborne dust, and the remains of dead plankton.

Maximum particulate concentrations in the upper 100 m are on the order of 50 μg/l. Below 300 m, the concentration is relatively constant, varying between about 15 and 5 μg/l. The total amount of naturally occurring particulate matter in the upper 100 m is roughly 2.5 g/m^2.

Phytoplankton

Dr. Sayed El-Sayed, Texas A & M University: Analysis of the biological productivity data collected at 45 stations enabled the following conclusions to be drawn:

Phytoplankton standing crop (in terms of chlorophyll a) at the stations occupied during Transects A, B, and C was low; the average value for surface water samples was 0.141 mg/m^3 and 13.19 mg/m^2 for values integrated from the surface to the depth of 0.01% of surface light intensity. Chlorophyll a maximum values were consistently found between 60 and 110 m. These values, in general, occurred at depth corresponding to the thermocline or the nutricline or both. Primary production, using the *in situ* ^{14}C uptake method, was also low at the stations occupied during the three transects. Surface and integrated values were 1.59 mg C/m^3/day and 0.125 g C/m^2/day, respectively. Maximum primary productivity generally occurred at 25% of surface light intensity (corresponding to 30 - 50 m depth). Below the depth of 1% of surface light intensity, chlorophyll a values averaged 17% of total phytoplankton standing crop in the water column. Primary production below the 1% light depth, on the other hand, contributed an average of 8% of total production in the water column. It is evident from the data collected during this cruise that the nanoplankton (organisms smaller than 20 μm) contributed an average of 92% of the phytoplankton standing crop in the water column studied. Also as part of the phytoplankton investigation, detailed measurements have been made of both incident and subsurface radiation in energy units. Dr. Guy M. Franceschini presented these latter results.

Zooplankton

Dr. Jed Hirota, University of Hawaii: Preliminary results were presented for the standing stock of macrozooplankton captured in surface deployed, neuston net samples and in horizontal, stratified Bongo net samples for the upper 1000 m.

In addition, abundances and patterns in the vertical distribution of microzooplankton from the upper 200 m in pump samples were given. Selected samples at each DOMES site from both neuston and Bongo net tows have been analyzed for species composition and numerical abundance of larval fishes; counts of copepod species have also been made from a few selected Bongo net samples. Most of the larval fish species are from midwater taxa (Myctophids and Gonostomatids), but commercially important species are also present (Skipjack and Yellow Fin tuna).

The neuston standing stock data showed that site A had lower average stocks than either sites B or C, and the night-time abundances were higher than corresponding daytime values. Patterns in the vertical distribution of macrozooplankton show that most of the stocks occur in the upper 200 m of the water column, without vastly different distributional patterns day versus night. As with the neuston data, sites B and C had larger stocks than site A but not at every station or depth. The distribution of macrozooplankton stocks at the deepest depth sampled with Bongo nets (about 1000 m) showed the highest values at site B with the gradient axis from lower values in the northwest to higher values in the southeast.

The vertical distribution of microzooplankton from samples analyzed thus far showed that different taxa have maximum abundance at different depths: (1) near-surface or at shallow depth (tintinnids); (2) below about 100 m (Oncaea sp.); (3) intermediate depth (total copepod nauplii). The most abundant microzooplankters numerically are copepod nauplii, tintinnids, and sarcodine protozoans (Radiolaria and Foraminifera).

Summary of Symposium

Throughout the discussions, potential impacts were identified where possible. For example, the question of mortality of benthic organisms due to the dredge head operations was discussed. It was pointed out that, due to the very fragile nature of the organisms, one might expect close to 100% mortality in the area of the sea floor covered by the dredge head. Also, it was the opinion of the benthic biologists that organisms stirred into the near bottom waters and which settle to the sea bed would stand very little chance of survival. Organisms such as nematodes and protozoans which live within the nodule fissures would be lost. Inferences of the effect on organisms of settling of sediments on to areas of the sea bed not directly affected by the dredge head are being addressed in a study by Dr. Bruce Heezen of Columbia University. He is examining historical cases of benthic smothering of organisms by rains of fines from natural occurrences. As part of Dr. Jumars' study, an assessment will be made of a special case of benthic disturbance in the San Diego Trough.

The major impacts discussed in the upper water column relate to the discharge of nutrient-rich water as well as the effect of sediment discharge. Typically, this region of the ocean is a low production, nutrient-impoverished area with high values of light penetration due to the relatively low concentration of particulate material. Knowledge of the fate of surface-discharged bottom water and sediments will come from the development of the upper water column dispersion model. Predictions from this model will allow calculations of the increase in nutrient concentrations within the euphotic zone, as well as the effect of nutrient enrichment on phytoplankton production. One effect of sediment discharge will be to reduce light penetration which may in turn result in a reduction in phytoplankton production. Thus, the effect of nutrient enrichment and sediment discharge may have opposite effects on phytoplankton production and must be assessed quantitatively. A secondary effect of reduced light penetration from sediment discharge may be related to changes in the vertical distribution of the phytoplankton. Because of the partial dependence of the subsurface chlorophyll maximum on incident radiation, light may be diminished at depth to such an extent that the chlorophyll maximum may be reduced in concentration or may disappear entirely. Experimental shipboard studies on the effect of additions of bottom water and sediments on phytoplankton metabolism were outlined and will be carried out in the coming field season.

An important consideration related to surface sediment discharge is the possibility of increased bacterial growth due to the greatly increased substrate surface area for bacterial attachment. The sinking of sediment particles with attached bacterial cells may increase the oxygen demand in the shallow oxygen-minimum zone. This effect must be studied carefully to see if anoxic conditions could result. Again, experimental shipboard studies on the effect of sediment additions on microbial growth will be carried out in the coming field season. One other effect which may be mentioned would be the possible accumulation of fines in the pycnoclines and the resultant effect upon organisms which either live within or migrate through these regions.

The impact on zooplankton may be more difficult to assess, but potential problems were discussed. If the depth of the oxygenated upper water column is reduced due to increased bacterial activity, this would result in a comparable reduction in habitable waters for the zooplankton populations. Also, if the subsurface chlorophyll maximum were to disappear, a possible important feeding area for the zooplankton may be removed. On the other hand, if phytoplankton production increases, there may be a resultant increase in zooplankton concentration and ultimately in fish; however, the latter effect is complex and depends to a large extent upon the species of phytoplankton organisms produced and the ability of the consumers to assimilate increased standing stocks of organisms within various trophic levels.

Concluding Remarks

It appears that the greatest need for future NOAA work in the assessment of environmental impact from manganese nodule mining is the speedy implementation of the program for DOMES-Phase II. For reasons stated earlier, Phase II studies are designed to provide the verification for impact assessment derived from Phase I studies. That is, Phase II is intended to deal with perturbations produced by prototype mining operations and will allow the impacts to be measured quantitatively.

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Environmental Assessment of Sand and Gravel Marine Mining

Dr. Larry G. Harris
Department of Zoology
University of New Hampshire

INTRODUCTION

Interest in marine sand and gravel deposits has increased substantially in recent years. The demand for sand and gravel for fill and for the construction industry continues to increase as land based supplies decrease due to depletion or reluctance of communities to allow aggregate mining in their boundries. The purpose of this report is to summarize NOAA-supported research activities relating to the environmental impact of marine sand and gravel mining and to suggest areas for future research emphasis.

With the exception of dredging for navigational purposes, little mining of marine sediments has been undertaken in the United States. Several european countries and Japan have substantial marine sand and gravel industries. However, other than a French study currently underway, little effort has been made to understand the environmental implications of these mining efforts. In a comprehensive description of the British sand and gravel industry Hess (1971) reported that government interest in research relating to marine mining was limited but increasing.

Hess(1971) covered all aspects of the British industry from a description of the geology of sand and gravel deposits and the technology used for its exploitation to a discussion of the economic, legal and social climate in which the industry functions. The study provides an excellent foundation for consideration of marine mining in the United States. Several aspects of sand and gravel mining should be emphasized to provide a perspective of the industry with which to consider environmental impact studies.

1. Sand and gravel deposits are derived from past glaciation (Hess, 1971 and J.R. Schubel, 1975. Marine Sciences Research Center, SUNY at Stony Brook) or coastal erosion.
2. These are typically well sorted sediments resulting from strong current systems and/or regular storm generated wave action.
3. The time frame for marine mining is long range with removal of the deposits the goal.
4. Offshore sand and gravel mining will be done with self-contained systems that are actually mining sediments only a few hours each day. Therefore, introduction of fine sediments into the water column will be in pulses instead of continuously as occurs in channel dredging.

Owen (1973) outlined a series of guidelines for conducting an environmental impact study of a marine mining operation. The procedures and analyses are organized according to the four areas of oceanography - geological, physical, chemical and biological. The studies discussed in this report correspond to these categories. In each section, there will be a summary of the research conducted to date and suggestions where further work needs to be done. The final section of the report consists of a series of recommendations for (1) increasing our basic knowledge of the geology, hydrography and ecology of sand and gravel deposits and (2) conducting an environmental impact study of a future sand and gravel mining operation.

GEOLOGY OF SAND AND GRAVEL

Hess (1971) characterized sand and gravel deposits as being well sorted sediments in hydrologically active areas. Owen (1973) suggested morphology of the region, sediment composition, rates of sedimentation and sediment transport as important geological parameters for understanding the environmental impact of marine mining. Furthermore, the most important factor determining the species composition of benthic communities is substrate type. Suspension of fine materials during dredging is an obvious and short term perturbation, but it is the removal of the aggregate that has long range implications for the ecology of a region due to alteration of substrate composition and bottom morphology.

Several studies have included surveys of sediments in areas to be mined or dredged (Owens and Moore, 1976 and Schubel, 1975), but these studies have not progressed to the level of predicting the geological consequences of removing substantial portions of a sediment deposit from a region.

Grant, et al. (1974) reported on analyses of core samples taken from the sand and gravel deposit in Massachusetts Bay which was to be mined in NOMES. This deposit was limited in fines and had no appreciable accumulation of organic materials which might cause oxygen depletion when released during mining.

Studies have been conducted on the geology of sand and gravel deposits (see summary by Mc Kenzie) but this information must be included as an integral component in the assessment of the environmental impact of marine mining, particularly relating to the long range affect of altering the substrate composition of an area. It is the substrate that remains or that is transported into the area after mining operations have concluded that will determine the composition of the future benthic communities.

HYDROLOGY

A substantial research effort has been committed to modeling current patterns and the dispersion of fine sediments for these are critical to an understanding of the impact of all types of marine mining. This is based on the assumption that siltation caused by mining operations is a potentially significant perturbation affecting the health of nearby marine communities. A knowledge of the current patterns of an area is also essential for describing the forces which affect sediment transport, deposition and sorting.

Owens and Moore (1976) described current patterns along a portion of Alaskan coast as part of a pre-mining survey which is also designed to test the usefulness of the guidelines proposed for such surveys by Owens (1973). Schubel (1975) has initiated current studies in Long Island Sound to determine the impact of local dredging on water movement patterns.

A number of hydrographic studies have been done in Massachusetts Bay, stimulated in part by NOMES. Conner and Wang (1972) and Karpen (1974) described current patterns in Massachusetts Bay and Boston Harbor while Bumpus (1974) summarized all available hydrographic information on Massachusetts Bay.

A particle dispersion experiment was conducted in Massachusetts Bay in June, 1973, when 1000 lbs. of sphalerite particles and 2000 lbs. of glass beads were introduced into the bay at the NOMES dredge site and their dispersion followed for eight days (Hess and Nelson, 1975 and Mayer, 1975). The study was successful and the results were used to test a circulation model (Conner and Wang, 1973) and a dispersion model (Christodoulou, et al., 1974; Pearce and Christodoulou, 1975). The results of the dispersion study confirmed the basic predictions of the models and demonstrated the value of this approach.

Schroeder and Pyles (1975) described a dispersion model for pipeline dredge spoil dumping which has been tested during actual dredging operations in Oregon estuaries.

The success of hydrographic models to date clearly demonstrates their usefulness and the value of their continued development. However, more emphasis on bottom currents is essential for developing a complete picture of the hydrography of an area. Divers conducting benthic community studies in Massachusetts Bay as a part of NOMES regularly encountered bottom currents flowing in directions distinct from surface currents and the bottom currents were often flowing at significantly greater rates. In September, 1975, the German habitat, Helgoland, was set up on Stellwagon Bank, an area of considerable interest to the sand and gravel industry. The best information on currents over Stellwagon Bank when the Helgoland was put in place indicated that currents rarely exceeded one knot. As a result, no one was prepared for the currents exceeding 4-5 knots which they encountered.

CHEMISTRY

The chemistry of the water column must be determined as well as that of the sediments to be mined to evaluate the potential affect that suspension of the sediments might have on the water column. Sediments containing high concentrations of undegraded organic molecules, toxic metals or pesticides may prove toxic to marine organisms or present a public health hazard by accumulating in marine food chains involving commercially important species.

Karpen (1974), Manohar-Haharaj and Beardsley (1974) and Mulligan (1974) have all collected water chemistry data in Boston Harbor and Massachusetts Bay. Copper and zinc concentrations in marine sediments were measured by Owen and Moore (1976). Grant, et al., (1974) did a complete chemical analysis of the sediments in the NOMES dredge site. Grant, et al., found only 1-3% fines and negligable concentrations of organics, heavy metals or pesticides; based on their analyses and experiments to measure the adsorption properties of the fine sediments, they predicted that the fines would not release toxic substances into the water column during mining.

If sand and gravel deposits tend to be in hydrographically active environments and are typified by low concentrations of fines, then fine sediments from these deposits may be in equilibrium with sea water. This would minimize the potential impact of these sediments on marine communities. Soft substrate deposits in areas that are hydrographically quiet and contain high percentages of fines are unlikely to be in equilibrium with the water column and should receive special attention during premining studies.

BIOLOGY

The impact of sand and gravel mining on marine communities is of two possible types - interference due to intrusion by suspended fine sediments or total destruction due to substrate removal. The affect of suspended sediments will depend on the relative percentage of fines and their chemistry as well as the hydrology of the area. At best, the limited fines from well sorted deposits, suspended in pulses by self-contained dredges and dispersed quickly by currents should cause minimal damage. At worst, deposits containing heavy, contaminant-laden fines mined in areas with minimal currents could cause serious damage to nearby communities. Once silt deposition has stopped, natural processes such as currents and surge from storm waves will redistribute the fines and recruitment of organisms will begin reestablishment of damaged communities.

The removal of substrate has greater potential for causing long range damage to the environment. Removal of sand and gravel deposits will alter the morphology of the bottom which could affect current patterns. The community that recolonizes the mined area will be determined by the substrate characteristics. Permanent alteration of an area must be considered on at least a regional basis. Hess (1971) stated that certain areas in Great Britain are not mined because they are spawning areas for herring. A similar situation exists at Stellwagon Bank off the Massachusetts coast; it is a major herring spawning ground and is rich in sand and gravel.

Several field and laboratory studies designed to provide an understanding of the impact of sand and gravel mining on marine mining have been supported by NOAA. Mulligan (1974) followed phytoplankton populations in Massachusetts Bay for two years. One outcome of his study was to verify the net southerly current flow predicted in the hydrographic models (Conner and Wang, 1973, and Christodoulou, et al., 1974). Mulligan found that two distinct water masses and corresponding plankton communities merged in the vicinity of the dredge site. East of the dredge site was the oceanic water mass typical of the Gulf of Maine. West of this water mass was the outflow from Boston Harbor which deflected south and ran along the coast and into Cape Cod Bay. Work on a model of phytoplankton population cycles had begun but termination of NOMES precluded its completion.

A benthic communities study was begun as a part of the NOMES study (Harris, 1976). Monthly quantitative samples were taken at 12 permanent stations in Massachusetts Bay over an eight month period. The stations were on the four major substrate types - hard (5), cobble (2), sand (2) and mud (3). In addition to describing the basic communities found in each substrate type, several conclusions pertinent to future studies of this type seem relevent:

1. Species diversity indices are essentially useless. The within station variation was often greater from month to month than the between station variation. A species list which ranks species according to some combination of numbers and biomass should be far more useful than present diversity values.
2. Massachusetts Bay has a heterogeneous substrate composition, topography and hydrography. There was a great deal of overlap among species between stations, especially when monthly samples are considered. A few species of polychaetes, amphipods and

bivalves were charactdristic of distinct substrate types, but identification of an environmental impact from a limited dredging operation, such as that planned for NOMES, may have been impossible.

3. Gravel substrates are intermediate between hard and soft substrates and will contain species typical of each of these substrates. Well sorted deposits in hydrologically active areas are likely to contain a limited fauna which undergoes large natural population fluctuations. Assessing an environmental impact in such systems will be difficult.

4. The most likely groups of animals to use as indicator species for impact studies are polychaete worms, molluscs and small arthropods. These groups have numerous species, are often substrate specific and can be quantitatively sampled.

5. Long term natural population cycles which are taken for granted in terrestrial systems have been poorly studied in marine benthic communities (Buchanan, et al., 1974). The need to conduct impact studies over several years with well chosen control stations is extremely important.

Laboratory studies on the effects of suspended fines on marine animals have been conducted by Cobb (1972) and Peddicord, et al, (1975). Cobb (1972) found that quartz and kaolin particles inhibited respiration in larval stages of the eastern lobster, *Homarus americanus*, by a direct blockage of the gill chambers. Peddicord, et al., (1975) found that bentonite particles also affected fish and shrimp by blockage of respiratory cavities. They found that fish were the most susceptible to harmful effects from suspended particles, followed by invertebrates occurring in fouling communities. Invertebrates from soft sediment habitats were unaffected by high concentrations of suspended sediments.

The studies of Grant, et al., (1974) on adsorption by fine sediments suggests that fresh kaolin and bentonite may be more toxic than natural fines. Clay particles newly introduced to sea water will not be in equilibrium with sea water. By adsorbing various ions from the medium, they may affect the pH or ion concentration of sea water enough to stress some organisms. Future sediment impact studies should consider the adsorption properties of the substrates being used.

RECOMMENDATIONS

Suggestions for further research have been made in the review of previous studies. These recommendations fit into two categories - (1) general studies relevent to sand and gravel mining but not requiring a dredge, and (2) specific environmental impact studies of a commercial dredging operation.

1. General Studies
   A. The geology and hydrography of sand and gravel deposits: Characterize the origin and composition of major deposits and the hydrographic parameters which form them. Bottom currents should receive special attention here.
   B. The dispersion and chemistry of fines: Continue development and refinement of the hydrographic and dispersion models available utilizing dispersion experiments such as the glass bead experiment (Hess and Nelson, 1975). Conduct further experiments on the ion exchange and adsorption properties of fines. Are fines in sand and gravel deposits a minimal environmental threat?
   C. The ecology of sand and gravel deposits: Determine the role of sand and gravel substrates in the ecology of a region. Are they consistently spawning or feeding grounds for commercially important species? Describe the community associated with sand and gravel deposits and the natural long term fluctuations of dominant species in these communities. Develop an alternative to species diversity indices which weighs both numbers and biomass.

2. Environmental Impact Studies
   A. Prebaseline: Describe the geology and chemistry of the deposit and the current systems. How will these change with removal of the deposit? Determine the role of the deposit in the ecology of the regional fisheries. Study one or two stations intensively to characterize the community; select dominant species and develop sampling and analysis procedures.
   B. Baseline, Dredge Monitoring and Followup: Review all information gathered during the prebaseline study and design a monitoring program to study those geological, hydrographical, chemical and biological parameters relevent to the specific deposit and type of mining to be done.

In summary, I feel it is important to emphasize the fact that sand and gravel mining could, over time, remove an entire substrate from a region. This would permanently alter the environment. A major goal of research on the geology, hydrography, chemistry and ecology of sand and gravel deposits must be to determine the long term affect of their removal.

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ENVIRONMENTAL ASSESSMENT OF MARINE MINING: PHOSPHORITE AND LODE DEPOSITS

Dr. Peter J. Fischer
Department of Geosciences
California State University, Northridge

Introduction

During the past decade, an increasing awareness of environmental hazards culminated with the Platform "A" oil spill in the Santa Barbara Channel. Subsequent adoption of the National Environmental Policy Act (1970) and in California the creation of the California Coastal Commission have resulted in a near "zero-growth" state of marine mineral exploitation. Despite the late 1975 Federal OCS oil and gas lease sale, the development of proven parcels acquired by "winning bidders" in 1967 remains frozen.

Even an onshore mineral prospect, such as the late Miocene phosphorite deposit at Pine Mountain, which was leased in 1969 is entangled in the environmental impact decision making process (Runvik, 1972; Appleyard, pers. com., 1975). At this time, to quote Mr. Runvik, "we are waiting." However, his suggestion to "do your homework--that is, be sure you have thoroughly investigated all of the environmental factors and established a background of basic data..." is obviously relevant for our offshore mineral deposits. Indeed, unless detailed environmental baseline data studies are initiated, it will be too late for the environment is changing daily. An ongoing baseline investigation of the southern California Bight (fig. 1) sponsored by the Bureau of Land Management, is concerned with petroleum exploration and production. Many of the offshore phosphorite deposits (fig. 1) are not included in this study. In addition vital parameters (e.g. bottom current measurements, transmissometer studies of suspended sediments, etc.) are not a part of the study (Science Applications, Inc., 1975). The Santa Barbara oil spill (1969) emphasized the overall lack of data and the inadequacy of sampling methods to detect subtle changes in the environment and the biota (Straughan, 1975); this lack still exists.

Pre-mining Baseline Surveys

The aspects of pre-mining baseline surveys for marine mineral operations were recently reviewed by Owen (1973), Owen and Moore (1974) and the National Academy of Sciences (NAS, 1975; Moore, Chairman). Although the NAS panel did not deal with the production of oil and gas nor mining operations in the coastal zones, the environmental considerations for all of marine extraction operations are quite similar. For example, the oceanographic data required to predict the dispersal pattern of oil spills is essentially that needed to predict the path of the suspended sediment plume from a dredging operation. Obviously certain physio-chemical parameters are unique to each resource and its extraction.

As proposed by Owen and Moore (1974) the "Environmental Analysis Guideline Model" is divided into the classical subfields of oceanography. With the writer's modifications and additions an outline of their model is tabulated below:

1. <u>Precision Navigation</u>
   If all of the other data are to be meaningful, a precision navigation system (e.g. RAYDIST, SHORAN, etc.) is essential.

2. <u>Geological-Geophysical</u>
   Precise bathymetry and depth profiles
   Geologic map of the sea-floor (including overburden isopachs)
   Seismicity ("active" faults defined - epicentral data plotted)
   Stability analysis (including slump and slide mapping)
   Sediment texture and composition
   Engineering properties of sediments
   Sedimentation rate
   Transmissometer studies (sediment)
   Age determinations (including paleontologic, radiometric and amino acid)
   Geochemical studies (under chemical)
   Groundwater considerations (e.g. Woolsey and Harding, 1975)

3. <u>Physical</u>
   Current meter studies
   Upwelling measurements
   Tidal analysis
   Wave spectral analysis
   Mass transport
   Temperature-salinity-sound velocity
   Transmissometer studies

4. <u>Chemical</u>
   Profiles and horizontal variations; temperature, salinity, O_2, N, PO_4, pH, etc.
   Trace metals (water column, sediment and selected organisms)
   Hydrocarbons (essential for petroleum baseline study, but natural seeps may indicate a necessity for other operations as well)

5. <u>Biological</u>
   Abundance, composition, diversity and general health of the fauna (ranking, index of dominance, etc.)
   Primary productivity
   Seasonal and secular variations
   Spatial distribution
   Laboratory studies (e.g. Turbidity Bioassay; Davis and Nudi, 1971)

6. <u>Meterological</u>
   Wind direction and velocity
   Storm spectra
   Evaporation/precipitation ratio
   Sunlight (average hours/day)

In addition to their model, Owens and Moore (op. cit.) proposed seven specific guidelines for the preparation of impact statements for potential marine mining operations:

1. Define the physical boundaries of the mining site.
2. Conduct a literature survey and examine previous environmental impact statements.
3. Review the legal situation regarding permits, claims and environmental regulations pertaining to the mining site.
4. Apply the environmental analysis model to obtain the required baseline data.
5. Develop a systems model of the mining site based on data obtained from field studies.
6. Establish several observation stations at the mining site to monitor the environmental impact of the mining operation.
7. Select a control site that is geographically near the mining area and subject to the same meteorological and oceanographic conditions.

Phosphorite Areas

Phosphorites (fig. 1) from the southern California Continental Borderland were discovered by Emery in 1937 and reported by Dietz, Emery and Shepard in 1942. Only one area, The Coronado Bank, has been studied using precision navigation, seismic reflection, detailed sediment sampling, underwater television and submersible observations (Barnes, 1970). As this study was concerned with resource genesis and assessment, most pertinent environmental data was not gathered. Two recent studies discuss the resource potential of Borderland phosphorites (Inderbitzen, et al., 1970) and their character and genesis (Pasho, 1973).

Within the phosphorite areas of the Borderland environmental data is predominantly sediment characterization (Fischer, 1975; Fischer and Richmond, 1976, in prep.). A tabulation of this data is presented in Appendix I.

Recently, regional syntheses of the southern California Bight were completed by the Southern California Coastal Water Research Project (1973) and the Southern California Ocean Studies Consortium (Dailey, et al., eds., 1974). These reports contain background data and references and satisfy the literature survey element of Owens and Moore (op. cit.).

Recently published geological studies of the Borderland by Vedder, et al. (1975), Greene, et al. (1975) contain information regarding: bedrock geology, seismic hazards, sea floor instability, sediment character and thickness and hydrocarbon-trace metal distribution. Phosphorite areas within this survey include: Tanner and Cortes Banks, Northern Santa Rosa-Cortes Ridge and the Santa Monica shelf.

In Georgia, Woolsey and Harding (1975) are initiating a study of the "confining strata associated with the principal coastal Georgia Aquifer. Their study will provide data on the economic geology of the phosphate deposits of the "confining strata."

Great Lakes - Lode Deposits

The extension of the Kekeenaw Peninsula "greenstone" trend of insitu vein and disseminated copper deposits beneath Lake Superior will create complex environmental mining problems (Tuerkheimer, 1969). Alternative mining methods discussed by Moore (in Tuerkheimer, 1969) include: onshore to offshore tunnels under the lake bottom, a vertical shaft from a surface "island", or a leaching process using an offshore rig. A delicate biological-chemical balance of the cold oligotrophic lake waters and a natural flushing period of 500 years are major obstacles to a leaching process involving toxic solutions (e.g. H_2SO_4, Kennecott, in Mining Engineering, 1967; acid cyanide, Cruickshank, 1967, etc.).

Areas of Near-term OCS Mining

The areas listed below were identified by the National Academy of Sciences (1975) as being potential near-term marine mineral mining sites:

1. Bering Sea (lode deposits: barite, copper, lead and zinc sulfides, molybdenum and possibly authigenic uranium-bearing minerals).
2. California Continental Borderland (phosphorite).
3. Great Lakes (lode deposits, copper and manganese).
4. Georgia (phosphorite? - Woolsey and Harding, 1975).
5. Gulf of Mexico (finely divided authigenic metallic sulfides).
6. Massachusetts (coal?)

Recommendations

Studies to gather baseline environmental data in the potential near-term OCS mining areas identified by the National Academy of Sciences (1975) should be given high priority. In at least three instances these areas represent areas of ongoing or immediate oil and gas development and environmental baseline studies. Initiation of the Environmental Analysis Model as proposed by Owen and Moore and modified by the writer requires a great deal of scientific manpower. No one agency is funded, staffed or equipped to undertake these studies. Indeed the studies should be undertaken by groups of individuals from academic institutions, governmental agencies and private industry.

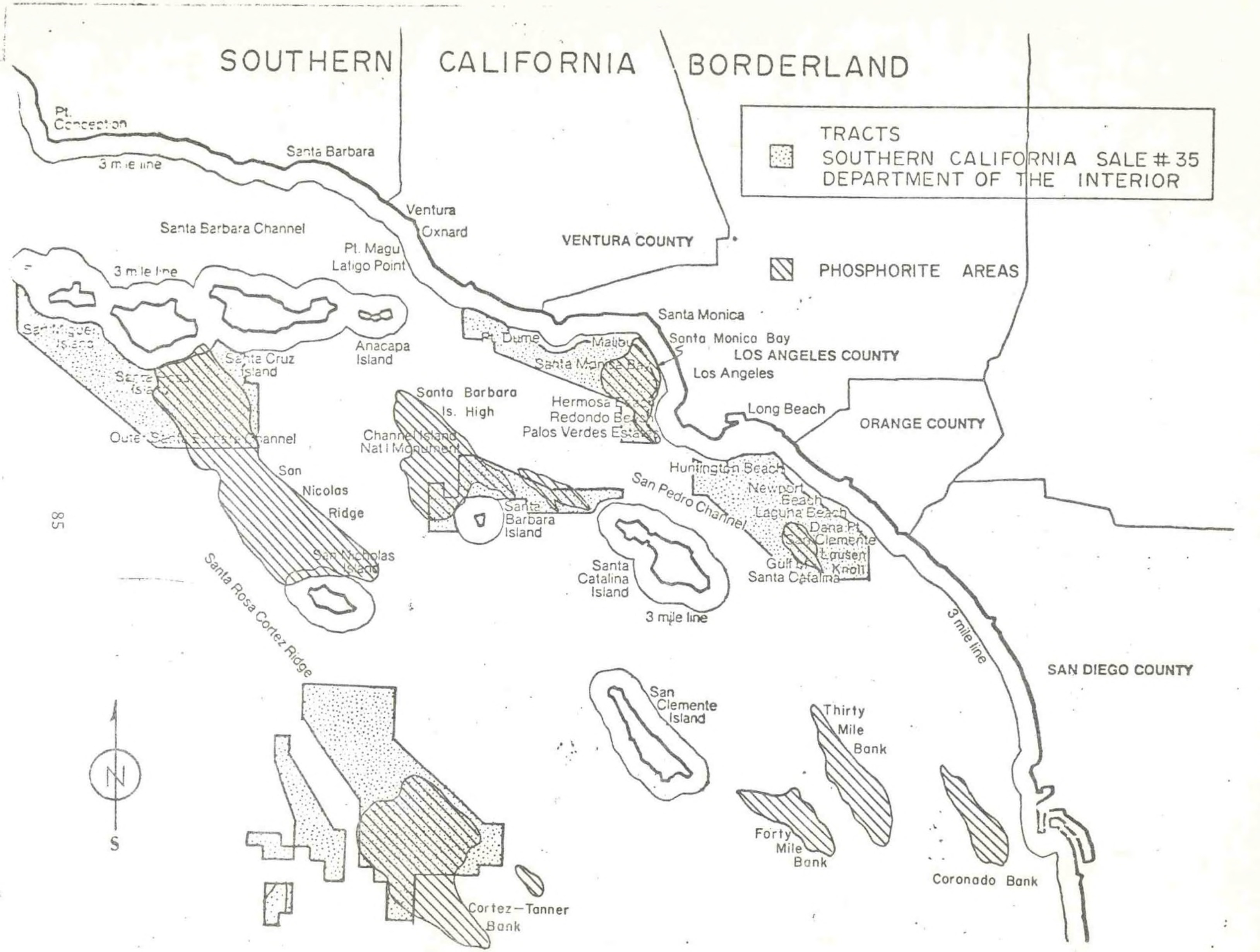

Figure 1. Phosphorite Areas and OCS Lease Tracts

APPENDIX I

Post 1960 Studies of Selected Areas of the Continental Borderland

(related to Phosphorite deposits)

AREA	AUTHOR(S)
Northern Channel Islands	Weaver, *et. al.* (1969) Yeats, (1970) Palmer, (1965)
Palos Verdes Shelf	Uchupi, *et. al.* (1963)
San Clemente Island	Merifield, *et. al.* (1971) Ridlon, (1969) Ridlon, (1962)
San Diego Trough	Emery, *et. al.* (1963) Shepard, *et. al.* (1962)
San Nicholas Island	Vedder, *et. al.* (1963) Burnham, *et. al.* (1963)
Santa Catalina Basin	Gaal, (1966)
Santa Cruz Basin	Barnes (1970)
Santa Rosa-Cortez Ridge	Uchupi, (1966)
Santa Rosa Island	Orr, (1960)
Tanner Basin	Gorsline, *et. al.*, (1968)

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Environmental Assessment of
Marine Placer Mining

Dr. Robert Moore
Marine Research Laboratory
University of Wisconsin

Introduction

With enactment, in 1969, of the National Environmental Policy Act, it has been, and continues to be, a requirement that any company planning to mine in United States waters must prepare an impact statement. This requirement is perhaps nowhere of greater importance than in marine placermining. By the very nature of placer mining, the bottom sediments must be disturbed in order to recover that small amount of ore (frequently less than 1% of the material mined) present in the deposit. Additionally, the several processes currently available for handling the mined muds and sands, chiefly beneficiation processes, also require further disturbance of the local mine site waters. Inasmuch as such mining is conducted in shoal waters close to shore, and is frequently in waters also used by fishermen and other interest groups, it has high visibility and commands much attention and concern. Unfortunately, there has been very little in the way of hard information that could be used by mining companies to prepare impact statements, although some recent N.O.A.A.-Sea Grant research has provided initial data for designing a safeguard.

Interestingly, even prior to the enactment of the Environmental Policy Act of 1969, the author was approached by management personnel from several American mining firms seeking guidance on how to conduct marine placer mining with concern for environmental protection, and in fact, requesting aid in how to conduct environmental monitoring surveys. Clearly, the interest in seeking environmental safeguards for offshore placer mining preceded the Act of 1969.

Previous N.O.A.A. Investigations

During the past seven years, N.O.A.A.-sponsored research on placer mining environmental assessment or on ancillary dredging problems has led to a better understanding of the causes and cures relevant to dredging, handling, and beneficiation processes in coastal waters. Several of the N.O.A.A. projects are reviewed, briefly, below.

W.L. Schroeder (Oregon State) investigated (1972-1974) the fate of hydraulic dredge spoil. Although his research was not directed toward placer mining, his results are readily applied to the hydraulic mining system employed by placer miners. He has shown that it is possible to predict, within limits, the fate of sandy spoils ("gangue") that are discharged into coastal waters through hydraulic mining. Much of his study involved the application of basic sedimentation properties to a model discharge system including currents. Clearly, the results are useful, not only for application to dredging predictions, but also to provide a base for further expansion of the textural grades, current velocities, and other parameters in a model system.

In another N.O.A.A. project, with aid from the Corps of Engineers, John Padan, Clyde David, and Floyd Nudi conducted laboratory studies (1969-1972) on the effects of suspended sediments on marine organisms. Again, the research was not specifically directed toward placer mining, but the research did cover, in part, the problem of what influence suspended detritus (from dredges) has on organisms. The single most important accomplishment, as reported by the principal investigators, was the construction of a specialized laboratory for such research at the Bodega Marine Laboratory, University of California. Subsequent use of early data has been made by the Corps of Engineers.

From 1972 to 1976, Richard Petticord continued the suspended sediment/organisms research at the Bodega Laboratory. He expanded the laboratory to accomodate large aquaria with controlled sediment concentrations. Resulting information includes data on "different concentrations of several minerals at different temperatures, salinity, and dissolved oxygen - on San Francisco Bay organisms".

In response to inquiries from several placer mining firms, two agencies, and the National Sea Grant Office, requesting information and guidelines on "how to conduct an offshore pre-mining environmental survey", J.R. Moore undertook a study of this problem between 1972 and 1975. The research was carried out in conjunction with a platinum placer exploration project at Chagvan Bay, Alaska, and this locale was used as the model test and guidelines design site. University of Wisconsin personnel recommended the following systematic approach based on the premise that potential marine mining sites vary with respect to geographic location and the type of mining operation that is planned. However, despite these variations, there are certain guidelines that should be followed to facilitate the preparation of an impact statement, and these are presented below:

1. <u>Define the system</u>. The initial step of the study should be concerned with defining the physical boundaries of the area to be studies.
2. <u>Conduct a literature survey</u>. Because of the interdisciplinary nature of an environmental survey, many sources can be examined to obtain data about the area of interest.
3. <u>Examine previous impact statements</u>. Impact statements that were prepared for geographic areas similar to the study area, or that are concerned with the same mining technique that is planned for the study area should be reviewed to determine what were considered to be the critical environmental parameters.
4. <u>Determine the legal situation</u>. To a great extent, environmental law is still in the development stage. However, the present laws pertaining to permits, claims and environmental regulations in the study area should be reviewed.
5. <u>Apply the environmental analysis model</u>. Based on the information obtained in steps 1-4 above, those portions of the environmental analysis model that are applicable to the study area should be selected and then carried out in field studies..
6. <u>Develop a systems model</u>. The data obtained from the field studies should be incorporated into a systems model of the study area. This model can then be subjected to sensitivity analysis to predict the possible environmental impact of the mining operation.
7. <u>Establish monitoring stations</u>. Stations located at critical points within the study area should be selected for monitoring the environmental conditions during the mining operation. This will allow for rapid detection of any problems that develop as a result of the mining operation and enable corrective action to be taken immediately.

8. Select a control site. All environmental changes that occur in the study area after mining has started are not necessarily caused by the mining operation. Therefore, a control site should be selected that is geographically near the mining area and subject to the same meteorological and oceanographic conditions. By establishing monitoring stations at the control site as well as in the mining area, a better assessment of the changes caused by the mining operation can be obtained.

In one other investigation sponsored by N.O.A.A.-Sea Grant, Robert Heins and Ted Tiemann pursued (1971-1974) a study of clean undersea mineral processing using hydrocyclones to selectively separate placer metals from mud and sand. While their project was chiefly directed to solving a technological problem, it was, nevertheless, developed in the framework of concern for environmental quality. Such research, including other devices and a variety of ore types, when matched to the environment, is much needed by industry.

Investigations by Other Organizations

Recently, personnel from the Institute of Marine Science, University of Alaska, conducted a thorough study of the sediments, fauna, and waters off Nome, Alaska. This survey was supported by a grant from the American Smelting and Refining Co., with the objective of providing environmental base-line data for the ASARCO-Shell offshore placer gold lease at Nome. This investigation, although not yet published in the open literature, is known to have provided ASARCO with sufficient data to meet regulatory agency requirements. It should be noted, moreover, that ASARCO had assembled considerable environmental information on their lease prior to the University of Alaska survey, notably data on currents, water temperature, ice conditions, sediments, and an underwater photographic survey of the seafloor. The early ASARCO survey was designed by Joseph R. Wojcik, the geologist in charge of the Nome placer development.

Several companies, in making research grants to the Underwater Minerals Program at the University of Wisconsin, have insisted that initial base-line observations be made in the course of conducting exploration research on marine placers. These firms include Callahan Mining, Chandler Mining, Engelhard, and American Placer Gold. By including some base-line measurements, chiefly data on the trace metals in mobile sediments of the areas under study, it has been possible to commence environmental assessments well in advance of any mining activities, if such are warranted. Nonetheless, these surveys have been only ancillary in nature, and no "definitive" environmental survey has yet been made.

There may well be other commercial organizations that have conducted pre-mining surveys at marine placer sites, but the traditional proprietary treatment of in-house investigations has largely restricted open publication of the data.

In short, there appears to be no systematic approach to environmental base-line and monitoring at marine placer sites by the industrial sector. Moreover, no environmental surveys specific to potential placer development have been conducted by either industry or government groups in outer continental shelf waters.

Recommendations

Obviously, recommendations that benefit from deliberations of the N.O.A.A. workshop participants, as a group, will be based on broad cumulative expertise. Nevertheless, in order to promulgate early discussion, we submit the following recommendations as prudent initiatives, and while they are based on practical experience and reason, they are, nevertheless, clearly subject to challenge, debate, modification, expansion - or deletion. Accordingly, it is recommended:

1. That a multidisciplinary team undertake an in-depth study to determine the critical parameters to be determined in pre-mining environmental base-line surveys, and in monitoring during mining operations. Such a project must include team members in the physical and biological sciences, in engineering, and in statistics.
2. That three marine placer sites, either active or potential, be investigated over an extended period of time (Ca, three to five years) in order to establish variability of selected environmental parameters with time. Such results will provide a scale of limits to be expected under "normal" seasonal conditions, and, hopefully, lead to realistic regulations.
3. That a special study of the impact of offshore placer mining on the adjacent coastal zone be conducted. Such a study to consider the on-land environmental aspects of processing plants, barge loading sites, passage of slurry pipelines across the beach, and socially related amenities.
4. That an in-depth "post mortem" study be made of a mining site after the mining has terminated. Not only would such an investigation include a technical review, but, also, environmental and cost/benefit reviews.
5. That development of electronic monitoring (sensor) stations, for use either on buoys or on the bottom, be designed and tested, and given field trials at active or potential placer mining sites. Such monitors should include sensors for dissolved oxygen, temperature, suspended sediments, currents, and such other useful variables as could be incorporated.
6. That an economic/technical/environmental assessment be made of alternate uses of placer tailings. Such uses might include land fill, breakwaters, sand sources, and beach nourishment.

The above suggestions are only examples of research that may lead to fruitful solutions. There are many others. In short, let us combine our talents at the Workshop and provide new pathways leading to wise use of our resources - including the environment.

Resource Research and Quantitative Assessment of Manganese Nodules

J.E. Andrews
Department of Oceanography
University of Hawaii

In view of the wide range of statements which have been made about the manganese nodule resource it is appropriate to define the nature of a resource more clearly and to relate this to the situation with manganese nodules. The terms resources and reserves as applied to ores are specific measures of geologic and economic practicability, and are quite distinct from the simple existence of metal bearing materials. The AGI Glossary of Geology defines reserves as "known ore bodies that may be worked at some future time", or in the case of petroleum reserves as supplies "discovered, developed and producible, but not yet produced". A.A. Archer (Imperial College, London) at a recent CCOP/SOPAC meeting presented a more specific analysis for the case of manganese nodules as an industry in the course of development. Reserves in this case should be considered as the recoverable metals in nodule deposits that are "workable in the current, local and prevailing economic conditions." Total resources would, of course, be larger, being the reserves as defined plus deposits of lower grade or abundance that are likely to be workable in an economic fashion at some time in the future.

While nodules exist in all of the world oceans, the current public data base defines only one general area of first generation exploitation - that is the zone between the Clarion and Clipperton fracture zones and between about 120° and 165° W. This pattern is defined by the 530 analyses presented in Horn et al. (1972) and Frazer et al. (1972). This is a rather biased sample set as the samples were not collected as part of a program of resource assessment, but rather in conjunction with

with other marine geological investigations. The sample coverage roughly one station per 700,000 km^2 of sea floor, but is not that regularly distributed. This is sharply pointed up by the recent discoveries of Cu and Ni enriched nodules in both the South Pacific (CNEXO) and the South Indian (D. Cronan, UK) oceans.

Two critical parameters define the economic viability of a manganese nodule deposit: grade and abundance. Published accounts of industrial plans show that the principal metals of interest are copper and nickel, with potential adjunct production of cobalt and manganese metal. Average nodule assays from the clarion/Clipperton zone are 1.3 % nickel, 1.1 % copper, 0,25 % cobalt, and 27.5 % manganese (data only from the early IDOE reports.) For commercial purposes one may define a cutoff limit in grade at about 2.25 % CU + Ni (+ Co?). Of course, first generation mines will aim for much higher averages - perhaps 3 %+. Aside from the Clarion/Clipperton region only 13 % of all of the other assays in the data bank show values at or above even 2 % combined metal values. This means that for first generation mines the area of potential exploitation is limited. Again, note that the limits in the data base may contribute to this fact.

The second factor which is critical in determination of exploitability is the density of distribution of nodules on the seafloor in any given area. Again, for economic considerations one may take 10 kg/m^2 as a first generation limit (approx 2 lb/ft^2). None of the data acquired prior to 1970 gives any direct measure of this factor. Indirect measures may be derived from bottom photographs in data files show nodules. Again, the prime goal of the photography was not nodule research, and so a bias exists. It is open to question whether one can estimate the total seafloor area with high density coverage by multiplying the two above percentages by the total area of the seafloor. In any event, the area of densities fitting first generation criteria must be regarded as limited.

Of course, grade and abundance are independent variables. Thus one is left with an estimate of a relatively small number of appropriate first generation mine sites based on a rather inadequate and biased data bank. Where detailed studies have been made of nodule distribution on a quantitative basis as in the 1972 CLB test (NOAA and State of Hawaii support) or in the IDOE-NSF Nodule project it is seen that topography also strongly influences distribution (and possibly grade). Greatest nodule abundances appear to occur on slopes of abyssal hills, and perhaps toward the base of the slopes. However, at the base and between hills the downslope movement of sediment either buries nodules or impedes their growth. Hill tops have intermediate populations of nodules. Such local variations, occurring over distances of 1 km or less are important in defining a mine site also, as they mean that the mineable portion of a given region may exist only as segregated zones within the region. Quantification of such patterns is necessary for the economic assessment of an area described as being of the reserve category. Such information is not generally and certainly not systematically available in the public domain. The data may be obtained through systematic quantitative sampling, detailed survey work using deep towed systems and/or narrow beam echo sounding systems, bottom photography, and acoustic navigation control.

At present, a great deal of such work is being done within the Clarion/Clipperton zone. Industrial groups in the U.S. have been carrying out systematic mapping programs for a number of years. The Applied Geology group from CNEXO-COB will have completed sampling of the intire region on a fifty mile grid of sample groups by the end of 1977 (using free fall equipment for quantitative sampling and relatively precise sample location). The German research program using the RV/Valdivia is working to a more detailed scale throughout the western portion of the zone sampling also with free fall gear, and using TV and photographic systems for continuous observations of deposit continuity. The Japanese are currently working in the extension of the Clarion/Clipperton zone west of the Line Islands. This is under the direction of the Japan Geological Survey, and is also a systematic study of the resource.

The only other programs currently in operation are those of the NOAA-DOMES program and the IDOE-NSF project. Both are operating within the Clarion/Clipperton zone and are adding detailed data for small regions. These do not have direct economic assessment as goals, but are the only programs adding to the public data base. Outside of the Clarion/Clipperton zone investigations are being carried out by the New Zealand Oceanographic Institute in the southwest Pacific and by the group at Imperial College, London in the Indian Ocean. These are the only work being done on areas other than the restricted equatorial Pacific belt, and unfortunately, at present neither is doing quantitative work. All sampling is by dredging.

At this point it is appropriate to look more closely at U.S. operations. NOAA has been involved in the investigations of manganese nodule deposits as a resource in several areas and through several funding branches. These have been the Sea Grant Program, the Marine Minerals Technology Center, and the DOMES project. Some earlier support was given to investigations connected with mining system tests - operations of Deep Sea Ventures on the Blake Plateau with an air lift system, and operations in the equatorial Pacific with the syndicate sponsoring the Continuous Line Bucket system development. In all of the NOAA projects three general types of nodule settings have been examined: deep marine deposits (ca. 4500 m), shallow marine deposits (200 - 2500m), and lacustrine deposits.

Deep Sea Deposits

Two deep sea areas have been investigated with NOAA support on cruises from the University of Hawaii. In 1969 studies were made in the north Pacific adjacent to the Mendocino fracture zone. These constituted some of the first formal work on nodule/ fracture zone associations. An extension of this work is currently being proposed in a joint study with CNEXO to examine systematically and in detail fracture zones in the north and south Pacific. Publications from the earlier work to date are Andrews (1971) and Hubred (1970). There is evidence from the work showing Fe and Co enrichment in nodules along the down thrown side of the fracture zone (seen for both the Mendocino and the Murray). This is accompanied by changes in nodule nucleation material, and possibly by changes in the rate of nodule accretion (recent work of Morgenstein and Burnet shows rates up to 80 mm/ 10^6 years).

The area of the equatorial north Pacific was visited during 1972 in conjunction with a test of the CLB mining system and an environmental assessment of the test impact. Some results of this work are published in Andrews and Meylan (1972). At the present time investigations of nodules from the Clarion/Clipperton nodule belt are continuing under the DOMES project.

The relationship between nodule nuclei and nodule composition in the marine environment has been examined by workers at the University of Wisconsin between 1972 and 1975. They have used separation techniques, bulk analysis, and microprobe analyses to demonstrate that 1) iron, though perhaps necessary to Mn growth, often acts to impede inclusion of transition metals in the nodules; 2) that the iron also impedes the removal of the transition metals due to the highly intergrown structure of the nodules; 3) the presence of calcite in the nodules makes acid extration inefficient, but does not prevent use of reductive dissolution methods on the Mn phase; and 4) silicates do not appear to play an active role in growth of the nodules except as included dilutents. A dissertation by C. Morgan (1975) resulted from this work. Moore and others at Wisconsin have also reviewed the general problems of marine mineral exploration and exploitation as they apply to Mn nodules.

Studies of the mineralogical composition of nodules were carried out at the U.S. Bureau of Mines, and demonstrated the use of infra-red techniques in mineralogical determinations (Estep, 1973). Similar work at Hawaii showed poor resolution for chemical species (eg., MnO and MnO_2) by such techniques.

Shallow Marine Deposits

Since 1971 (with a hiatus in 1973) studies of shallow marine ferromanganese deposits adjacent to the Hawaiian Islands have been carried out at the University of Hawaii. Following the 1969 cruise to the north Pacific it was recognized that large volumes of manganese crusts and nodules were forming at high rates on the submarine terraces of the island group. The rapid growth rates and the sedimentary relationships found on the terraces were examined in order to clarify the roles of mechanisms proposed for nodule growth. Principal work was in the Kauai Channel (between Oahu and Kauai) and is presented in the dissertation of M. Morgenstein (1974). Nodules and crusts form extensive covers on the surface of the terraces, and occur also as horizons within the sedimentary sequence. Dating of the substrate by hydration rind techniques on basaltic glass has shown growth rates up to an order of magnitude more rapid than those reported from deep sea nodules. Precursor affinities of manganese oxides following iron oxides are also clearly seen in the sedimentological and micro-chemical data. Crystalographic parallelism has been discussed by R. Burns et al. (1974) with similar conclusions. The deposits are iron rich and manganese poor when compared to the deep sea deposits. Additionally, they, like the fracture zone deposits, are Co rich and Cu poor (Ni values are intermediate to low). During the study independent assays from commercial laboratories showed unexpected and unusually high values of noble metals (especially platinum and paladium) in the crusts form the Waho Shelf (Kauai Channel). Emphasis was placed on this potentially valuable deposit, and while early assays showed high metal values, a series of extensive cross checks showed that all of the original work had been in error. While concentrations of the metals are higher than normal, for marine oxides, they are not of economic significance. The study has been refocused on the contrast of rapid and slow growth patterns in the shallow and deep marine environments. Any economic potential of the deposits lies in their cobalt content in conjunction with political and logistic considerations (distance from port, water depth, and geographic location within the Hawaiian archipelago).

Lacustrine Deposits

Studies of nodules in the lacustrine environment have been conducted by J.R. Moore at the University of Wisconsin during the period 1968 - 1972. A low grade manganese deposit has been mapped in Green Bay (Lake Michigan). Mn content varies form 4.4 % to 16 %.

A complete lack of correlation between nodule composition and that of the underlying sediments suggests that material incorporated into the nodules is not derived immediately from the substrate. Investigations of this material for use in catalytic operations are currently underway in industry.

All of these studies have examined limited aspects of the problems of nodule growth and origin, andhave touched only briefly in specific instances on questions of immediate economic importance. This was in accord with the scientific goals set for each project. The resource and reserve centered work discussed earlier has not been duplicated by U.S. agencies or grantees. This is information which is appropriate and necessary to intelligent control of the resource and/or to negotiation for control of the resource. It is also clear that a great deal of duplication of effort is going into obtaining this information at present, and one goal of this workshop should be directing NOAA's efforts in the matter.

Listed here are briefly some specific topics for considertation:

The resource - the general extent of deposits in all oceans at various cutoff levels in grade and abundance. That is, a definition of the extent of 1st, 2nd, ...nth generation mine sites.

The reserves - systematic information on the distribution of grade and abundance within the Clarion/Clipperton zone, and in the South Pacific and Indian Ocean zones. Especially, the extent of first generation mine sites.

Factors affecting exploitation - topography and its effect on nodule distribution, small scale features which may dictate restrictions on mineability.

Factors affecting nodule growth - growth mechanisms, seed sources, environmental controls on metal enrichtment.

Environment - near bottom (benthic boundary layer) and surface zones must be defined for both environmental and engineering purposes.

It is presumed that most of these will be handled by industry as need arises during mine site development. It may also be presumed that there should be a public source of this data and its analysis.

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Resource Research and Assessment of Sand and Gravel

Mike D. McKenzie
Office of Sea Grant
NOAA

INTRODUCTION

Several factors indicate an increased utilization by the United States of its marine sand and gravel resources in the future. Foremost among these factors are increasing demand and a decreasing supply of onshore resources.

Demand

The production of the sand and gravel industry was valued at $1.2 billion in 1972, a value which was greater than all but three non-fuel commodities. This value was realized on a production of approximately 670 million cubic yards. Even conservative forecasts of demand indicate that consumption of sand and gravel will double by the year 2000. These demand estimates are based exclusively on use as construction aggregate and do not consider sand and gravel in beach nourishment and erosion control, or future uses such as offshore island construction.

Supply

With the expansion of the urban areas which have the greatest need for sand and gravel, future onshore sources are being covered and made inaccessible. Combining this urban expansion with zoning restrictions, increasing environmental controls, and increasing land costs, one can easily understand predictions of a decreasing supply of onshore resources within close proximity to urban areas.

The marine sand and gravel deposits of the United States' continental shelf represent a huge potential resource. Although less than one percent of the shelf has been surveyed in sufficient detail to define reserves, these surveys indicate the existence of over 16 billion cubic yards of sand. The majority of continental shelf sand and gravel is contained within morphological features resulting from marine processes. In an effort to supplement the survey work done by other agencies, evaluate the material located for suitability to various uses, and better understand certain marine processes and their morphological expressions, NOAA has funded several projects in sand and gravel resource research and assessment. The following are summaries of the majority of these NOAA-supported projects. These summaries deal only with the project objectives related to sand and gravel resource research and assessment.

COMPLETED STUDIES

Resource Assessment

In conjunction with project NOMES, Loren Setlow of the Massachusetts Department of Natural Resources conducted sub-bottom profiling and drilled sample holes at and around the dredging test site off the coast of Massachusetts. The thorough description of the physical characteristics of the dredging site which resulted from this field work insured that the environmental studies to follow would be related to a potentially commercial sand and gravel deposit.

J. B. Lassiter of MIT directed research to develop a probabilistic model for estimating the volume of sand and gravel resources in an offshore area. The model was developed and then was applied to the analysis of core and grab sample data from western Massachusetts Bay.

A general agreement between model estimates and estimates derived by more routine methods was noted. The researchers concluded that their modeling approach could be useful as another approach for determining the volume of offshore sand and gravel resources, particularly in cases where some data already exists.

During a one-year study to evaluate sedimentary materials on a portion of the Virginia shelf, Maynard Nichols of the Virginia Institute of Marine Science analyzed over 300 sediment samples previously taken and defined the textural characteristics and mineralogic composition of the samples. The results indicate, based on an assumption that surface distributions extend to a depth of 3 meters, the presence of two billion tons of sand. Two major types of sand with differing distributions were described. A well-sorted, gray-colored, relatively clean, quartz-rich fine sand is distributed along the inner shelf between 5-35 km offshore. A poorly-sorted, medium to coarse sand with 5-15 percent shell occurs on outer portions of the shelf and on isolated ridges of the inner shelf. Deposits of gravel were located in isolated patches within the 20-23 meter depth range. An estimated 143 km^2 of gravel were charted, including several areas within 25 km of the Bay mouth.

One of the objectives of a project at the University of Georgia conducted by James Harding is the application and testing of sand and gravel reconnaissance survey techniques developed under another objective of the project. Some 1,200 samples were taken from 138 sites from rivers, estuaries, and continental shelf of Georgia. These samples were then correlated with existing seismic profile records. Major emphasis was placed on the Satilla, Atlamaha, and Ogeechee rivers and their sounds and estuarine tributaries. The most significant aggregate deposits of the region are the Quaternary alluvial deposits found within these rivers and estuaries. Results indicate that the best potential for commercial deposits of aggregate occur within the Altamaha River system with the Ogeechee River system second in potential.

By far the largest NOAA-funded project, either completed or current, on sand and gravel resource assessment was conducted by Ralph Moberly at the University of Hawaii. The project is the largest in terms of funding, area surveyed, and volume of sediment located. Reconnaissance sand inventories were completed for windward Oahu and leeward Oahu, Molokai and Maui, as were detailed surveys of Kahana Bay, Kaneohe Bay, and offshore Oahu. The general inventories located an estimated six billion cubic yards of sediment. These reconnaissance surveys were based solely on either seismic reflection data or widely separated grab samples. Very few inferences could be drawn regarding the commercial potential of such deposits from this type of information. However, the researchers did suggest several areas which appeared to warrant detailed surveys. Of particular interest were three areas off Oahu: 1) off Sand Island; 2) off Mokuleia; and 3) on Penguin Bank.

Resource Research

Two studies conducted at the University of Delaware developed additional information on the geology of the Delaware Bay estuary. The work directed by J. C. Kraft characterized four basic situations associated with the transgression of the Delaware Bay shoreline. In addition, the seismic substructure and sediment distribution within the Bay were defined. Cross-sectional models at several different locations were prepared from the data obtained during this phase of the research. R.E.Sheridan investigated the origin and structure of linear sand shoals of the Bay. The resulting publications described the morphology, behavior, and internal features of several typical shoals and developed models for the formation of the shoals. The ridges are structurally similar to those found on the Continental Shelf, but are formed by tidal currents and by processes like the ones which build river and stream levees. Shoal growth and migration results from erosion on the steep face channel side and deposition on the gentle flank. The researchers proposed that these linear sand ridges be named subaqueous tidal current levees.

Working in North Carolina estuaries, particularly in the area around Roanoke Island, East Carolina University investigators Stanley Riggs and Michael O'Connor demonstrated that significant redistribution of relict sediments can occur within this type of estuary. They concluded that two systems of relict estuarine sediments occur: a system parallel to the coast as a result of channel scour and deposition responding to the opening and closing of barrier island inlets, and a system perpendicular to the coast from older fluvial or tidal channels. This perpendicular system is further modified by subsequent parallel system erosion and scour.

ONGOING PROJECTS

Resource Assessment

The objective of a project directed by Peter Fischer of California State University - Northridge, is to locate and estimate the magnitude of potential sand and gravel deposits of the Southern California Shelf from the Mexican border to Point Conception. Preliminary estimates indicate the presence of 26.5 km^3 of unconsolidated shelf sediments. Seismic profiling and historical core-hole information provided by industry are being utilized to prepare a series of shelf maps for five southern California counties.

Also working on the Southern California Shelf are Tom Henyey and R. H. Osborne of the University of Southern California. The objective of their research is the characterization of sand and gravel potential of selected shelf areas off Southern California with special attention given to the areas off San Pedro and Santa Monica. Studies completed to date include the compilation of detailed surface sediment distribution maps and the identification and delineation of the principal Pleistocene and Recent unconformities. The researchers have noted a lack of correlation between the surface sediment distribution and the sedimentary units defined by seismic reflection. Areas already identified as interesting enough for further study include the mouths of Ballona Creek and the San Gabriel River and the head of the Redondo Submarine Canyon.

A project at the University of Wisconsin recently was initiated to identify and evaluate accessible sand and gravel deposits of Western Lake Michigan. Directed by Robert Meyer, the study is moving towards its first year goal of surveying by direct and indirect means areas which previous studies have identified as possible sand and gravel deposits.

Resource Research

In an attempt to define further the value of the sand and gravel deposits located in previous research, Richard Barksdale of the Georgia Institute of Technology is evaluating samples from the Ogeechee River for use as construction or specialty materials. Future evaluations will include samples from the Altamaha and Satilla Rivers and St. Simons Sound.

SUMMARY

NOAA funds expended to date on these projects total almost $800,000. The exact portion of this amount spent on sand and gravel resource research and assessment is difficult to figure because of the multiple objectives of several projects. Nonfederal matching funds for Sea Grant projects total almost $500,000. The projects presented in this paper cover a broad geographic (Figure 1) and subject range. For the most part the NOAA studies are not duplicative of the work done by other federal agencies, particularly the Corps of Engineers and U. S. Geological Survey. The majority of published information on inner shelf sand and gravel resources has been the result of Corps of Engineers research. Reports have included the east coast of Florida, selected areas of the New Jersey coast, the New England coast from Long Island Sound to Maine, and the Norfolk, Virginia area. The NOAA-supported resource assessment studies help fill in the picture of East Coast sand and gravel resources.

FUTURE RESEARCH DIRECTIONS

One appropriate and, it seems to this author, worthwhile research direction for future NOAA-supported sand and gravel resource assessment work would be a detailed and thorough study of one particular sand and gravel deposit. The Office of Sea Grant with its present legislative mandate to promote research related to the development and economic utilization of marine resources is a suitable vehicle for a joint industry-university program. Assuming the appropriate combination of industry, university, and location could be found, such a study program could provide the kind of information which must be known before industry is likely to venture into the very high cost world of offshore sand and gravel mining in the United States. It also might be possible to involve the local government in such a study because of their involvement in leasing and regulation. Unfortunately, the cost of such a study program is also very high, and the economic realities of the situation preclude the probability of any such study being undertaken in the near future.

Another direction is the continuation of the type of studies which have been undertaken to date. These general surveys are helpful in locating areas which might warrant detailed studies in the future. Such studies are particularly helpful in locales where no previous work has been done by other agencies and none is planned.

With regard to sand and gravel research throughout government, academia, and industry, two points should be made -- communication and cooperation. If offshore sand and gravel ever is to become a viable part of the economic picture, tremendous amounts of effort and money are going to be expended. The questions to be answered involve almost all disciplines. Each of the three participants listed above has something to gain by working closely with the other two. If efforts are not to be duplicative and progress is to be made, cooperation and communication are of the essence.

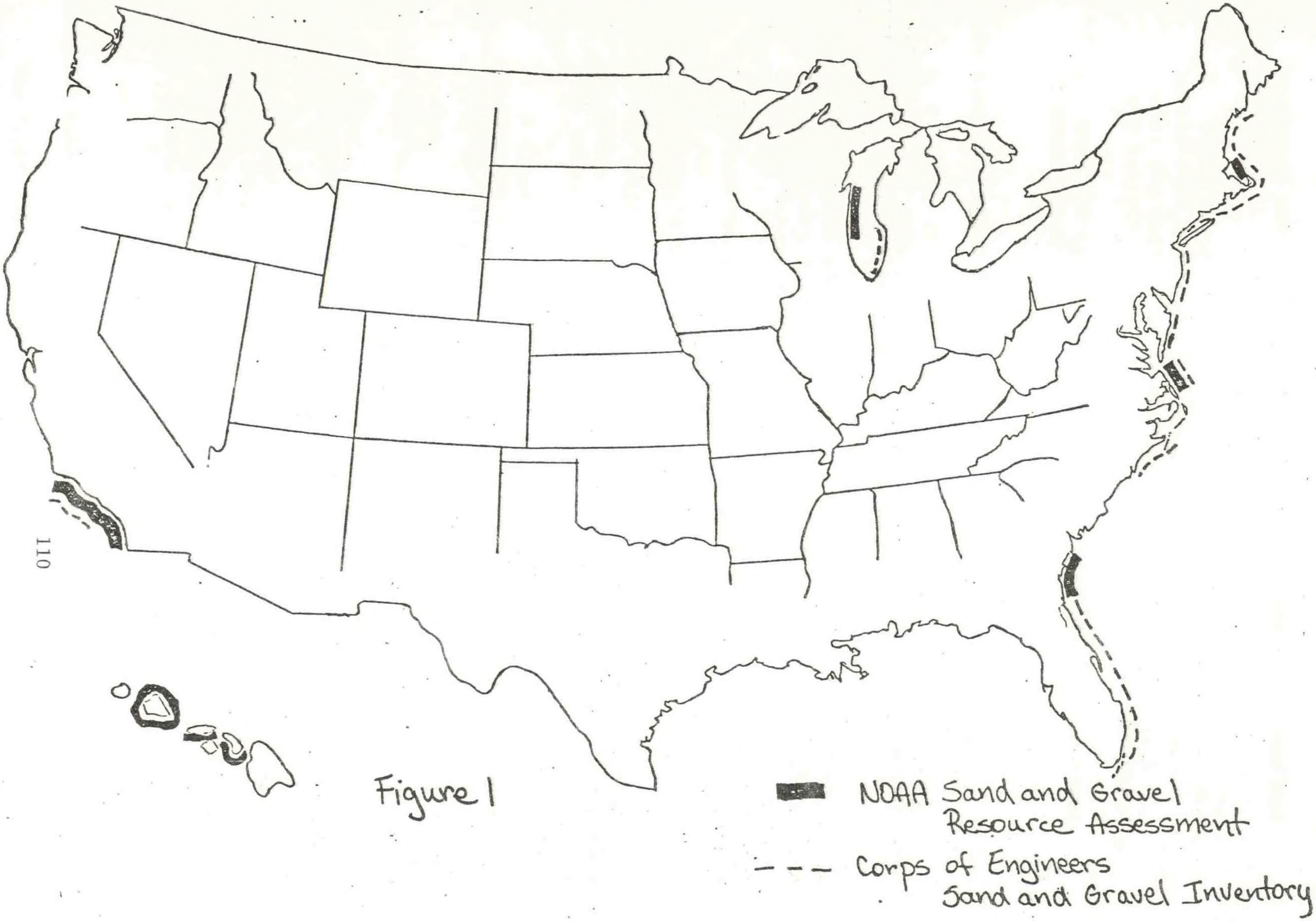
NOAA Sand and Gravel Resource Assessment
Corps of Engineers Sand and Gravel Inventory

Figure 1

Resource Research and Assessment of Marine Phosphorite and Hard Rock Minerals

Peter A. Rona
National Oceanic and Atmospheric Administration
Atlantic Oceanographic and Meteorological Laboratories

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) is involved in six projects related to assessment of marine phosphorite and hard rock minerals (Table 1). NOAA involvement constitutes support through the Sea Grant Program of four of the projects (S-3, S-9, S-28, S-32), and actual implementation of two of the projects (M-4 and S-37, NOAA Metallogenesis). Brief summaries and a list of publications are presented for each of the six projects.

PROJECT SUMMARIES

Evaluation and Economic Analysis of Southern California Phosphorites and Sand-Gravel Deposits (S-3).

The Principal Investigators of this project are Peter J. Fischer of California State University, Northridge, and Walter Mead of the University of California, Santa Barbara (Table 1). The project objective is to make a geological evaluation, integrated with economic and socio-economic assessment, of offshore and onshore sand and gravel and phosphorite deposits.

The assessment of the sand and gravel resource potential of the southern California shelf is nearing completion. The study extends from the Mexican border north to Point Conception, a distance of 460 km. Based upon preliminary estimates, the volume of unconsolidated shelf sediments is 26.5 km^3. Economic studies are in progress to determine which, if any, of these deposits are viable resources.

With regard to phosphorite, a set of maps of the southern California continental borderland has been completed showing all available phosphorite resource data.

Undersea Mineral Survey of the Georgia Continental Shelf (S-9).

The Principal Investigator of this project is John Noakes of the University of Georgia. The project was completed in 1975, accomplishing the following:

1. The technique of neutron activation analysis using a Californium 252 neutron source has been applied to both

shipboard and in situ identification of elements in seafloor minerals.

2. Field tests have demonstrated the potential of using a mobile sled equipped with radiation detection equipment to locate and differentiate between thorium associated with heavy mineral deposits and uranium associated with phosphorites.

3. Over 300 miles of Georgia coastal area have been covered by reconnaissance surveys.

Lake Superior Copper Survey (S-28).

R. P. Meyer of the University of Wisconsin is the Principal Investigator of this project which was completed in 1975. Accomplishments of the project include the following:

1. Five areas adjacent to the copper producing area of the Keweenaw Peninsula were investigated and were identified as possible target areas for future development.

2. Bottom-towed and surface-towed resistivity arrays were successfully applied to the location of known copper-bearing veins and sand deposits with high heavy mineral content.

3. An active-source audiomagnetotelluric system with towed receivers successfully detected conductivity anomalies associated with known copper-bearing veins.

4. A first-order analytical method was developed to distinguish resistivity anomalies related to bottom topography from those due to changes in conductivity.

Marine Lode Minerals Exploration (S-32)

The Principal Investigator of this project is J. R. Moore of the Marine Research Laboratory of the University of Wisconsin. The project objective is to provide basic chemical, mineral, and textural exploration clues that will indicate the presence of sub-seafloor lode bodies, particularly ores of copper, lead, zinc, nickel, and barite. The project has already received cooperative assistance from Chromalloy Corp. and ASV Corp. for surveys at industry mining sites at Castle Island (barite) and Ellamar (copper), Alaska.

Coronado Bank Phosphorite Deposit (M-4)

The Principal Investigator of this project is B. B. Barnes of the former Marine Minerals Technology Center. The project was completed in 1971, accomplishing the following:

1. A typical marine phosphorite deposit on Coronado Bank offshore southern California, was investigated to test equipment and techniques for phosphorite deposit delineation. The investigation included bathymetry, seismic reflection profiling, bottom photography, and dredging.

2. Areas of Coronado Bank that yielded the highest percentage of P_2O_5 (nodules) were related to zones of deep weathering, fractures in the sea floor, and organic activity.

Metallogenesis at Dynamic Plate Boundaries (A-1)

In 1972 the NOAA Trans-Atlantic Geotraverse (TAG) project (P. A. Rona, Chief Scientist) of the Atlantic Oceanographic and Meteorological Laboratories (AOML), dredged hydrothermal manganese oxide crusts from the wall of the rift valley of the Mid-Atlantic Ridge at latitude 26° N. Subsequent multidisciplinary investigations including narrow-beam bathymetry, gravity, magnetics, bottom photography, near-bottom water temperature and chemistry measurements, dredging and coring revealed both active and relict hydrothermal manganese oxide deposits covering at least a 15 km square area, in and adjacent to the rift valley, that has been designated the TAG Hydrothermal Field.

The TAG Hydrothermal Field is hypothesized to be the discharge zone of a voluminous sub-seafloor hydrothermal convection system involving the circulation of seawater through oceanic crust driven by intrusive heat sources beneath the rift valley. From geochemical considerations and analogy with ophiolites, such as the Troodos Massif of Cyprus, massive copper - iron stratabound sulfide bodies, are inferred to underlie the hydrothermal manganese oxide crusts, although only disseminated sulfides have been sampled to date.

A new NOAA project, Metallogenesis at Dynamic Plate Boundaries (see A-1) is being proposed to increase understanding of the hydrothermal process of metal concentration in oceanic crust, to develop exploration criteria for both active and relict hydrothermal deposits in oceanic crust *in situ* and in ophiolites, and to determine the distribution of hydrothermal deposits in oceanic crust. The Principal Investigator of this project is P. A. Rona (AOML, Miami). Ophiolites, slices of oceanic crust formed about an oceanic ridge and incorporated into certain islands and continents are presently accessible to exploitation, and are being mined for base and precious metals at certain localities such as Cyprus.

TABLE 1.

NOAA Activities in Assessment of Marine Phosphorite and Hard Rock Minerals

Project Identification*	Principal Investigator(s)	Title	Term
S-3	P. J. Fischer and W. Mead	Evaluation and economic analysis of southern California's phosphorite and sand-gravel deposits	1975-76
S-9	J. Noakes	Undersea mineral survey of the Georgia continental shelf	1970-75
S-28	R. P. Meyer	Lake Superior copper survey	1971-75
S-32	J. R. Moore	Marine lode minerals exploration	1975-78
M-4	B. B. Barnes	Coronado Bank phosphorite deposit	1968-71
A-1	P. A. Rona	Metallogenesis at Dynamic Plate Boundaries	1976 (pursuant to work initiated in 1972) - 1980

* S - Sea Grant Program
* M - Marine Minerals Technology Center
* A - Atlantic Oceanographic and Meteorological Labs, NOAA

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Resource Research and Assessment of Marine Placers

Dr. Leal Kimrey
Pacific Marine Environmental Lab.
NOAA

Projects Summarized in This Paper

Sea Grant

Project Title:	Marine Mineral Placers
Principal Investigator:	J. R. Moore
Affiliation:	University of Wisconsin
Project Title:	Marine Noble Metals Exporation
Principal Investigator:	J. R. Moore
Affiliation:	University of Wisconsin
Project Title:	Inventory of Mineral Resources Off Chesapeake Bay
Principal Investigator:	Maynard Nichols
Affiliation:	Virginia Institute of Marine Science
Project Title:	Undersea Mineral Survey of the Georgia Continental Shelf
Principal Investigator	John Noakes
Affiliation:	University of Georgia
Project Title:	Size Analysis and Heavy Mineral Distribution in Delaware Bay Sediments
Principal Investigator:	B. P. Glass (Project terminated before completion)
Affiliation:	University of Delaware

Non-Sea Grant

Project Title:	Alaska Marine Heavy Metals
Principal Investigators:	Marine Minerals Technology Center STaff
Affiliation:	Department of the Interior (Subsequently, MMTC became a component of the Environmental Research Laboratories of NOAA.)

INTRODUCTION

In view of the accelerating diminishment of our terrestrial mineral resources, it becomes increasingly imperative that we develop the ability to locate and exploit marine mineral deposits. Of the potentially exploitable ocean-related mineral resources, it would seem that the near-shore, marine placer deposits should provide the most likely candidates for early exploitation. Their potential is believed to be enormous, but despite decades of research, we still lack a precise understanding of the nature and genesis of such deposits. NOAA's interest in marine placer research has been evident since its establishment in 1970. The initial focal point of this interest was the Marine Minerals Technology Center, which was dedicated to marine minerals research until its demise in 1973. In addition, NOAA has funded considerable academic study of marine placers through its Sea Grant Program. The following summary covers those Sea Grant projects that have been concerned either with the genesis of marine placers, or with the development of tools and techniques for assessing marine placers. The summary also includes some pre-NOAA work conducted by MMTC because of its relevance to the subject.

Project Title: Marine Mineral Placers

The objectives of this project are to establish exploration guides for low and high energy commercial marine placers. In an early phase of this project, research was directed toward achieving a better understanding of the processes related to placer genesis. A heavy mineral study area in Dare County, North Carolina, was used to observe the location and conditions under which placer minerals accumulate in various marine environments. The study area, which included Oregon Inlet, a portion of Pamlico Sound, the Atlantic Ocean, and coastal beaches, was physically monitored with respect to wave and current regimes, bathymetry, and sediment texture in order to classify existing marine placers. Seafloor surface sediment samples were collecting using a pipe dredge and SCUBA methods. Laboratory analysis of 550 samples yielded median diameter, sorting, skewness, and density values.

In the laboratory, flume studies, concerned with the critical conditions of incipient motion, transport, bypassing, and deposition of heavy and light minerals in the 2.65 to 5.18 gm/cc density range, were conducted to quantify the dynamics of placer formation. Known fluid conditions of formation were then related to the dynamically less understood natural area.

Two types of loose boundary marine placers were observed in the field and artificially formed in the flume: (1) Laminar placers formed on a planar bed and preserved above mean sea level and (2) disseminated placers formed in a ripple environment below mean water level.

The laminar deposit often approaches a one hundred percent concentration of heavy minerals and contains a high ratio of dense, economically significant minerals. Light mineral bypassing during heavy mineral deposition accounts for the richness of the laminar deposit. The disseminated placer on the other hand, may contain only two to six times the heavy mineral concentration existing in the average sediment in a region. This is due to the heavy placer minerals being deposited with their equivalent light mineral sizes in aggrading ripple troughs.

Based on the dynamic mechanisms of placer formation, this study provided a generalized process-response model for locating and spatially delimiting heavy mineral accumulations in the high-energy, near-shore, estuarine, and beach zones.

In a different phase of this multiphased project, studies of selected bays along the Alaskan coast indicated the presence of very fine-grained placers formed under low energy conditions. Careful study of the grain size, constituent mineralogy and specific surface area shows that the low energy placer is in no way related to the winnowing process associated with high energy deposits. Once the fine-grained heavy mineral or metal particles are introduced into the transport system alongshore, they remain in suspension for considerable lengths of time and only when they are transported into bays or inlets, where the water turbulence is greatly reduced, do they settle and become a part of the bottom deposits. It is also pointed out that while density limits the size range of particles that respond to Stokes Law, the small-size ranges (2 to 50 microns) are largely controlled by the electrical and other surface properties of the particles. Precisely how, and under what natural conditions these placers form, is still not understood.

Project Title: Marine Noble Metals Exploration

The objectives of this project are to trace regional dispersal trends of gold and platinum, to define the economic potential for gold and platinum in the area of Kuskokwim Bay and Seward Peninsula, and to acquire basic data on noble metal particles in order to design mining and processing systems.

The contribution of the project to date has been the discovery of potentially economic deposits of gold in the Tuksuk Channel and its extension into Grantley Harbor, and the development of an "exploration window" concept whereby correlation ov V, Mn, Fe, Cr, and Au provides clues to locating underwater low-energy deposits. In developing the exploration window concept, the researchers departed from the noble metal halo-mapping approach, which former explorationists had used with less than resounding success and, instead, approached the problem from the trace-element and textural relationship to the processes occurring in the offshore conduit. Subjecting chemical and textural data obtained from samples in the Goodnews Bay area (a known platinum producing placer area) to a computer statistical program and deriving correlation coefficients for several chemical and textural parameters, the researchers were able to establish a new, albeit empirical, approach to the locating of noble metal placer deposits. They concluded that:

(1) Critical empirical relationships between selected trace elements exist and identify sites of marine noble metal placers

(2) The key parameters which are strongly positive in inter-parameter correlations are, for elements, vanadium, nickel, copper, zinc, and manganese; for textural grades, are granule, very coarse sand, and coarse sand. A strong negative correlation is reported between very fine sand and the above parameters.

(3) For a marine gold placer, the key parameters which are strongly positive in their inter-parameter correlations are, for elements, vanadium, iron, cobalt, nickel, copper, and zinc. The sole textural grade showing a high positive correlation is mud, while the only negative textural parameter is fine sand.

(4) Although positive correlations exist between some parameters common to both gold and platiunum systems, regression plots show distinctly different ratios. These differing ratios suggest that different processes are operative in the respective placer formation regimes. Instructive examples are the ratio of copper/cobalt and copper/zinc, by which identification and separation of the gold and platinum placers is recognized.

(5) Although the observations are empirical, it is believed that they may be fruitfully applied in marine placer exporation programs.

In a different, but somewhat related phase of this program, possible economic deposits of gold were discovered in the Tuksuk Channel and its extension into Grantley Harbor. The source of the gold is believed to be the Bluestone River, the site of mining activity in the early 1900's. Geochemical analysis shows that the silty schistose gravels along the shore of the Tuksuk Channel have high iron, cobalt, nickel, zinc, manganese, silver, lead, and copper concentrations relative to the rest of the study area. This enrichment in trace metals reflects the geochemistry of the rocks believed to be the source of the gold in the area (the schists of the Nome Group).

Variation analysis comparing fifteen pilot mining samples, which showed gold concentrations, with a second group of fifteen pilot mining samples which showed no gold concentrations, shows that, as a group, the samples with gold tend to have significantly more coarse sediment, less fine sediment, coarser mean grain sizes, a tendency towards more positive skewness, higher kurtosis values, and higher levels of copper, zinc, nickel, silver, iron, manganese, chromium, and vanadium than the samples without gold. Concentrations of molybdenum and cobalt were higher in the samples without gold than in the group of samples which contained gold.

Correlations between trace elements and petrography reveal the "conduit" processing of sediment originating in the Grantley-Tuksuk area as it disperses through Port Clarence into the Bering Sea. Few correlations are found between trace elements in the sediments from the bottom of the Tuksuk Channel and in the stream samples from the Grantley Harbor area. This is due to the mixture of material derived from schist and slate outcrops, quartz veins, and fine-grained silt and clay found in these sediments. A greater number of correlations between trace lements is found in the beach sediments collected from the shores of Grantley Harbor due to the low amount of find-grained sediment in these samples. To a large extent, these correlations reflect the trace element content of the outcrops in the immediate vicinity.

The extensive correlations between trace metals found in the organic-rich muds from the bottom of Grantley Harbor suggest that the presence of organic matter may be important in the enrichment of certain trace elements in these fine-grained sediments. This is further suggested by the fact that the same trace elements which correlate with each other in sediments collected in the offshore Seward Peninsula region from Port Clarence to Cape Prince of Wales also correlated with the percentage of fine-grained matrix shown in petrographic thin-sections of these sediments. The slopes of copper vs. zinc regression plots for samples in the offshore Seward Peninsula region, the muds from the bottom of Grantley Harbor, and the beach sediments from the shores of Grantley Harbor are almost identical, suggesting that these sediments are derived from the same source area. The fact that samples collected in Norton Sound offshore of Bluff show the same pattern suggests that the slope of the copper-zinc plots reflects the nature of the metallogenic province as a whole, and not just the rock outcrops found in the Grantley Harbon area alone. Textural, petrographic, and geochemical analysis of the offshore Seward Peninsula show three distinct areas of sediment types. A broad shelf along the shore from Cape York to Tin City is characterized by coarse sediments derived mainly from outcrops and glacial debris in the area. A large sea valley which may represent the extension of the Tuksuk Channel into the Bering sea during a previous lower sea level is partially filled with fine-grained sediments which are in part derived from sediment originating in the Grantley Harbor region and the rivers draining into the Imuruk Basin (which is connected to Grantley Harbor by the Tuksuk Channel). Low ridges of quartz sand found south of Cape York and just west of Port Clarence may represent relict beach ridge-bar complexes formed during lower sea levels. Gold concentrations have been found in sediments along the coast south of Port Clarence at the mouth of the Feather River. It is possible that the submerged beach ridge complexes off Port Clarence may also be potential marine gold placer sites.

Project Title: Inventory of Mineral Resources off Chesapeake Bay

The objectives of this project were to evaluate sedimentary materials on a portion of the shelf off Virginia for potential mineral resources, and to define the textural and mineralogical composition and concentration.

The one-year effort consisted mainly of laboratory analyses of more than 300 samples collected on prior cruises. Grain size was determined with a Woods Hole Rapid Sand Analyzer and gravel was determined by sieving. Mineralogical composition of sand size material was accomplished under a binocular microscope and heavy mineral content was determined by heavy liquid separation as well as by petrographic examination. Results were compiled into a series of distributional charts showing the location, extent, composition and grade of surface sediments. The heavy mineral fraction comprises between 0 and 20 percent by weight of the total sample, averaging 5.3%. The dominant heavy minerals are garnet, magnetite, ilmenite, hornblende and epidote. Less abundant are kyanite, sillimanite, andalusite, apatite, tourmaline, rutile, and zircon. In general, weight percent of the heavy mineral fraction varies inversely with the grain size. Garnet, hornblend, and the opaque minerals dominate the coarser fractions. Combined percentages of economically important rutile, ilmenite, and zircon locally reach 1 to 1-1/2 percent. Distribution of the heavy mineral assemblage exhibits a concentration paralleling the coast in a depth zone between 9 and 18 meters. Enrichment in this zone is most likely produced by hudraulic fractionation of wave action. Heavy minerals are supplied to the area from the Chesapeake and Delaware as well as from relict deposits on the shelf floor.

Project Title: Undersea Mineral Survey of the Georgia Continental Shelf

The objectives of this project are: (1) to develop and apply a Cf-252 neutron activation analysis system at sea for a) in situ seafloor mineral analyses; b) shipboard analysis system, and (2) to determine applicability of newly developed tools and techniques to mineral exploration in the Georgia coastal area.

In an early phase of this project, a series of field tests were conducted to determine the feasibility of using neutron activation systems for in situ exploration of marine mineral deposits. Cf-252 was selected as a neutron source material because of its dual merits of high neutron production and record of dependable operation.

A sodium iodide thalium-activated crystal detector was selected for gamma-ray measurements due to the high cross section of the crystal for detection and the wide operational range.

A multi-channel analyzer provided pulse height analysis and data storage. The field tests of the system involved three modes of transport to deliver the neutron system to the seafloor: a SCUBA diver team, a manned submersible, and an underwater sled.

The first series of field tests involved the use of the Westinghouse Deepstar 2000. The housing for the Cf-252 was placed in a container attached to a 12-foot boom rigged forward of the hull and in full view of the observation ports. The radiation detector, encapsulated in a watertight container was attached beneath the bow overhand. Activation was accomplished by maneuvering the submersible so as to bring the activation source directly over the target sample.* After activation, radiation measurements were made by moving the Deepstar forward until the detector was positioned on the sample.

The second series of tests utilized a towed underwater sled. The source was attached to a 7-foot handling hook, which was swivel-mounted on a mast to allow activation of targets within a 7-foot radius. The detector unit was similarly mounted. The activation-detection sequence paralleled that of the manned submersible. The source was positioned over the target sample, activated for 4 minutes and then the sled moved forward to position the detector on the sample for radiation measurement. In the last series of tests, a two-man SCUBA diving team was used in shallow water. One diver handled the neutron source container mounted on the end of a 7-foot pole while the second diver handled the detection system.

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* Since the primary objective of these initial tests was to establish the feasibility of the neutron activation system, synthetic ore samples contained in plastic jugs were used in all tests.

The Deepstar, with its self-contained power and life-support capabilities is the superior survey vehicle for delivery of the neutron activation system to depths greater than 60 feet. In shallow water, the diver team proved a good method of delivery. The sled, on the other hand, while functional, would require some mode of self-propulsion for practical application.

The analytical results obtained in this initial series of field tests not only showed the feasibility of this approach to in situ marine mineral analysis, but also suggested a technique for a rapid, accurate, and non-dstructive technique for the analysis of marine samples aboard ship.

The concept fo a non-destructive neutron activation analytical technique for shipboard use materialized as a system consisting of a 1-milligram Cf-252 source housed in an irradiator constructed in the form of a sphere and designed to accept both bulk and core samples. The analytical system consisted of two lithium-drifted germanium crystal detectors, NIM bin electronics, casette magnetic tape storage, a PDP-11 8K memory computer, and a 4096 channel pulse-height analyzer.

Irradiated samples were analyzed in a 4-inch walled, lead-shielded counting chamber which had sample entry ports at the sides and top. The two detectors were mounted at the top and bottom of the counting chamber to provide optimum gamma-ray detection. The system was tested on a four-week cruise during which a wide spectrum of oceanographic samples were collected and analyzed. The samples consisted of marine sediments, manganese nodules, sediment cores, biological samples, air particulate samples, and sea water samples, which were analyzed for trace metals. Duplicate analyses of these samples were subsequently conducted ashore at the Georgia Institute of TEchnology Nuclear Reactor Center.

From the analytical data obtained, it was concluded that neutron activation analysis at sea with Cf-252 can be a very versatile tool, but in order to produce sensitivity levels required to analyze oceanographic samples ranging from trace metals in sea water (ppb) to whole percentages of potential ore minerals, a Cf-252 source of 10 milligrams or larger must be used to reach the flux levels necessary to analyze all elements of interest.

During the course of the work with these neutron activation systems, highly sensitive radiation detector tools were developed with which, it was believed, naturally occurring radioactivity of certain amrine mineral assemblages could be measured. Basing the approach on the established association of thorium and its associated decay daughters in heavy mineral deposits, which contain monazite, epidote, sphene and zircon, and the uranium and its decay daughters associated with phosphate deposits, especially those with high apatite content, a system was developed that can differentiate between the thorium associated with heavy mineral deposits and the uranium associated with phosphorites. The system allows rapid and real time measurements of these two radioisotopes on the seafloor.

The instrumentation includes a towable sled and a static radiation analysis system. The sled is the basic vehicle used to carry a rapid analysis system to the seafloor, and can be towed at speeds between 3 and 5 knots. Contained within the sled, which is constructed of heavy stainless steel, are four gamma-ray detectors consisting of three-inch, thalium-activated sodium iodide. This system is used to identify the gross radioactive parameters of the seafloor relative to high anomalies of natural gamma radiation. A companion, static system, encompassing a lithium drifted germanium detector is used for specific isotope identification to verify the uranium-thorium daughter family affiliation and further delineate the target zone of potential interest within the area surveyed with the sled system.

One of the latest products of this project has been the development of a sophisticated surveillance system for seafloor survey and mineral exploration. The Seafloor Surveillance System (S^3) is essentially a controllable undersea platform for transporting various instrumentation beneath the sea. It is 10 feet long, 6 feet wide and 4 feet high from the bottom of the skid to the top of the stabilizer fin. It is constructed of aluminum and fiberglass and weighs 700 pounds without instruments. The vehicle is readily transportable and easily launched from a vessel. Tow and control characteristics are excellent. In sea tests, the platform proved very stable. a characteristic that greatly enhances the sensitivity of side scan sonar and underwater TV. Provisions have been incorporated for the easy attachment or removal of instrumentation as dictated by the task, thereby eliminating the need for tying up excessive permanently installed instrumentation. The S^3 also contains a servo-operated sampler that can be operated by the shipboard controller to retrieve seafloor samples when the vehicle is towed with its runners touching the seafloor. A 7-conductor, 3/8-inch diameter armored cable is used to tow and supply operational DC power to the S^3 and affords a means for multi-instrument data retrieval to the surface ship.

Based on the success of the S^3, plans are now underway to design two advanced surveillance systems, one capable of operating at 600-meter depths for outer continental shelf work, and another capable of operating at 6000 meters for deep water mineral explorations.

Project Title: Alaska Marine Heavy Metals

The objectives of this project, conducted in the Norton Sound near Nome, Alaska during the summer of 1967, were to test and evaluate geophysical, drilling and shipboard sample processing equipment and techniques.

Vessels

To provide a suitable platform from which to conduct this work, a 205-foot, former Navy Fleet Tug (AFT 108) was acquired and converted to the drilling research vessel, R/V VIRGINIA CITY. The R/V VIRGINIA CITY was equipped with a 40-foot drilling tower designed to permit over-the-side drilling by the two drill systems scheduled for testing during the project. Storage facilities for both systems and their drill pipe were also installed to permit ready exchange of the systems on site. Other modifications included installation of sample processing facilities, a chemistry laboratory, a mineralogy laboratory, helicopter landing pad, and modern navigation and communications equipment. When completed, the R/V VIRGINIA CITY provided working and living accommodations for 25 crew members and 25 professional and technical personnel.

Arrangements were made with the U.S. Corps of Engineers to use the 40-foot tug, YAMHILL, stationed at Nome, Alaska, for the geophysical survey work and also to provide logistic support and assist in the 4-point mooring of the R/V VIRGINIA CITY at drilling sites.

Geophysical Survey

A high resolution, shallow penetration (less than 1000 feet) subbottom profiling system, developed by the Shell Oil Company to delineate shallow features associated with the bedrock and overburden was used for the survey. Five hundred twenty-seven line-miles covering a 200 square-mile area extending from Cape Nome on the east to a point 13 miles west of Nome, Alaska, and extending from the shore to an average distance of 5 miles seaward were surveyed during the project period.

A sea-borne cesium magnetometer-gradiometer system was also tested, but because of major structural damage to the tow vehicle suffered early in the operation, only about 50 line miles of data were acquired.

Precision location during the survey was provided by a Hastings-Raydist radio navigation system, a non-line-of-sight system consisting of two accurately located shore received-transmitter stations and a shipboard navigator (transmitter-receiver) which provided both digital and strip chart readout. Operated in the range-range mode, distance from each shore station was determined by means of phase comparison of continuous radio signals. Position accuracy of the system was checked by daily pre- and post-survey calibration at a known and fixed point.

Positioning accuracy of the system depended on many factors, and could range from a theoretical 1.5 feet to 15 feet. At worst case, the accuracy of the system was still far greater than the ability to plot the data on any map or chart of a practical working scale.

During the survey, preliminary interpretations were made in the field providing data to assist in selecting drill sampling sites. Final interpretation of the data resulted in the compilation of a series of contoured maps, charts, and cross-sections which defined salient bathymetric, structural, and isopach features pertinent to the project area and to the related deposit delineation research performed therein.

Drilling Systems

Two drilling systems, designed for the purpose of obtaining samples in unconsolidated sediments were tested. Both were adaptations of conventional pile-driving hammers. The difference between the two systems was principally in the driving head. Neither device rotated the drill.

The Becker Hammer Drill was driven by a Model 180 Link-Belt diesel pile driver hammer, which delivered 8000 foot-pounds of energy approximately 91 times per minute to the 5-1/2-inch O.D., double-walled drill pipe. Incremental samples were obtained at six-foot intervals by pumping compressed air or water through the annulus to a point 3 inches above the cutting face of the "crowed-in" bit, where it was introduced into the 3-inch I.D. inner pipe to flush the sample increment to the surface.

The SoniCo Resonant Frequency Drill, an experimental system developed by SoniCo, Inc., a subsidiary of the Shell Oil Company, was driven by a modified Bodine vibratory pile driver head. An oscillator, operating at 50 to 100 cycles per second, induced longitudinal vibration corresponding to the resonant frequency of the drill pipe. When the frequency of oscillation exceeded the resonant frequency of the surrounding sediments, a "fluidizing" effect was produced which allowed the penetration of the drill by simple gravitational force. However, in practice, a "pull-down" was needed to achieve satisfactory penetration rates. The SoniCo drill pipe with a 4-inch O.D. and a 2-1/16-inch I.D. was somewhat smaller than the Becker pipe. Sample retrieval was accomplished in the same manner as with the Becker system.

During the test period, 56 holes, ranging to a depth-below-seafloor of 244 feet, were drilled producing 627 incremental samples having a total dry weight of over 21 tons.

Operationally, the differences between the two systems were negligible. Set-up time and penetration rates were comparable, with the SoniCo appearing to have somewhat the better depth penetration capability. This was possibly due to the smaller diameter of the drill pipe used by the SoniCo.

The principal problems encountered were: ship movement during drilling operations, plugging of the bit by cobbles, sample "run-ins" which produced excessive sample, and the length of the sample increment. This latter, together with the mixing produced by the sample retrieval method, obliterated any fine stratigraphic detail and precluded any attempts to correlate seismic horizons with physical characteristics of the sediment.

Sample Processing

Because detrital gold was believed to be the principal economic mineral contained in the sediments of the test area, the sample processing facilities were designed primarily to accommodate conventional placer testing procedures, but to preclude overlooking possible sub-visible gold values, the capability of making gold analyses by a combination of wet chemical and atomic absorption spectroscopy techniques was also included.

Typically, the incremental samples were processed in successive steps as follows: volume and weight of solids were measured and recorded; screening to remove plus-3/16-inch material and disintegrate clay lumps, desliming, concentration of heavy metals and minerals by hand panning, removal of the gold from the pan-concentrate by amalgamation with mercury, parting of the gold from the mercury and, finally, weighing the gold. After the visible gold was removed from the pan-concentrates, the remaining material was analyzed by atomic absorption techniques to determine the subvisible gold.

Most of the mineral dressing and analytical equipment adapted readily to use aboard ship. Precision weighing, long a problem in performing precision analyses at sea, was satisfactorily overcome by use of a gimbaled weighing platform designed and constructed by MMTC. Using this apparatus, and a Cahn Gram Electrobalance, weighing to 0.01 milligram could be accomplished routinely.

Six hundred twenty-seven drill core increments and 111 miscellaneous samples having a total dry weight of 42900 pounds were analyzed for gold content aboard ship.

Mineralogy/Petrology

The small, but well-equipped mineralogy laboratory examined all 627 incremental drill samples while aboard ship. Mineral constituents were identified and their relative abundance estimated by microscopy techniques. Grain size was also estimated and the shape, roundness, and other characteristics of the grains recorded. Petrologic examinations and identification of the rocks found in the samples were also made. The mineralogist also logged core as it was received and obtained samples for future study ashore.

From these preliminary studies, it was concluded that the sediments were a heterogenous mixture of glacial detritus consisting of varying amounts of boulder, gravel, sand, and "rock-flour". Compositionally, these materials reflected the predominantly metamorphic nature of the rocks of the adjacent land mass in that, for the most part, consisted of schistose, gneissic, and other metamorphic rock fragments together with the minerals derived therefrom. Calcareous material was relatively common, either as somewhat metamorphosed limestones, or as calcareous, graphitic schists and shales. Locally, organic matter, shells, foraminifera and authegenic pyrite were abundant.

The bedrock underlying the sediments is predominantly schistose, but limestone and grandiorite were also encountered in the drilling.

Technology Development for Manganese Nodule Mining

Dr. Thomas W. Chapman
Department of Chemical Engineering
University of Wisconsin

One aspect of NOAA's marine minerals program relates to the development of technology for exploration, characterization, mining, and processing of manganese nodule resources. Accordingly, NOAA research projects in this area have been aimed at generating basic data and providing appropriate methodologies that complement and support the efforts of the underwater mining industry in these various phases of their endeavor.

Almost ten years ago the staff at the Marine Minerals Technology Center (MMTC) in Tiburon, California, developed a vertical test tank as a facility for testing seafloor sampling devices and underwater tools. This facility was used by MMTC staff as well as NOAA contractors to evaluate various core samplers, lift devices, and other sampling tools in order to assess possible sample distortion by their use in seafloor investigations.

Specific efforts aimed at determining the physical characteristics and engineering properties of the sea floor by electrical and acoustical measurements were carried out by B. B. Barnes and co-workers at MMTC from 1969 to 1973 (1,2,3). The geophysical methods developed there were used from shipboard to classify the bottom sediments in San Francisco and Monterey Bays, and the results were tested by core samplings. Unfortunately, the closing of MMTC in 1973 precluded further development and application of these important techniques within NOAA.

Geotechnical properties of marine sea floor sediments are important factors in the design of any system or structure which derives support from the sea floor or subsea floor materials. Sea Grant sponsored research at the Marine Geotechnical Laboratory, Lehigh University (Adrian F. Richards and others) from 1970-1974 was directed toward development of new equipment to measure, in-situ, geotechnical properties of deep-sea sediments from research submersibles, although with slight modification the techniques were adaptable to a surface vessel. With cooperation from industry, two in-situ probe systems (vane shear and combination core penetrometer and gamma-ray densitometer) were designed, built, tested and used (3a).

With the instrumentation developed a large number of measurements were made (and compared to analogous measurements in sea floor samples obtained in cores) in the Wilkinson Basin (off northern New England) and the San Diego Trough (off southern California. Because of the numbers of measurements and the consequent knowledge of these areas, they have been proposed as marine geotechnical development and demonstration areas.

In addition to the techniques and technology developed, the Lehigh team have demonstrated that in-situ density of silty sediments is less than cored sediments from the same site, and that shearing velocity, not rotation speed, controls the vane shear strength tests (3b).

In 1972 MMTC supported work at the U.S. Bureau of Mines by P. S. Estep on the chemical and mineralogical characterization of ferromanganese nodules (4). Infrared macro and microanalyses provided information about the structure of manganese nodules from diverse geographical locations; such information is relevant both to research on the genesis of nodules and to considerations of potential processing techniques.

Under the auspices of Sea Grant considerable manganese nodule research has been conducted at the University of Wisconsin at Madison, primarily by Professor J. Robert Moore in the Marine Research Laboratory and more recently in our hydrometallurgy research group in the Department of Chemical Engineering.

Professor Moore's initial concern was with the manganese nodule deposits found in Green Bay, Lake Michigan (5,6). Between 1968 and 1972 a very thorough study of the region yielded an assessment of the manganese nodule resource, a mapping of the sub-lake structures, and a unique environmental base line. The nodules in Green Bay are unusual in their low content of valuable transition metals and their small size (0.1 to 1.0 cm) so that they are not economically comparable to the deep-sea nodules. On the other hand, their accessibility at a depth of less than 100 feet may make them attractive for some purposes. For example, the manganese reserves in this location are estimated at 4.5×10^9 kg (6), which may be of strategic significance. Also, the high surface area of the Green Bay pellets makes them interesting as an inexpensive natural adsorbent or oxidation catalyst for industrial applications (7,8).

The Wisconsin work on ferromanganese nodules was expanded by C. L. Morgan and J. R. Moore in a detailed study of the microscopic structure of nodule samples obtained from various Pacific and Atlantic sites as well as those from Green Bay (9,10, 11,12). Morgan employed a selective leaching method using hydroxylamine hydrochloride which dissolves the manganese phase and separates its constituents from those associated with the iron phase. The differential dissolution results, which were corroborated by electron microprobe analyses of the same samples, indicate that copper and nickel accumulate primarily on manganese-rich surfaces, whereas cobalt may be at least partly tied up with the iron. This result has particularly important processing implications.

Because most of the visible research and development in this area has been aimed either at locating the nodules and explaining their formation or at the mechanical harvesting or mining problem, there has been relatively little discussion of the processing problems associated with commercial extraction of metals from the nodules. On the other hand, inspection of the current patent literature reveals that several companies are quite actively seeking technology for economical processing. Because of their unique physical and chemical structure, nodules are not amenable to the conventional technology used to process land-based ores. The metals in the nodules are so intimately mixed that they require new separation schemes. It seems quite likely that a primarily hydrometallurgical process will be required to accomplish the necessary chemical separations of the nodule metals. That is, the metals must be put into aqueous solution (leached), separated while in the ionic form, and then reduced to the pure metal state. Such wet chemical methods will be required because the traditional physical and pyrometallurgical techniques are not capable of performing the required separations.

With the benefit of Professor Moore's cooperation we have been studying the application of hydrometallurgical technology to the processing of marine ferromanganese nodules. With samples generously donated to Dr. Moore by several industrial groups, we have been able to investigate leaching rates and efficiencies. Specifically, we are looking at aqueous ferrous chloride as a reducing agent and have found that copper, nickel, and cobalt are readily brought into solution at room temperature in a matter of minutes with this system.

The metals in solution can be concentrated and separated by solvent extraction with liquid ion exchange. We have worked with several commercial extraction reagents to provide basic engineering data and to determine under what conditions quantitative fractionation of the metals present in the nodules can be accomplished (13). For example, copper and nickel in sulphate solution can be separated by di-(2-ethylhexyl) phosphoric acid (14), and similarly copper and zinc in chloride solution can be separated cleanly by tri-octylamine (15). The extension of these results to additional metals is currently under consideration. Electrochemical cell design for ultimate metal recovery as well as for the regeneration of the nodule leaching reagent is also under study (16).

Finally, in collaboration with our colleague D. F. Rudd, we are seeking to elucidate general principles of process flowsheet synthesis and optimization for multiple-metal extraction schemes. The objective of the engineering work outlined here is not to develop a specific process for nodule treatment but rather to provide basic information that will be relevant and applicable generally to any of the class of hydrometallurgical processes currently under consideration for commercial development.

Within the context of this workshop it seems appropriate to recall a 1973 report by J. R. Moore and M. J. Cruickshank of MMTC on the gaps to be bridged in exploration technology for marine ferromanganese deposits (17). This thorough review cited a need for extensive basic data from a variety of disciplines as well as for instrumental methods for efficient seafloor sampling and in situ analysis. Beyond the enumeration of specific gaps, Moore and Cruickshank made an interesting proposal. They suggested that all of the problems involved with nodule resource development will become clear only when an attempt is actually made to locate and mine a deep-water deposit. They proposed that a pilot project be undertaken in the public sector with participation by scientists and engineers from various fields in industry and universities as well as government. In this way, the true technological problems to be faced could be brought to light. Even though industry is apparently moving ahead to such a pilot mining project on their own, the political uncertainties in the underwater mining area may yet jeopardize such plans, and the proposed arrangement may deserve serious consideration.

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Sub-Title: Project S-10
Project Title: "Geophysical Investigation of Potential Aggregate Resources in the Georgia Coastal Area"

Principal Investigator: James L. Harding
Affiliation: University of Georgia

INTRODUCTION

The lack of quality construction aggregates is creating an economic problem for industrial sand and gravel users in some parts of Georgia. This scarcity is caused to some extent by depletion of acceptable local deposits and higher costs of transportation of aggregates from distant locations. The shortage is magnified by the rising costs of transportation of materials both by rail and trucks. There is a need for locating new sources of sand and gravel and the purpose of this project was to investigate the feasibility of using local river sands and gravel to alleviate the shortage of aggregates in the coastal plains area. In addition the investigation dealt with materials available from the continental shelf. Samples were obtained from various locations and the materials were tested in the laboratory to determine their value to the construction industry. Other potential users considered were those who produce glass, abrasive sand and those who are involved with beach replenishment.

EXPLORATION TECHNIQUES FOR AGGREGATE RESOURCES

Three principal areas of investigation were selected; these are the rivers Satilla, Altamaha and Ogeechee and their estuarine tributaries. The exploration was done in a 52-ft research vessel with a navigation draft of 6.5 ft and a 20-ft catamaran raft constructed to carry the coring gear. The draft of the raft was of the order of 2 feet of water. The equipment used in exploration can be divided into three types: 1) geophysical, 2) drill sampling, and 3) support apparatus. Most of the gear in the last two categories was designed and built especially for this project.

The geophysical gear included the seismic profiler, using lower frequency pulses which were less attenuated in traveling through sediments, thus capable of reflection from additional interfaces below the bottom. These interfaces represent differences in acoustical impedance, which is the product of the density of the material and speed of the sonic energy. It was possible to record the density changes, such as from sand to silt, from sand to clay, gravel to sand, etc. The profiler used on this project was the EG and G UNIBOOM and the records obtained show penetration of over 200 feet in certain areas.

There were two types of drilling systems used. First, the jet-airlift system, and second, the hammer-water lift system. The jet-airlift involved the principle of an airlift pumping system; however, a casing was added to significantly reduce the sample contamination to acceptable levels. It was possible to attain a hole depth of about 50 feet in a near-shore marine deposit consisting of mud, sand and gravel. It was not possible to penetrate dense clay deposits greater than 3 ft thick or sedimentary rock thicker than 6 inches. The hammer-water lift system is based on a simple design where a casing is driven into the material to be sampled. The representative core is cut from the sediment by cutting shoe, which is then broken down by the combined action of a composite churn bit and water jets which extend down through the casing from the hammer. It was concluded that the expanded drill sampling program has worked well and when combined with more precise horizontal position system, would permit delineation of aggregate deposits with sufficient accuracy for commercial exploitation.

EVALUATION OF OFFSHORE SAND AND GRAVEL DEPOSITS

To accomplish this part of the research, the following methodology was used:

1. Review of available literature in the area of mining techniques, dredging methods and cost and applications of river materials,
2. Selection of representative samples,
3. Laboratory investigation which included gradation tests, specific gravity, absorption, and sand equivalent,
4. An evaluation of the feasibility of using sand and gravel from local sources as construction material.

SUMMARY AND CONCLUSIONS

This study indicated that there is an abundant quantity of quality sands and gravels available and suitable for commercial uses in the coastal regions of Georgia. Economics of mining of these sediments will depend on the mining technology, development of methods for locating and testing prospective deposits and adherence to the rules and regulations pertaining to the environmental impact of mineral recovery from the coastal regions.

The studies conducted in Georgia are good examples of what can be done to improve exploitation techniques for sand and gravel and how the deposits can be located and evaluated. This type of information should be available along all of the coasts of the United States and it appears that NOAA should encourage or sponsor not only the development of new tools and new technology for sampling these deposits economically, but also to convince the various states and other agencies to map potential sources of sand and gravel along all of the U.S. coasts.

Sub-Title: Project S-13

Project Title: "Evaluation and Recovery of Offshore Sand Resources"

Principal Investigators: Ralph Moberley, Fred Casciano and Robert Palmer
Affiliation: University of Hawaii

INTRODUCTION

There are two industries of great importance in Hawaii which depend strongly on the supply of sand. One is construction, the other, tourism. It is estimated that about 200,000 cubic yards of sand are used annually as concrete aggregate. Hawaiian beaches are prime attraction for tourists and are also used by Hawaiians for their own recreation. Since there are very few rivers carrying sediment in Hawaii, very little sand comes from the rivers to replenish the eroding beaches. In order to supply the construction industry with sand aggregate, beach sand is often used for that purpose and a conflict arises between the construction industry needing the sand resource and the tourist industry trying to protect beaches.

Sands in Hawaii are in a state of dynamic equilibrium and for each beach system there appears to be a long-term balance between the supply of new sand and permanent loss of sand. A number of studies were conducted between 1963 and 1968 prior to the initiation of this project on the origin of sand, the fluctuation of beaches in nearshore sand and permanent loss of littoral sand. A bibliography on previous work was reported in June 1969 .

ACCOMPLISHMENTS

Reconnaissance work off windward and leaward Oahu, Molokai and Maui was completed as well as detailed surveys of Kahana Bay, Kaneohe Bay and offshore Honolulu, Oahu.

The methods used included the analysis of all available aerial photographs and sampling charts with a view of locating the areas of sand deposits. Sub-marine sand deposits are usually visible on aerial photographs up to depths of 20-30 feet off Hawaii. There are a number of large sand-bottom channels which cut through the reefs and it is believed that sand moving from these channels to deeper water is usually completely lost to the beach system. Consequently, the location of these channels are of prime interest to any offshore mining operation.

Reconnaissance surveys were used employing a sparker-type seismic reflection system of the Hawaii Institute of Geophysics. Such a system consists of EG and G sparker, an Alpine wet-paper recorder and a 25-ft towed hydrophone array as well as HP differential amplifiers and two Khronhite filters. It is believed by the researchers involved in this project that the bottom and sub-bottom reflections can be traced with sufficient confidence and that sediment deposits as thin as five feet can be mapped.

SAND OFF LEEWARD OAHU

The surveys indicate that the sector between Makua and Kepuhi Points contains about 40 million cubic yards of sand and about 2/3 of the sand was found to be between 180- and 300-ft depths. Between Kepuhi and Maili Points it was found that about 75 million cubic yards of sand was available and the major deposits of sand were found at depths shallower than 60 feet. From Maili Point to Barbers Point there is about 85 million cubic yards of sand and almost half of which is in the 120-180 ft depth range. The two sectors between Barbers Point and Keahi Point and Keahi Point and Honolulu Harbor entrance have about 80 and 90 million cubic yards, respectively. The sand is deposited between 120- and 300-ft depth contours. The total sand deposits off the leeward side of Oahu are of the order of 3.7×10^8 cubic yards.

SAND DEPOSITS OF LEEWARD MOLOKAI AND MAUI

The sand deposits off the leeward coast of Molokai contain about $1{,}138 \times 10^6$ cubic yards of sand in depths ranging down to 300 feet. A lot of the sand is quite fine and even after discarding all of the finer sand sizes, the medium grain size is lower than that required by the ASTM standards for concrete aggregates. There are two areas of Molokai which contain some coarser sediments and are deserving of further investigation. The areas surveyed off Maui contain $2{,}898 \times 10^6$ cubic yards sediment. Much of the surface sediment contains a lot of fine material not suitable for concrete aggregate. There are a few areas which look more promising and should be investigated further.

SEDIMENTS IN KAHANA BAY, OAHU

This study at Kahana Bay concentrated principally on the description of the sedimentology of that bay in connection with the sediment transport. The data indicated that there is a seaward transport occurring along the eastern reef edge and that the wave oscillations present at depths of at least 30 feet may be responsible for some lateral distribution of sediments as well as seaward transport at depths exceeding the Null Point. Most of the sediments and calcareous sands from the eastern reef were primarily responsible for the prograding of the stream mouth sandbar.

OFFSHORE AND OTHER SAND RESOURCES FOR OAHU, HAWAII

A summary report was prepared and published in May of 1975 on projects sponsored by NOAA. It was concluded that sand was a vital raw material for the construction industry in Hawaii and the greatest usage occurs in Oahu from sources at Papohaku Beach and Molokai and crushed dune sand limestone at Waimanalo. In view of the law ending exploitation of beaches alternate sources for future supply of sand must be found. Factors of economics, quality and pollution will have to be considered in a decision-making process as to which of the following sources will be used:

1. All beach ridges and dunes, now inland and commonly needing crushing on Oahu, Kauai, and Maui,
2. Basalt lava to be quarried,
3. Quartz sand to be imported from a continental source, and
4. Sand bodies offshore but beyond the beach systems to be dredged from around and near Oahu.

The final summary also provides information on location, thickness and extent of offshore sand bodies near Sand Island, Mokuleia, Waimea, Kahana, and Penquin Bank. It is recommended that the quality of these deposits be determined either by private dredging or coring.

COMMENTS

Sand aggregate is an important resource in the construction industry and this project was certainly worthwhile as a step in the evaluation of offshore sources of sand. The same type of approach should be used in all coastal states to determine sand sources for concrete aggregate as well as for beach replenishment projects. In addition to obtaining samples and corings an effort should be made to obtain deeper corings as well as run some pilot channels by cutterhead dredging to determine the extent of sand deposits.

Sub-Title:	Project S-17
Project Title:	"The Science and Technology of Utilizing the Bottom Resources of the Continental Shelf"
Principal Investigator:	Robert Corell, A. Yildiz and B. Celikkol
Affiliation:	University of New Hampshire

INTRODUCTION

The recovery of useful engineering data necessary for efficient utilization of the sea floor is difficult and expensive. A low cost and effective, surface-borne acoustic soil assessment system is an attractive concept but it has not been fully developed to date. Preliminary site information is usually obtained by physical tests performed on the sediment core samples. The acoustic tests on core samples or reconstituted ocean soils serve two basic purposes: 1) they provide the dynamic soil constants, thus eliminating the laboratory measurements, 2) they provide the compression and shear wave velocity and attenuation information which can be correlated with remote acoustic surveys.

The most common acoustic measurement on soils has been to determine the longitudinal sound velocity and a great deal of work has been done on evaluating this problem. However, little information is available on the transverse wave speed. Theory and operation of a system that is capable of directly measuring shear wave velocity and attenuation has been attempted in this project and a laboratory shear wave velocity meter was developed. The system was designed with an idea of extending its use to in situ measurements.

ACCOMPLISHMENTS

The accomplishments may be summarized as follows:

1. A field theoretical model has been developed to predict interactions of acoustic energy with the ocean multi-layer sub-bottom. Computer studies were conducted to develop predictors of multilayer sub-bottom characteristics.
2. Shear and compressional wave velocity meters have been designed, built and are operational.
3. New coring and penetrometer techniques have been developed.
4. The Raytheon Company has the field data acquisition capability.
5. Raytheon Company has the computer programs that will rapidly analyze field data and determine reflection coefficients, sound speed, density and attenuation on a multi-layer basis.
6. Wave propagation properties of marine sediments such as visco-elastic, thermal, random and couple stress effects have been studied on models.
7. First order geological in situ validation of acoustic indices have been completed.
8. Project NOMES was conceived, planned and partially implemented as part of this project.

APPLICATION OF RESULTS

1. Coring technology developed in this project is being used to answer the U.S. Navy's operational needs in the Arctic.
2. Compression and shear wave velocity meters are being used as well as the theoretical modeling to investigate deep sea sediments to meet the scientific needs of the U.S. Navy.
3. Raytheon Company is making use of the surveying technology developed in the continental shelf sediment studies to identify sediment types and characteristics.
4. Studies are continuing in acoustic classification techniques in gas-laden soils for an understanding of load bearing properties of such sediments. The current studies involve the Mississippi Delta.

CONCLUSIONS

A system was developed to measure the shear wave velocity and attenuation of marine soils which appears to be adequate for soils that are predominantly coarse sand or finer material having a water content of 0.5 to about 0.2. One of the main advantages of the system is that it is of low cost and easy to apply under laboratory conditions. The accuracy of the system appears to be quite adequate.

A field theoretical model that has been developed is useful for predicting the interactions of acoustic energy with the ocean multi-layer sub-bottom and first order geological in situ validation of acoustic indices has been achieved.

It would be useful and timely to extend the application of the laboratory models to field conditions and further develop theoretical models to correlate the acoustic signals with types of sediments.

Sub-Title: Project S-25
Project Title: "Development of Vibratory Marine Sediment Samples"

Principal Investigator: R.J. Harker
Affiliation: University of Wisconsin in Madison

INTRODUCTION

Retrieval of vertical core samples in marine sediments involves the penetration of the material by hollow probe and movement of the core into the tube. Successful sampling techniques require minimization of shear forces at the probe-soil interface. One approach to minimize this problem is to employ vibration of the probe to reduce surface resistance and to achieve penetration. The optimal response of sedimentary materials to various vibration parameters is not generally known or available.

ACCOMPLISHMENTS

A test machine was designed and built in the laboratory in which a hollow cylindrical tube was driven by crank and connecting rod mechanism to produce torsional vibration about the vertical axis. Instrumentation was provided to measure the input vibratory torque by means of string gages on the drive arm. Both magnitude and phase of the torque relative to the vibratory motion were monitored. It was possible to determine from the vector relationships the effective dynamic mass, elasticity and damping components of the soil samples due to probe action as well as the basic rate of penetration.

Two soils were selected for experimental tests: red, silty clay and uniform, fine-grained silica sand.

CONCLUSIONS AND SUMMARY

It has been shown that torsional probe vibration produces satisfactory penetration rates in cohesive and granular sediments in the laboratory. In the cohesive materials the vibratory action apparently reduces the shear strength by means of dynamic remolding of these sediments. The interface phenomena are quite complex, as possibly involving local liquefaction, pore pressure, lubrication and dispersion effects.

Participation of the soil in the vibratory probe action was minimal in sand but pronounced in clay.

Equations have been developed from the laboratory data which may be used in designing the actual marine coring systems. These data and equations, however, require considerable extrapolation and should be regarded only as general indications of possible results.

It appears that a torsional probe vibration, as a coring technique, has good potential for development, particularly for surveying the bottom deposits in the ocean. Further work should be encouraged, particularly in the area of field testing of torsional vibratory core sampler.

Sub-Title: Project S-35
Project Title: "High Resolution Sub-Bottom Profiling"

Principal Investigator: Allyn Vine
Affiliation: Woods Hole Oceanographic Institute

INTRODUCTION

On land many minerals are found by this simple method; the exploration can be done by driving over the area or walking over the area in case of very rough terrain. The exploration has been going on for a great number of years and fairly good knowledge is available in regard to deposits of minerals underground.

At sea it is much more difficult to determine the mineral deposits. It takes more money and a much greater effort to locate and evaluate deposits under the continental shelf. Consequently, much less information is available and only in more recent years the information obtained was aimed directly at the possibility of one day recovering minerals from the ocean floor and from deposits below.

In spite of the tremendous progress and geological insight, transportation in high resolution observations may be needed at sea as they were on land. In order to achieve the exploitation at a reasonably fast rate and at reasonable cost, better methods must be developed to locate and evaluate deposits from the ocean floor. The projects aims involve improvement of the geophysical reflections seismography to achieve this objective.

ACCOMPLISHMENTS

A 3.2M diameter parabolic reflector was obtained and reconditioned and covered with acoustically reflective material. This reflector has been used in full-scale tow-tests to develop towing techniques. Much work remains to be done and if this method is successful it would provide the industry with a good tool for locating mineral deposits offshore. There has not been any application of equipment to a special problem, but discussions were held with many geophysicists as to whether this objective or technique may bypass some of the theoretical limitations of conventional sub-bottom measurement techniques.

COMMENTS

Both government and industry should seek new methods for facilitating exploration of mineral resources offshore and promote studies to improve the geophysical reflection seismography. This appears to be one of the methods that could provide shortcuts in both costs and time of exploration techniques.

Sub-Title: S-36

Project Title: "Development of an Acoustic Probe for Ocean Bottom and Sub-Bottom Surveys"

Principal Investigators: Willard Dow
Affiliation: Woods Hole Oceanographic Institute

INTRODUCTION

It has been shown in the past that high-frequency echo-sounders operating in shallow water are capable of penetration of the bottom up to 40 fathoms.

If a high-powered, high-frequency short pulse echo-sounder could be designed to operate closely to the bottom in any depth of water, the structure of bottom and sub-bottom sediments layering in many areas might be resolved in considerable detail. For example, a resolution of 12 kHz could theoretically approach 6 in.

Since the transmitter and receiver would be operating close to the bottom the high attenuation of the high-frequency sound over the long two-way transmission path between the surface and bottom in deep water would be eliminated. In addition, the full power of the transmitted pulse can now be concentrated over a small area of the bottom and the confusing side echoes would vanish.

If the reflectivity of various common sediments were known from prior measurements and if the receiver in deep water gear was calibrated and if the amplitude could be made linear over a wide dynamic range, it might be possible, not only to micro-contour bottom and sub-bottom layering, but eventually it may be possible to predict the composition and mineral character of the sediments from their reflectivity.

DEVELOPMENT OF EQUIPMENT

The specifications of the transmitter called for an extremely short (250 micro seconds) high level pulse containing only 1 to 2 cycles of energy at 12 kHz, and a peak power approaching 120 dB/microbar, or up to 30 dB higher than conventional sounders. Such a receiver should have a dynamic range of 80 dB to accommodate the wide range of amplitudes expected in bottom and sub-bottom returns. The deep sounder must be self-contained, battery-operated and capable of being lowered to 20,000 ft in the ocean by a ¼-in. diameter single conductor logging cable. The electrical conductor would serve to relay a trigger pulse originating at the graphic recorder keying contact to fire the deep transmitter and also to conduct output signals from the deep receiver back to the same recorder for display purposes.

A single 6-ft relay rack houses all the gear required to operate the system except for recording. These include a monitor scope, a line amplifier, filter system for processing the signals from the deep receiver prior to readout on a precision graphic recorder, a calibration signal generator, a special trigger generator which supplies pulses to fire the deep transmitter, a keying chassis for the generator, and various power supplies and battery chargers to operate these units and to recharge batteries in the deep instrument.

Field trials were conducted and those in the area southeast of Iceland were quite successful. A record from another area with the deep probe located 15-20 fathoms off the bottom indicated that there were eight sub-bottom layers spaced from 2-6 ft apart with random structure between them.

SUMMARY AND CONCLUSIONS

It is believed that a deep probe is capable of producing an accurate indication of bottom and sub-bottom reflective layering to depths ranging from 40-240 ft below the sea floor, depending on the transparency of the sediments to 12 kHz transmission. The resolution in the acoustic records is sufficiently high that excellent correlation of deep reflectors with reflective layering in sediment cores was generally realized. In addition, it appears that this resolution is far superior to that attained with conventional echo-sounders operating on the surface at least for water depths of 1500 fathoms or more. It is believed that if an alternate sounder operating at 3.6 kHz were added to the deep package, the maximum penetration would be increased significantly in many areas, but at a sacrifice in resolution proportional to the wave length.

At present the physical structure of the instrument limits towing speeds to 1 knot; however, streamlining of the deep probe would permit towing at speeds up to 4 knots.

Sub-Title: Project M-10

Project Title: "Geophysical Identification and Classification of Sea Floor Sediments"

Principal Investigator: Burton B. Barnes

Affiliation: Marine Minerals Technology Center

ABSTRACT

The experiments were developed to test and evaluate prototype tools and advanced techniques to predict geologic conditions on the sea floor. Emphasis has been placed on determining the mass physical properties of sea floor sediments and rocks using geophysical tools for the identification of associated parameters. A direct current resistivity system, utilizing a high current, low voltage source was successfully developed. It has been shown, through theoretical studies, that it may be feasible to use electromagnetic sounding to measure conductivity and thereby deduce porosity at shallow depths below the sea floor-water interface. A seismic shear wave generator prototype tool was built and successfully tested to produce the transverse wave form in saturated marine sediments. The reflectivity experiment to classify sea-floor sediments, by a ship underway, has verified previous field measurements. A relatively high degree of correlation links acoustic absorption (bottom loss) to parameters of porosity, density, median grain size, fine-grained sediment types (silt and clay) and sorting coefficients. These parameters are shown to have a decided interdependence and, more importantly, provide necessary information for practical application to engineering problems relating to underwater operations and/or excavation of the sea floor.

ACCOMPLISHMENTS

1. Determination of sediment properties was tested by means of electrical and acoustic methods.
2. Sea floor sediments were classified by a moving ship both in San Francisco Bay and in Monterrey Bay. Predictions were correlated with core sampling results.

Sub-Title: Project M-11
Project Title: "United Kingdom Offshore Sand and Gravel Mining"
Principal Investigator: Harold D. Hess
Affiliation: Marine Minerals Technology Center

ABSTRACT

"The United Kingdom marine sand and gravel mining industry is the largest and most advanced offshore mining operation of its type in the world, supplying an increasingly large portion of the concrete aggregate for the construction industry of the United Kingdom (U.K.) and bordering nations on the European Continent.

Some 32 different companies are operating more than 75 sand and gravel sea dredgers in U.K. waters, with a total capital investment for dredgers alone approaching £40,000,000, or $100,000,000. With the exception of a few barge-mounted grabs, these vessels are principally suction hopper dredgers, mostly with trailing pipes and many with self-discharging sytems. Most dredging operations are conducted on a 24-hour cycle, taking advantage of the high tides for approaching shallow-water discharge points."

PRODUCTION OF AGGREGATE

"Annual production of sea-won aggregate in 1970 was approximately 14 million tons, or about 13% of the total U.K. production, and is steadily increasing. Reliable estimates indicate that the annual offshore production in U.K. waters will approach 20 million tons in 1971, with about 12 to 13 million tons landed in the U.K. and the balance exported to the Continent. Value of the unprocessed aggregate ranges from about 12 shillings ($1.44) per ton in the U.K., to about 22 to 26 shillings ($2.64 to $3.12) per ton at more distant points on the Continent.

Approximately 80 different dredge sites fall within six principal offshore dredging areas bordering England and much of Scotland. They supply aggregate to as many as 80 and perhaps more than 100 different discharge points on the U.K. coast, plus sizable quantities exported to bordering coastal nations of Western Europe. Shoreside treatment plants, primarily for washing and sizing the aggregate, are operated at most discharge points. Shipboard processing facilities, although few, are highly advanced."

ACCOMPLISHMENTS

1. A comprehensive report describing the nature, magnitude and activities of the British sand and gravel industry was published.
2. Environmental concerns were evaluated.

CONCLUSIONS AND RECOMMENDATIONS

"With the outlook of a viable sand and gravel industry operating in the U.S. coastal waters probably within the next 5 years, it is suggested that U.S. coastal authorities and research organizations charged with basic responsibilities in this area would have much to gain from close examination and study of conditions surrounding a similar industry which has evolved over the years in another part of the world. Such an industry of relative maturity, which has already experienced much of its growing pains and many of the same problems as anticipated in U.S. waters, exists off the shore of the United Kingdom.

The basic characteristics, problems, and restraints that characterize the U.K. marine sand and gravel industry - whether they be environmental, legal, political, social, economic, or technological - all closely resemble those anticipated for a similar U.S. industry. As two very closely aligned English-speaking nations sharing a common heritage, the United States and the United Kingdom even share many the same social and economic problems, such as recent economic trends and Government anti-inflationary measures which in both cases had a profound impact on the building and construction industries of the two nations. Environmental concern in both nations is equally strong, where similar conditions and the same types of problems can be expected."

Sub-Title: Project M-12
Project Title: "Anchor Blocks in Laterally Loaded Piles"

Principal Investigators: Gordon R. Keller and James M. Duncan
Affiliation: University of California

ABSTRACT

The general objective of this research was to review and summarize the literature on the passive resistance of objects embedded in soil. The information gathered may be useful to engineers who are designing placement of objects on the bottom, whether they be anchors, platforms, or devices for mining.

ACCOMPLISHMENTS

A report was prepared which is applicable to the placement of objects, such as anchors, platforms or devices for mining on the sea floor.

Sub-Title: Project M-13

Project Title: "Diver-Operated Sea Floor Sampler"

Principal Investigator: Richard L. Jenkins

Affiliation: Marine Minerals Technology Center

ABSTRACT

A diver-operated sampler, capable of taking relatively undisturbed samples 8.9 cm in diameter and 70 cm in length was developed. The sampler was designed specifically to obtain reliable samples of near-surface unconsolidated and semi-consolidated marine sediments. Samples of sediments, taken from a selected test site in San Francisco Bay, were analyzed for their mass properties (porosity, density, etc.) and engineering properties (shear strength, bearing capacity). These data were correlated to acoustic measurements made in conjunction with a geophysical experiment conducted over the same area. The data obtained confirms a better sampling capability over devices previously used. With some engineering modification, this tool may have application in sampling placer-type mineral deposits of marine occurrence.

ACCOMPLISHMENTS

1. A diver-operated sampler capable of taking good sea floor samples 8.9 cm in diameter and 70 cm in length was developed.
2. A steady thrust, produced by pneumatics was incorporated into the design to provide penetration with minimal sample distortion.

IDEAS REGARDING FUTURE DIRECTIONS OF EXISTING PROGRAMS AND ACTIVITIES NEEDED

A. Work should continue in:

1. Development of new tools for exploration:
   a. Disturbed samples
      i. jet-airlift, hammer-water lift, submarine recovery system
   b. Relatively "undisturbed" samples
      i. vibratory torsional probe
      ii. diver-operated sampler
2. Development of remote sensing methods for exploration
      i. high frequency echo sounders
      ii. sonar systems
3. Continue exploratory methods (which are still underway, i. e., Coastal Engineering Research Center's study)

B. Work should be started on:

1. Development of new tools for exploration
      i. novel ideas should be explored to develop inexpensive, fast and reliable tools and/or methods.
2. Exploration along all coasts of U.S., Great Lakes and possessions with a purpose of completing an inventory of sand, gravel and shell (magnitude of deposits, quality and characteristics, thickness of overburden, etc.).
3. Development of new dredges purposely for sand, gravel and shell dredging (conceptual designs only). These dredges should be efficient, being able to work in significant waves up to 6 feet and designed to minimize the environmental impact (reduction of turbidity at suction, underwater pipelines, underwater discharge, etc.

   Ideas, such as catamaran hull, semi-submersible body, pump at the end of ladder, hood over the suction head, ladder movement separated from the hull movement, etc. should be evaluated.
4. Suggestions for modification of existing dredges to minimize the environmental impact and to increase seaworthiness (operation in up to 4-6 ft. significant waves).
5. Development of sorting and grading plants on the dredge itself, or on an auxiliary vessel.

C. Other Ideas

1. Review present environmental rules and regulations, particularly with regard to long-term effects.
2. Review present permit procedures with an objective to point out where bottlenecks exist and how to speed up the time now required to obtain a permit.
3. Evaluate the increase of unit cost of dredging due to environmental requirements. Obtain a benefit-cost ratio for present environmental rules and regulations.
4. Integrate all data collected by various agencies and industry (including petroleum industry - if made available) on offshore minerals. Catalog the information available, or where it could be obtained.

Technology Development for Phosphorite and Hard Rock Marine Mining

Dr. Robert P. Meyer
Department of Geology and Geophysics
University of Wisconsin

Introduction

Twenty years ago, in 1956, the Advisory Committee on Minerals Research submitted a report to its convening body, the National Science Foundation. They faced a similar problem of direction to the one we are now facing. Spurred by the continuing precarious mineral position of the United States, i.e., the uncertainty of domestic supply in terms of reserves or availability, the unpredictability of foreign supply as related to political stability, the needs for fundamental and applied research in terms of ore-forming and localization process leading to the understanding of the physical, chemical and geological character of economic deposits, they needed, as do we, to provide enough insight to "get on" successfully with the technological process of efficient targeted exploration where exploitation was politcally and practically feasible.

During the last twenty years, through called-for regional studies, using tools well-recognized and recommended by this esteemed panel, but with results from areas which were not called-for and were unpredicted, we have made immense progress in the understanding of the basis of metallogenesis-- the beginning understanding of the regional process called plate tectonics.

As regards the application of technology, what generalizations are to be drawn from this revolution in geologic thought? To my mind, the single most important technological advance which made this conceptual advance possible was the development and application of remote sensing tools suitable for continuous profile or areal measurements, instruments which are inherently self-calibrating, and which are of extreme reliability. The successor to the flux gate magnetometer, the marine proton precession magnetometer, is, of course, the premier example of this class of instrument and in the case of the evolution of the plate tectonics hypothesis, provided most of the key measurements for our new understanding.

Two key corollaries arise, one global and one technological. First, understanding of metallogenesis and development of and experience with technique is likely to need to continue as a global enterprise. The second corollary is that, in view of the high variability of physical parameters in the areas now reasonably well sampled by the profile methods, interpolating between or extrapolating away from spot sample measurements without auxilliary profile measurements is likely done at great peril, especially in potential mineral areas.

The above, I think, makes clear my first bias as a technology evaluator--highest priority in development must go to those instruments and supporting technologies which provide parameters (perhaps simple one-number spatial parameters) which can be measured widely with confidence so as to quickly and easily build properly-sampled data matrices. With the present state of our knowledge, economy of measurement in terms of quickness and continuousness is essential because of our state of ignorance about the variability of most parameters in marine areas considered in the light of sampling theory.

The smallness of the targets sought for (marine) mining purposes was brought into sharp focus in the 1956 report:

> ...90% of our metallic wealth has come from a scant thousand square miles of our domain. At the rate we are extracting what remains in this restricted area, it behooves us to start looking for another thousand square miles. Our economy and even our survival depend upon the success of our quest.

While the 1956 Committee on Minerals Research called for finding the next thousand square miles, interestingly, they did not make recommendations for or seriously consider marine minerals exploration (Sigmund Hammer, personal communication, 1976). In 1956 the oil industry was still largely based on land, as is mineral industry today, and in a technological sense the very substantial efficiencies of exploration offshore were yet to be realized by the oil industry. These advantages of marine exploration are still to be realized in the mineral sector. In terms of technological assessment in the view of this reviewer, high priority must be given to technological developments which make use of the advantages that the sea provides over exploration on land, with avoidance of the unconscionable one-for-one transplanting of technology and tools developed for land use to the sea floor, e.g., transplants of land exploration technique by the use of divers.

The next bias of this reviewer concerns nevertheless the full utilization of tools, instruments, and techniques developed by others for other reasons before embarking on adventures of wholesale redevelopment. Only by borrowing and adjusting every developed theory, technique and tool possibly relevant and sensible in the marine environment can we hope to achieve a fully multidisciplinary approach--an approach which will be required.

In the very practical realm, while we accept the need for various separate individual skills--whether they be in theory, application or analysis--I believe that in experimental programs one key individual must carry through all phases from conception through instrumentation, to application and through analysis and synthesis. Scientists and program heads who fault on participation, especially in the physically uncomfortable phases of data collection or who contract with physically remote facilities for key parts of analysis requiring scientist interaction are immediately considered suspect in this reviewer's view as to the significance of their reported result.

And finally, some evaluation of the programs to be reviewed needs to be made as to administration's expectations and realism in terms of time given and support to complete programs, and realism as contrasted with rigidity as to goals initially programmed and eventually achieved. Flexibility and utilization of serendipitous discovery is the keystone to research.

Reviews of Individual Programs

I. Real Time Electronic Positioning and Navigation at Sea

Principal Investigators, B. B. Barnes and R. Newman, Marine Minerals Technology Center. 1968-71

The need for real time shipboard information on ship's position in order to accomplish close order guided surveys is met by real time plotting aboard ship. In this system, range-range data from a Raydist DR-S system (lane width 150 feet) is interfaced to a Hewlett Packard calculator with extended memory for conversion to xy coordinates suitable for driving a plotter and digital printer (the latter vs. time). Plots are controllable as to scale and starting point, and software allows different chart projections.

The value of this development lies in the demonstration of the solution to a common problem and not in the specific hardware or the particular range-range system. This technique is now a common commercial capability.

II. Marine Geophysics: Self-Potential

Principal Investigator R. F. Corwin, University of California, Berkeley. 1969-71

Seawater filled plastic tubes terminating within the sea through graphite pencil leads and on shipboard at liquid Ag-AgCl junctions claimed stable in seawater have been developed to form the conductors for field sensing small self-potential gradients within the sea. Advantages of stability (a few millivolts noise) are claimed based on a single one-day field test without controls, e.g., comparison to more conventional metallic conductors with normal terminations (Pb). Later phases of the project are to theoretically estimate potential fields expected within the sea from sulfide ore oxidation at the sea floor and to test the probe system using a man-made deposit formed by dumping of unoxidized ore on the sea bottom.

Lab tests show the salt water electrode tube conductor system fairly well reproduces the expected shape but not amplitude of step function currents artificially induced from an external power supply into a test tank also containing the plastic tube probes.

III. Geophysical Identification and Classification of Sea Floor Sediments

Principal Investigator B. B. Barnes, Marine Minerals Technology Center. 1969-73

This was a multifaceted program focusing closely on the sediments at or very near the present sea floor. While the analysis of sediments for "geotechnical" physical engineering properties (mean grain size, sorting coefficient, shear strength, density and porosity) are conventional and well-established, the geophysical technology was not particularly well rooted. The major technological thrusts centered on the underway determination of the reflection coefficient using two different sound sources (one conventional and one new), the direct transplant of land resistivity to the sea floor using diver-operated waterproofed equipment, and attempts in the very near field to determine compressional and shear wave velocities in surface sediments using a novel (and difficult to employ) modified airgun source.

Auxilliary developments included a diver-operated pneumatic slow injection corer to achieve less disturbance to core material. Laboratory studies include examination of the role of specific ions on sediment resistivity, theoretical calculations which lead to the conclusion that the use of electromagnetic induction with a horizontal coil on the sea floor and carefully-oriented sensing coils in the very near field (up to five feet) will not adequately discriminate between various hypothetical layered sediments of various resistivities.

The investigations did not produce the expected results for, perhaps multiple, reasons. For example, in Monterey Bay, the acoustic reflection (bottom loss) experiments produced no satisfactory correlations between either the 5 kc and 12 kc source bottom loss, or between bottom loss calculated from either source and any of the physical parameters determined from either source and any of the physical parameters determined from core samples. This is contradictory to fair-to-good correlations between 5 kc bottom loss and bottom physical parameters in a much smaller test area in San Francisco Bay found earlier.

Many reasons are considered for the failure in Monterey Bay. However, the procedures in analysis were quite different for San Francisco Bay and Monterey Bay studies. In the first and successful San Francisco Bay test analogy, "hand" measurement of reflected pulses calculated at Tiburon were used, while the Monterey Bay test data were measured digitally through a contract service at a location remote from Tiburon.

Close-order experiments on the bottom using the newly-developed shear source and source receiver ranges of up to five feet produced questionable results as well. The program leaves doubt that shear waves are being generated in quantity directly from the source. V_P/V_S ratios reported are in the range of 3 to 4. Spacing of conventional geophones at one-ince increments at closer ranges, and as close as one ince from the newly developed airgun source leaves questions as to magnetic and mechanical interference and non-elastic deformation.

Finally, at least one other matter leads to uncertainty as to result, and that concerns a typical subbottom profile record (Barnes et al., 1973).* This record, made with the 5 kc sparker source used subsequently for the unsuccessful bottom loss study, shows electronic systems filter ringing after the initial bottom return in time frame of the amplitude measurement used for the bottom loss study.

IV. Undersea Mineral Survey of the Georgia Continental Shelf

Principal Investigator John Noakes, University of Georgia.
1970-75

This program is focused on the use of radioactivity whether induced or natural for sea bed assessment. Started with AEC support, the program has perhaps as an ultimate goal practical in situ towed neutron activation analysis (NAA). It has moved through a number of logical and related phases including irradiating and counting of fresh (unprepared) samples on shipboard followed with shore test controls, diver and submersible NAA testing of irradiation and detecting on a sea floor seeded with known atomic concentrations. Related is the development of cryogenetic "static underwater (proportional) γ ray detector" for natural radiation which apparently uses the same or similar shipboard proportional counters and shipboard digital analysis equipment developed for the neutron activation analysis program.

Also developed and carried furthest toward practicability is a towed sled with multiple (2) energy level detectors used to assess natural radioactivity at less than and greater than a chosen γ ray energy. An example of bottom discrimination cited is discrimination between phosphorites with associated apatite (Uranium and K^{40}) providing less than 1 mev γ rays and heavy mineral deposits (thorium) characterized by greater than 1 mev γ rays. This has been tested practically. A final corollary program concerns development of an unmanned "flyable" towed deep submergence vehicle for general exploration including TV, sampling, magnetometry with proposed terraine avoidance acoustic control but without author projection to use for in situ NAA.

*Barnes, B. B., et al. (1973) Geophysics applied to geotechnical problems in a marine environment; a case study: Monterey Bay, CA. NOAA/ERL Report to ARPA.

In regards to NAA, one is impressed with the considerable safety aspects faced in handling radioactive sources (Ca 252) at sea and by the author's remarks concerning the need for a 10 mg source, having moved from 200 μg to 1 mg during the continuing studies--apparently because of inability with reasonable radiation times, four to thirty minutes, to be able to detect (much less quantify) some "elements of interest." A detection capability test and comparison resulting has been made by retesting ashore samples analyzed at sea with a land neutron source having 10^7 higher flux than the one carried to sea (1 mg Ca 252). This summarizer's analysis is that a better detector is likely required for sea floor application rather than trying more dangerous, intense neutron sources, and that practical towed in situ NAA is still remote.

On the other hand, the relatively crude classifier of natural radioactivity, the towed sled device, seems potentially a generally operable tool having wide applicability, especially as related to heavy mineral placer and phosphorite (with apatite) exploration.

There seems to be unassessed potential in the more elegant bottom, static γ ray energy level detector system for variety of spot testing. As pointed out in a publication, there is a potential use in pre-site and continuing survey around nuclear plants, especially those intended for offshore. This is, however, not a reconnaissance tool, requires cryogenetic temperatures for the Ge(Li) detector, one-half to one hour on the bottom for one spectra and a shipboard support system including proportional counters and a computer.

V. Lake Superior Copper Survey

Principal Investigators Robert P. Meyer and J. Robert Moore, University of Wisconsin, Madison. 1971-75

The focus here was first on the offshore extensions--essentially extrapolation of an onshore mining district with an eye to the continuation offshore as well as to the inference which could be discovered offshore as regards onshore exploration. The program proceeded first with regional investigation, first employing reconnaissance tools--airgun and 3.5 kc sonic reflection profiling, refraction seismic measurements, towed magnetics, geologic inference from known bathymetry and structure, coring and dredging and beach mineralogical investigations assisted by a portable chemical lab.

The second phase, which involved both hard rock (veins) and soft rock (placers) and much the same tools, required the addition of electronic navigation and started to work toward detail in areas of anomalous behavior of trace elements and structure using inferences principally from trace elements from magnetic and sonic methods.

The third phase, specific targeting, especially required technological development to look for specific physical properties associated with copper and the testing of these methods (principally electrical) over diver-documentable deposits (veins). This again required electronic navigation and the addition of shallow water capability for all methods, i.e., transference of technology to smaller craft. The electrical methods employed were towed bottom resistivity (Wenner configuration), surface-towed resistivity (Schlumberger arrays) and prototype investigations using audiomagnetotellurics with a controlled 400 Hz source. All methods have been successful in verifying known vein deposits geophysically and in verifying a heavy mineral rich sand discovered by resistivity. Operational considerations now would favor short potential electrode towed surface resistivity coupled with towed magnetics, precision bathymetry from high resolution 3.5 kc data, and electronic navigation, all from a 35-foot shallow draft vessel as finally employed.

At the close of the final field season, widespread Keweenaw Peninsula application still remains uncompleted, as do experiments with induced polarization for the location of offshore disseminated copper deposits and deep core smmpling and drilling in targeted areas. These may be in part too expensive to undertake exclusively with Sea Grant sponsorship.

The receiving apparatus developed for resistivity includes provision for simultaneous self-potential and induced polarization measurement. The induced polarization would require extensive modifications of present power supply. Data logging capability would have to be augmented substantially to provide for these additional profile parameters yet to be employed.

VI. High Resolution Subbottom Profiling

Principal Investigator Allyn Vine, Woods Hole Oceanographic Institution. 1974-76

This current program is to develop new technology for and to explore the usefulness of narrow beam high resolution subbottom profiling. Two avenues are being pursued: up to 9 m parabolic or spherical reflectors, and the newer parametric technique to produce lower frequency narrow beams. Advantages seen in higher directivity are better S/N and minimization of side echoes. The problem is well posed, needed for rough terrain, and attempts to apply to marine problems, the techniques and technology of radio astronomy.

From a letter of 2 March, 1976, Vine to Lane (NOAA):

> On land many minerals were found by the simple method. Say 10,000 people for 5,000 years walking or riding a mile a day over frequently very rough terrain, approximately 1.0 billion eyeball miles plus.
>
> In the sea our history is very short, the numbers of people are small and the average distance per day is minute, certainly totaling less than a millionth of the work on land and highly biased towards flat sedimentary areas.

Future Directions and Priorities for NOAA and Other Government-Sponsored Research

1. If any lesson is to be learned from the experience of past work, it revolves about the need for appreciation of the media that the sea is, the need for flexibility, indeed opportunism, as to what can be quantified most rapidly with the least input of work, and especially leadership as to what and how each quanta of information knits, or can be knit, into achievable and generally useful results.

   The principle of working from the known to the unknown seems essential, and working in isolation with narrow straight-line engineering thoughts is inappropriate for marine research.

2. The problem should be turned to what can be discovered and quantified at sea and not what should be--especially as based on land experience.

   There are a reasonable number of highly successful marine technological procedures which have never been tested over known or inferable marine deposits. This should be the first order of business--to see what can be quantified over known or suspected marine deposits. One might best use reconnaissance methods, determining the regional setting--moving to local anomalies or known areas, going from general to specific both in terms of area and method.

3. Attempt extension or improvement of technology before embarking on new technologies.

Suggested order of geophysical technological applications:

1. Aero or marine magnetics, total field, total field gradient, vector field (?).

2. Simple marine profile methods:

   High resolution profiling using sources and receivers which are not omnidirectional;
   Sonobuoy refraction using airguns or equivalent;
   Towed electrical resistivity - self-potential;
   Side scan sonar, multi-beam bathymetry.

3. Higher technology profile methods:

   Short multi-element seismic streamer, principally for velocity coupled with reflectivity coefficient measurements, for these together have potential as far as bottom density determination is concerned (Porter and Bell, Raytheon).

   Consider chirp sources, parametric narrow beam techniques.

   Natural and γ ray radioactive methods, induced polarization and specific target profile methods, including deep towed equivalents of electrical, magnetic and seismic techniques, are usually justifiable by this stage.

4. Sampling--and bottom observations:

While some grid sampling is usually justifiable before this point, sampling guided by the above is far more useful now. The sampling theorem is widely violated by blind grid sampling when small targets and rapid changes are expected, as in mineral deposit studies.

A parallel land program of applicable measurement over type deposits using corollaries to methods employable at sea would seem required as well as a necessary parallel and simultaneous effort.

Technology Development
for
Marine Placer Mining

Dr. John Noakes
Geochronology Laboratory
University of Georgia

and

Dr. James Harding
Marine Extension Service
Skidaway Oceanographic Institute

S36 Development of an Acoustic Probe for Ocean Bottom and Sub-Bottom Surveys

Nature of the Investigation

An acoustical probe was developed and field-tested. This probe, consisting of a frame containing three titanium pressure cores (for electronic encapsulation) and weighing 420 pounds, was lowered to the seafloor where it measured the acoustical velocities of sub-bottom strata to a sediment depth of 15 fathoms (90 feet).

The conceptual design called for using a high-powered, high frequency short pulse echo sounder at the sediment-water interface. It was anticipated that by having both the transmitter and the receiver on the bottom, that the sound attenuation associated with two-way travel time between the bottom and the sea surface in deep water would be eliminated. An additional improvement over conventional, surface-oriented acoustical sounding devices was anticipated in that the full power of the transmission would be concentrated over a relatively small area of the seafloor, thereby eliminating side echoes.

The system consisted of the transmitter-receiver, the weighted frame, a graphic recorder on shipboard, and 0.25 inch, single conductor logging cable, which served the dual function of relaying the firing sequence to the transmitter at the bottom and conducting output signals from the receiver back to the recorder for visual display.

The transmitter utilized a 250 micro-second pulse, with 1-2 cycles at 12kHz, with a peak power of approximately 120 dB/microbar (which is about 30 dB higher than conventional echo sounders).

Test Results

The system was tested in the field at two sites: (1) in the Atlantic, north of Bermuda and (2) in the Rockall Trough southeast of Iceland.

During the first test, multiple stratification was detected to a sediment depth of 15 fathoms (90 feet), at which point a bed was encountered which was acoustically opaque to the 12kHz frequency. Problems were also met in that excessive ship rolling caused the logging cable (and hence the bottom-resting system) to make vertical excursions of up to 12 feet.

At the second test site, a 12-meter core was obtained, allowing direct correlation of the acoustical reflectors shown on the recorder with distinct lithologies. These interfaces were also compared with sound velocities measured on the core samples. The values were un-corrected for static pressure, etc. There was an abrupt increase in the velocities at silt or sand interfaces, which correspond very well with the depths of reflectors as recorded by the acoustical probe.

Application of this System to Placer Technology

This was designed as a deep water probe, and tested in water depths exceeding 1300 fathoms (7800 feet). Such depths far exceed the present state-of-the-art insofar as placer exploitation is concerned. In addition, the physical structure of the system tested precluded towing speeds in excess of 1 knot, making it essentially an *in situ* system.

As with any remote-sensing device, some form of "ground-truth" is necessary. In this case, it must be a physical core or sample.

Nonetheless, the summarizers feel that a modification of such a probe, designed for shallower water, would be a useful device in the exploration for placer deposits. It could, for instance, reduce the number of cores necessary to define a given prospect area. It also has potential in areas of the world ocean where surface access is severely limited, such as ice-bound zones of the polar and sub-polar regions. Any reduction in the number of core sites necessary for mineral site identification results in a significant saving of both time and money; and in the marine operations, time is money.

S26 Marine Mineral Placers

Nature of the Investigation

The principal objectives of this varied and widely-spaced research is to establish exploration guides for both low and high energy commercial marine mineral placers, including platinum, gold, tin, chromium, ilmenite and rutile, mercury and rare earth heavy minerals.

Although most of the investigative efforts have been spent in the bays and inlets of the Seaward Peninsula and adjacent portions of the Alaskan shore of the Bering Sea, concentrated studies have also been conducted in Lake Superior and on the North Carolina coast between Hatteras and Norfolk, Virginia.

Results of Studies

The Alaskan investigations began by applying a combination of oceanographic, hydrologic, geochemical, geophysical and mineralogic reasoning in order to delineate prospect areas. Two highly important (and impressive) concepts were developed. The first was the recognition of low energy, ultra-fine-grained placer deposits as potential exploration sites. Heretofore, the "classical" placer deposit search, more often than not, centered on areas where flowing water would have been the most effective process for separation of light versus heavy mineral fractions as well as subsequent concentration of the heavy minerals. This reasoning included stream placers, as well as beach placers formed along shore lines by the concentrating effects of waves and shore currents.

Moore and his associates resolved that perhaps a second type of marine placer may exist, in which relatively rich accumulations of extremely fine-grained (2-5° microns) particles (principally gold and platinum) could have been deposited at sites characterized by quiet, non-flowing waters, such as low-energy bays and basins. Such placer material would in no way be related to differential energy forces or to the winnowing process. Based on this research, these investigators have shown that once the ultra-fine metal particles are introduced into the transport system and as long as turbulence continues, they will remain in suspension. When transported into areas of quiescent waters, where turbulence is negligible, these particles will settle out of suspension and become incorporated into the bottom deposits. Rather than particle density (i.e. Stoke's Law) the behavior of these fine-grained particles is governed by the electrical and other grain surface phenomena associated with the individual particle.

The second exploration concept developed in these investigations concerns the "exploration window". This "window" has three basic components: (1) provenance or source; (2) conduit, or processing pathway and (3) a depositional sink. None of these are new ideas, but these investigators have broadened the scientific approach to each of these necessary components and have utilized geochemistry to a high degree in defining the most important of these components: the conduit, or processing pathway. Gold and platinum have both shown strong correlations with cobalt-copper ratios and zinc-copper ratios in bottom sediments. These trace metal studies, combined with textural, environmental and geophysical data interpretation, appear to have provided highly useful exploration guides.

The investigation conducted in Lake Superior concerned the search for underwater copper deposits adjacent or in close proximity to known copper-producing zones on the Keweenaw Peninsula. The original target was an extension of these disseminated ore-bearing zones. However, a placer copper deposit was discovered, associated with a trough-like valley, exposed during lower water levels coincident with Pleistocene glaciation.

Aside from high resolution seismic techniques, magnetics and a towed resistivity array and diver support, the field team in Lake Superior also utilized alternating current to energize vein material underwater.

The investigation conducted in North Carolina was aimed at clarification of the processes governing the formation of marine placers. The principal finding of the study was the delineation of two types of "loose boundary" marine placers: the laminar type, formed on a flat, bedding-plane surface, and the disseminated type of deposit, formed in a ripple environment. Of the two, the former is more important due to the heavier concentration of heavy minerals per laminae. Both types of deposits were studied with bed-load hydrodynamics in mind.

Applicability to Placer Technology

These studies as a whole, represent a significant contribution to the explorationist's knowledge and understanding of the processes whereby placer deposits are formed. Insofar as technology is concerned, the results to date can be used to more clearly and precisely identify the technological needs of the near future. These include such items as (1) direct metal sensing systems for *in situ* identification; (2) new and improved sampling tools for rapid evaluation of a given prospect area; (3) continued research into processes whereby placers are formed; (4) unmanned underwater mining systems possibly with diver support and (5) possible applications of remote sensing techniques.

M13 A Bottom Sitting Diver-Operated Sampler for Engineering Properties

Nature of the Investigation

This investigation was concerned with the design and testing of a pneumatically-operated bottom sitting coring unit, requiring divers for physical operation. The work was conducted in conjunction with a project designed to utilize acoustic measurements to delineate the geophysical identification of seafloor sediments underway (M-10).

The sampler was designed to take a short (2.5 foot) core, 3.5 inches in diameter. The steady thrust, produced by pneumatics, would hopefully reduce the sample distortion associated with percussion cores (gravity and piston types) and with rotary corers.

The 2.5 foot (70 cm) core length was dictated by the wavelength of the acoustical sources utilized in the ancillary investigation.

The unit was constructed of corrosion-resistant material and was built with simplicity of both operation and service in mind. Hydraulic cylinders were incorporated within the system, in order to deliver energy for core extraction.

Test Results

Three scuba divers were used on the field test in San Francisco Bay, two for operating the device underwater, and the third for topside support and safety. The divers activated valves located on the sampler, and penetration was accomplished by activating a three-way valve that drove a piston, with an attached shelby tube, into the sediments. When full penetration was achieved, a stream of air bubbles rose as air pressure was expelled through the exhaust port. A diver then closed the air tank and diverted air into one of the hydraulic reservoirs. This procedure activated the three hydraulic cylinders, slowly extending rods which caused the frame to lift from the base plate, pulling the sample barrel out of the sediment. As the barrel cleared the surface of the seafloor, caps (which were stored in a cage on the frame) were placed over the ends of the core tube. At a pre-determined stage in the ascent of the system to the coring boat, it was stopped, allowing the divers to completely remove the core barrel from the corer, and seal the tube with an O-ring seal for transfer to the deck. This procedure (capping and sealing underwater) was planned to insure that the water content of the sample remained as it was in situ.

Most of the cores obtained in the field test were between 52 and 70 cm long, with sample retention of approximately 90 percent.

The samples were analyzed for mass physical properties (porosity, density, water content, etc.) within 2 to 4 hours after retrieval. They were also analyzed for engineering (geotechnical) properties such as shear strength, bearing capacity, etc.

Applicability to Placer-Oriented Technology

Keeping in mind that this sampler was designed for a specific project which has nothing to do with placer deposits, the following favorable comments are in order:

(1) It is capable of rather rapid operation at shallow (30-40 feet) depths - average coring time per site was 15 minutes.

(2) It has good sample retention capabilities.

(3) It obtains a "relatively" undisturbed sample, which although not as important in placer technology as in marine soils mechanics, nonetheless insures sample integrity.

On the other hand, there are some drawbacks.

(1) Being diver-dependent, the cost of samples, per-foot, is very high. A remote-controlled unit may be less expensive in the long run.

(2) The core lengths are not sufficient to delineate a potential project area. Cores of at least 10-20 feet are needed to identify overburden and admixtures as well as target mineral tenor.

M10 Geophysical Identification and Classification of Sea Floor Sediments

Nature of the Investigation

A set of essentially *in situ* measurements were devised to predict the geologic and lithologic nature of the seafloor in advance of actual physical sampling. These "remote" sensing devices included the use of direct-current resistivity, using a high current, low voltage source, electromagnetic sounding to measure the conductivity and hence deduce porosity at shallow depths at or beneath the seafloor, a seismic shear wave generator and sediment reflectivity measurements. The direct current resistivity measurements were also conducted in a surface-tow array, while the ship was underway.

Test Results

(1) Resistivity

On land, resistivity is measured either by downhole logging or by using an expanding surface array (i.e. Wenner-spread). Probes have also been used on the seafloor, but an expanding surface array, deployed on the seafloor, was thought to offer important advantages; primarily, depth of sediments from which information could be obtained. Both surface and bottom-towed arrays were tested, and the results correlated with information obtained with a diver-operated pneumatic corer (Project Code M-13). In general, the bottom-deployed array gave better resolution than that towed on the sea surface; however, as the former required divers for deployment, it is much slower. Nonetheless, the test results showed that if the electrode spacings can be made large enough to force a sufficient amount of current into the bottom, and if this forced current is sufficiently large enough to produce signals well above the background noise level, important information can be obtained about the bottom sediment properties. Only the Wenner-spread was tested.

(2) Electromagnetic Sounding

This system employs a source in the form of a horizontal coil of wire (vertical axis), located at or near the seafloor, to which an alternating current is applied. The system was not tested in the field, but consisted instead of theoretical considerations only. The system yielded indistinguishable families of curves, insofar as plots of the response to parametric (frequency) sounding at constant separation between transmitting and receiving coils. Therefore, this method cannot resolve layering. Attempts were made to resolve gradient responses, but as with the field intensity plots, the families of curves were coincidental, rendering it also impossible to distinguish layering by this means.

It was concluded that a practical electromagnetic system cannot be used to yield data which can be interpreted in terms of the resistivity of a horizontally layered seafloor.

(3) Reflection Coefficient Mapping Experiment

Correlations in this study were somewhat inconclusive, but nonetheless, the investigators feel that the use of remote sensing acoustical mapping for physical properties of seafloor sediments, while the ship is underway, can be accomplished, at least qualitatively. Four problem areas arose: (1) difficulty in determining a representative statistical sample; (2) obtaining accurate near-surface sediment velocity data; (3) controlling the distance between the source-receiver system and the seafloor, in order to maintain a fixed differential area for the energy to impinge upon, and (4) maintaining the stability of the sensor package in a horizontal orientation.

(4) Shear Wave Experiment

The investigators felt that this seismic method successfully detected the direct S_h wave at one test site and in gravelly, coarse sand. In the other tests, they were uncertain as to whether the detected wave was the Shear wave or the Love wave. This was attributed in part to insufficient core lengths to ascertain sediment lithologies. However, as drastic changes in sediment properties are not generally anticipated (or encountered), and because the separation distances between source and receiver was small, the Love wave would have a velocity comparable to the Shear wave.

Application to Placer Technology

This work has more use in the engineering fields within the marine environment than in placer exploration. It could, however, have an important bearing on the production of placers, especially, if structures are involved which implant static loads. If one could relate, for instance, the textural properties, shear strength, bearing capacity, etc. to acoustical and/or seismic measurements made underway, then a physical sample (core) need only serve as an identification of mass properties (i.e. grain size, water content, etc.)

These systems also have potential uses in the deep-sea zones where ferro-manganese nodules, rather than placers, may be exploited.

M3 Heavy Mineral Placer Sampling Technique

Nature of the Investigation

Because of the relatively small volume content of valuable minerals and the ratio of these minerals to useless gangue material in any given placer deposit, the disturbance of the sample during penetration and withdrawal is thought to be a major cause of sampling error. In the case of the evaluation of placers, this disturbance could take the form of loss or addition of the valuable constituents (i.e., salting or dilution of the sample). The mechanisms whereby these changes may occur, could be the addition of mineral values from outside the sample casing, losses due to values migrating ahead of the bit, or by inflow of barren material.

Attempts were therefore made to examine the kinematic movement of particles induced by penetration of the sampling device. Experiments were carried out in a test tank located at the Marine Mineral Technology Center, Tiburon, California using sand as a simulated seafloor in the bottom of the tank.

Test Results

Tests conducted previous to this particular investigation at the Naval Civil Engineering Laboratory (NCEL) had shown that with non-cohesive soils (represented by fine sands), there was a decrease in bearing capacity when the bearing-plate area was increased. This behavior is contrary to all theories of soil mechanics, and was explained by the gradual release of pore pressure which had developed in the soil mass below the footing; the release then resulting in settlement of the plate. Based in large part on the results, it was decided that theories that are valid under atmospheric conditions were either not applicable in the hydrosphere or have to be adapted for use in the marine environment. It was therefore felt desirable to investigate the mechanics of penetration of a slender axisymmetric tube into seafloor sediments, and to do so with model-scale tubes under controlled conditions. The test tank afforded these conditions, and also allowed both fast-sequential as well as time-lapse photography for illustration of test results.

Three variables were examined: (1) diameter of the tube; (2) bit geometry and (3) sand moisture. From the results, it was concluded that all three factors have a significant effect on depth of penetration, with confidence levels of 99.9 percent for the geometry of the bit, 99.5 percent for the diameter of the tube and 97.5 percent for saturation by seawater. The geometry of the shoe and seawater saturation were considered of particular significance in penetration of the seafloor in connection with the development of sampling tools.

The shapes of the single bits employed were concave, convex and bevel angles of 60°, 45°, 30° and 15°, with bit widths ranging from 24mm to 1mm. The bit width no longer affected the width of the disturbed zone after reduction to 4mm.

Double-bit tests were performed using both crowd-in bits and crowd-out bits.

It was found that in order to reduce sample movement and distortion, the bit should be designed so that as little material as possible is forced inward.

Optimum design for conditions of light overburden pressure and/or shallow penetration appear to be as follows: (1) crowd-out bit configuration; (2) as thin a wall as possible to still insure durability and (3) as sharp a bit angle and still retain durability. Where the disturbance of the material is not detrimental, and where high-speed, high-volume sampling may be necessitated, and also where the substrate is partially indurated, the crow-in type of bit could be used.

<u>Applicability to Placer Technology</u>

In the reviewers opinion, more of this type of investigation should be conducted. Anyone who has obtained cores of marine sediments and has analyzed these for mass properties, geotechnical properties, or for mineral content, realizes the immense difficulty which can be encountered when the cores or samples are disturbed. Although not as important, perhaps, to placer technology as to engineering evaluation, the entire field of sample disturbance, including sample error, is in need of further study. This is especially true where the placer values involve the heavy specific gravity minerals such as gold and platinum.

Legal and Economic Aspects of Deep Seabed Manganese Nodule Mining

H. Gary Knight
The Law School
Louisiana State University

I. INTRODUCTION

The purpose of this paper is to summarize past and current NOAA sponsored research concerning legal and economic aspects of deep seabed manganese nodule mining. The paper is divided into two parts, the first dealing with a summary of the rather limited amount of NOAA sponsored work in this area, and the second addressing some comments on the needs and priorities for future government sponsored research in this area.

II. NOAA SPONSORED WORK

Research on legal aspects (there has been none on economics) of deep seabed manganese nodule mining sponsored by NOAA has been limited to Sea Grant support for Professor H. Gary Knight at the Louisiana State University Law Center and Dr. Edward Miles at the Institute for Marine Studies, University of Washington. In both cases the Sea Grant funds have been allocated for broader studies of national and international oceans policy, but the ensuing work did cover issues relating to the legal and political aspects of manganese nodule mining.

Dr. Miles' work is supported by Office of Sea Grant Programs grant No. 61-8246 UW, entitled "Marine Studies -- Alternative Impacts of Law of the Sea upon Organizations and Policies in Marine Affairs." This project began in 1975 and will extend through 1976 with a total expenditure of $32,200 supported by University matching funds of $25,100. The research consists of an analysis of trends in the law of the sea negotiations, a prediction of likely outcomes, and an assessment of the impact of those outcomes on organizational structure and programs in marine affairs. Two of Dr. Miles' publications relate to deep seabed mining. The first is "An Interpretation of the Caracas Proceedings," which was published in Christy, *et al.*, eds., *Law of the Sea: Caracas and Beyond* (1975) at 39. The second paper is entitled "An Interpretation of the Geneva Proceedings -- Part I," which was prepared for publication in the July-August 1975 issue of the *Ocean Development and International Law Journal*. In these papers, and most especially in the latter study, Dr. Miles has provided a meticulously detailed account of the negotiations on the deep seabed question in Committee I of the Third U.N. Conference.on the Law of the Sea. Involved in his account of the LOS Conference negotiations are such issues as (1) the relation of deep seabed mining to other important agenda items such as the establishment of a 200-mile economic zone, (2) the impact of underdeveloped countries' goal of a "new international economic order" on the seabed question, (3) the structure and impact of bloc politics in the LOS negotiations, (4) the negotiations on the treaty provisions concerning conditions of exploitation of seabed resources, (5) the conflict between res nullius and "common heritage" characterization of deep seabed resources, and (6) the negotiations on organizational structure for an international seabed mining agency.

Dr. Miles' work has a number of very useful applications. First, such accounts are important to the work of those persons in the Executive Branch of government charged with responsibility for negotiating in the Law of the Sea Conference and for developing United States ocean policy. Bureaucratic inertia being what it is, entities such as the Inter-Agency Law of the Sea Task Force often become enmeshed in their own policies and machinations, and it is therefore useful to have external inputs of the precision and clarity of Dr. Miles' work in order to facilitate the development of new perspectives on old issues. Second, such accounts are useful to members of Congress who are considering legislation to license and regulate United States citizens engaged in manganese nodule mining activities. Congress is at loggerheads with the Executive Branch on the desirability and form of such legislation, and an independent assessment of the political context in which such legislation would operate is vital. Finally, Dr. Miles'work is useful to representatives of the marine mining industry who, although assiduously following developments themselves at the United Nations, in the U.S. Congress, and elsewhere, can always benefit from the reasoned judgment of impartial observers since their economic planning must take into account developments at all levels and branches of government.

Professor Knight's work is supported by a grant from the Office of the Sea Grant Programs to Louisiana State University, and his first project was entitled "Legal Aspects of Ocean Resources Exploitation." This project continued from 1971 through 1975, and total Sea Grant expenditures during that period were $46,000 matched by $62,000 of funds from Louisiana State University. Also with Sea Grant funds, Professor Knight is pursuing a further study during fiscal year 1975 - 76 on the subject of "Alternative Methods for Effectuating United States Oceans Policy Goals After the Law of the Sea Conference." The object of the earlier study was the analysis of national and international ocean policy concerning the use of ocean space and the exploitation of ocean resources. Professor Knight has published sixteen articles directly attributable to Sea Grant support dealing with various aspects of the Law of the Sea negotiations, several of which have focused on the problem of deep seabed mining (see Annex A). Inputs from these reports have been made to the United States Law of the Sea negotiators as well as to members of Congress on various questions concerning Law of the Sea, including deep seabed mining. Whereas Dr. Miles has been concerned primarily with institutional and political science aspects, Professor Knight has concentrated on legal issues involved in Law of the Sea questions, and although both have addressed the deep seabed mining question, they have done so in different contexts avoiding any duplication of effort.

Professor Knight's current study assesses possible changes in the substance and method of achieving various U.S. ocean policy objectives under the assumption that the LOS Conference will not produce a timely, comprehensive, and widely accepted Law of the Sea treaty. In this regard he is evaluating various options for pursuing national interests in deep seabed mining other than a global treaty. Among the options he has identified to date are: (1) mining by U.S. industry on a res nullius basis without government regulation; (2) mining by U.S. industry pursuant to domestic law such as the "Deep Seabed Hard Mineral Resources Act;" (3) coordination of such domestic legislation with similar legislation in other technologically advanced nations to avoid conflicts over mining sites; (4) development of a multilateral treaty among technologically advanced nations to govern deep seabed mining; and (5) protection of U.S. deep seabed mining operations by the U.S. Navy. The utility of this research to the Executive Branch, to Congress, and to industry is similar to that of Dr. Miles, as noted above.

III. NEEDS AND PRIORITIES FOR FUTURE NOAA SPONSORED RESEARCH

The objective of any NOAA sponsored research with respect to the legal and economic aspects of deep seabed manganese nodule mining should be to facilitate exploitation of manganese nodules. This is not now national policy since the positions taken by the United States at the LOS Conference are primarily directed to other long-term foreign policy objectives and because the seabed question has been inextricably linked with other Law of the Sea and economic questions.

The fundamental needs in order to facilitate exploitation of manganese nodules are: (1) a dual change in the attitude in the Executive Branch toward a treaty on deep seabed mining: (a) a change in its negotiating strategy from seeking a global, comprehensive Law of the Sea treaty to seeking a multilateral agreement on seabed mining alone; and (b) a change from opposition to enactment of domestic legislation with respect to deep seabed mining; and (2) a change in Congressional attitude, with or without Executive Branch concurrence, with respect to bills pending before it which would license and regulate United States citizens in their deep seabed mining activities.

The likely effect of NOAA research to serve these needs is problematic. Certainly nothing can be done with respect to the changing of the attitudes of the Executive or Congressional Branch unless those charged with responsibility for deep seabed mining within the Department of Commerce are willing to challenge the strategic and tactical positions taken by the Inter-Agency Law of the Sea Task Force and by Congressional leaders. On the other hand, NOAA research could be of assistance by providing carefully researched recommendations when those attitudes do change and domestic legislation is seriously considered. Accordingly, I would make the following recommendations for NOAA sponsored research with the idea that this research should be conducted at the earliest possible time in order that the results be ready when changes in United States policy toward the LOS Conference come about.

Recommendations:

(1) Research and analysis on alternatives to a global Law of the Sea treaty to govern deep seabed mining, evaluating each alternative in terms of national policy, industrial, and consumer interests.

(2) Research on issues involved in enacting domestic legislation providing for the licensing and regulation of United States citizens' deep ocean mining activities. Among the problems which should be addressed are: lease term and area, operating regulations, royalties and fees, work requirements, risk insurance, and claim recognition reciprocity with other nations.

(3) Research on the presently applicable domestic and international laws, regulations, and procedures affecting deep ocean mining. Among the subject matter areas which should be investigated are: environmental protection, financing and taxation, safety at sea, labor standards, civil and criminal laws, liability, and responsibility.

(4) Research on the economic impacts of various alternative legislative and legal regimes to govern the exploitation of deep ocean mining.

(5) Examination of current United States laws, policies, and procedures for hard mineral mining leasing on the United States outer continental shelf. The objective would be to unblock the existing regulatory apparatus in order to facilitate access by mining companies. An examination could then be made of analogies (and limitations to those analogies) between outer continental shelf and deep ocean hard mineral mining.

Reports:

"The Draft United Nations Convention on the International Seabed Area: Background, Description and Some Preliminary Thoughts," 8 San Diego L. Rev. 459 (1971) [also published in Proceedings of the Eighteenth Annual Meeting of the Louisiana Institute on Mineral Law (1971) at 70].

"The Deep Seabed Hard Mineral Resources Act -- A Negative View," 10 San Diego L. Rev. 446 (1973) [also reprinted in Hearing on Status Report on Law of the Sea Conference before the Subcommittee on Minerals, Materials and Fuels of the Senate Interior and Insular Affairs Committee (93d Cong., 1st Sess., Sept. 19, 1973) at 300 and 370].

"United States Oceans Policy: Perspective 1974," 49 Notre Dame Lawyer 341 (1973).

"Special Domestic Interests and United States Oceans Policy," in Wirsing, ed., International Relations and the Future of Ocean Space (Studies in International Affairs, No. 10, Institute of International Studies, University of South Carolina, 1973) at 10.

"Principal Issues Before the Third United Nations Conference on the Law of the Sea," 34 Louisiana L. Rev. 155 (1974).

"Treaty and Non-Treaty Approaches to Order in the World Ocean" in Perspectives on Ocean Policy: Conference on Conflict and Order in Ocean Relations (U.S.Gov't Print. Off., 1975) at 251.

"The Third U.N.Law of the Sea Conference: Caracas," American Universities Fieldstaff Report, Vol. XVIII, No. 1, (October 1974).

"Alternatives to a Law of the Sea Treaty," paper prepared for Conference on the Law of the Sea, sponsored by the American Enterprise Institute for Public Policy and the U.S. Treasury Department (February 14, 1975).

"Jurisdictional Issues in Ocean Management," 10 Columbia Journal of World Business (No. 1) 5 (1975).

"Legal Effect of United States Signature of a Law of the Sea Treaty," in Status Report on Law of the Sea Conference, Subcommittee on Minerals, Materials and Fuels of the Senate Committee on Interior and Insular Affairs (94th Cong., 1st Sess., June 4, 1975) at 1417.

"The Potential Use of Reservations to International Agreements Produced by the Third United Nations Conference on the Law of the Sea," in Policy Issues in Ocean Law (West Pub. Co.; American Society of International Law, Studies in Transnational Legal Policy, No. 8 1975) at 1.

ECONOMIC AND LEGAL ASSESSMENT OF SAND AND GRAVEL AND SHELL MARINE MINING

Thomas A. Grigalunas
Department of Resource Economics
University of Rhode Island

I. INTRODUCTION

This paper was written for a NOAA-sponsored workshop on marine minerals. The major objectives of the workshop are threefold:

1. To provide an information base of past and present marine mineral-related activities conducted through the National Sea Grant Program and by other elements of NOAA:

2. To encourage better communications among those directly involved in marine mineral-related activities; and

3. To develop information regarding the future directions of NOAA's existing programs and activities needed to further development of marine mineral resources in an environmentally safe manner.

This paper is written in two parts. The first section contains a summary of selected NOAA funded projects dealing with the economic and legal aspects of the offshore mining of sand and gravel. This part of the paper thus deals with the first and second workshop objectives. In addition, in the second part of the paper an attempt is made to suggest at least some of what the author regards as future directions for research in this area.

It should be stated at the outset that an attempt to summarize neatly NOAA's projects on sand and gravel is frustrated for several reasons. First and foremost, many of the projects that are to be summarized have not been completed as yet, and the best we can do in such cases is to look at the kind of output we can expect when the study results become available. Secondly, as we shall see, the studies reviewed are pretty disparate and cover a range of subjects and geographic areas. With these caveats in mind, let's turn to a summary of the projects.

II. SUMMARY OF RESEARCH

A. General Comments

Six NOAA-sponsored projects on offshore sand and gravel mining are summarized in this paper. For convenience the projects are listed below.

REF.	PROJECT TITLE	INVESTIGATOR/ INSTITUTION
S3	Evaluation and Economic Analysis of So. California's Phosphorite and Sand and Gravel Deposits	Peter J. Fischer Cal. State, Northbridge Walter J. Meade Univ. California Santa Barbara
S12	An Evaluation of Coastal Sand and Gravel Deposits as Construction or Specialty Materials	R. Barksdale Univ. of Georgia
S18	Developing a Management Program for Offshore Mining of Sand and Gravel	J. Schubel SUNY, Stonybrook
S19	Marine Resources Legal Research	S. Wurfel Univ. of No. Carolina
S21	The Economics of the Ocean Mining of Sand and Gravel Off the Coast of Rhode Island	T. Grigalunas Univ. of Rhode Island
M11	United Kingdom Offshore Sand and Gravel Mining	H. Hess Mar. Minerals Tech. Center

As is evident from the above listing, the projects cover a range of subject areas, including physical/geological resource assessments (S3, S12), economic evaluations (S3, S12, S21), environmental issues (S3, S18), legal considerations (S19), and a review of offshore sand and gravel mining experiences and issues in the United Kingdom (M11). The projects primarily deal with offshore mining issues, although one study (S12) is concerned with sand and gravel mining in rivers. The studies seem to focus on the exploitation of offshore sand and gravel for commercial applications, and with the apparent exception of one project (S18), little attention is given to issues dealing with beach restoration or dredging in connection with navigation issues. None of the studies summarized here have looked at the mining of shell.

In terms of funding, NOAA has committed a total of some $164,000 for the six studies summarized here. The largest single NOAA grant is for $40,000 for legal research, although the study in question (S19) is much broader than just sand and gravel, and in fact offshore sand and gravel issues are only treated incidentally. The bulk of the research funding has been for work in the areas of marine sand and gravel resource assessment and economics.

B. Specific Comments

This section contains a brief summary of the six projects included in this section of the workshop.

1. Evaluation and Economic Analysis of Southern California's Phosphorite and Sand and Gravel Deposits (Drs. Meade and Fischer).

This project began in 1975 and is scheduled to be completed in 1976. The project involves a geological evaluation integrated with an economic and socio-economic assessment of offshore vs. onshore sand and gravel and phosphorite deposits.

The study area extends from the Mexican border to Point Conception. Considerable progress appears to have been made on the physical assessment of resources, and economic studies are in progress to evaluate which, if any, of the offshore resources are economically recoverable. A questionnaire regarding onshore resources has been mailed to southern California sand and gravel plants in connection with the economics portion of the study.

2. An Evaluation of Coastal Sand and Gravel Deposits as Construction or Specialty Materials (Dr. Barksdale).

The objectives of this study are to identify potential uses of coastal materials, develop mixture combinations of materials for potential uses, develop material specifications for specified uses and evaluate the economic feasibility of using these materials for particular applications. Samples of sand from three rivers and the St. Simon Sound will be used to assess their suitability for construction, and perhaps other uses. This project thus has elements of resource assessment, engineering, and economics/marketing. The study began in 1975, and the estimated date of completion is 1977.

3. Developing a Management Program for Offshore Mining of Sand and Gravel (Dr. Schubel).

This study began during the summer of 1975 and still is in progress, with a first report due in the early spring of 1976. The research objectives include: a determination of use and needs, and assessment of the quantity and quality of the resource and an evaluation of environmental impacts associated with a variety of mining strategies. The results are intended to assist the State of New York in the development of a management plan for the mining of sand and gravel from coastal waters.

4. Marine Resources Legal Research (Dr. Seymour W. Wurfel).

This project has been active since 1970 and is scheduled to be completed in 1977. A very broad spectrum of marine resource subject areas have been addressed in numerous reports. Based on the work that I have had the opportunity to see, sand and gravel issues have received only incidental attention in a report by Elliot Dahle, "The Continental Shelf Lands of the United States: Mineral Resources and the Laws Affecting Their Development Exploitation and

Investment Potential" (UNC-SG-73-11). This study deals primarily with a broad survey of legal and institutional issues, and the economics involved is of a very general, descriptive nature.

5. The Economics of the Ocean Mining of Sand and Gravel Off the Coast of Rhode Island (Dr. Grigalunas).

The objectives of this study are to assess the prospects for the mining of sand and gravel off the coast of southeastern New England under given conditions regarding geology (size and character of the deposit), technology, water depth, distance from port, cost and market price. The focus of the study is economics.

6. United Kingdom Offshore Sand and Gravel Mining (Harold Hess).

This study was initiated in 1970 and completed during the summer of 1971. The objectives of the study were to "investigate nature and magnitude of sand and gravel industry working in North Sea and other areas off the United Kingdom; learn if environmental impact problems were being encountered or studied." This study resulted in the publication of an extensive and very widely cited report, "Marine Sand and Gravel Mining Industry of the United Kingdom" (NOAA Technical Report (RL 213-MMTC 1)). The report summarizes the United Kingdom experience with offshore sand and gravel mining in such areas as the legal/institutional setting for leasing, technology, economics and environmental problems and issues.

Approximately 12.6 million tons of sand and gravel were mined off the coast of the United Kingdom in 1969, and the cost of sea dredging--exclusive of shoreside treatment and delivery costs--ranged from $.35 to $.49 per ton ($1969). Among the legal/regulatory issues encountered were: the terms for granting exploratory licenses, the design of leasing systems, and the monitoring of dredging activity.

III. SOME DIRECTIONS FOR FUTURE RESEARCH

Various estimates have been made of the possible future importance of offshore sand and gravel and shell mining. One recent estimate, for example, is that the volume of sand and gravel recovered from all marine sources could nearly double from 1973 to 1985, increasing from 44.5 to an estimated 82 million tons, and roughly double again from 1985 to the year 2000, from 82 to 159 million tons (U.S., 1974, pp. 42-43).[1] According to this report, the bulk of marine sand and gravel mining is expected to occur in bays and estuaries.

It bears emphasis that forecasts like the one cited here have been developed on a highly aggregated geographic basis. Such estimates are useful for the broad purposes for which they are intended but are of little use for management purposes. It remains to be seen how such estimates can be improved upon by the results of area-specific micro-oriented production studies of the sort summarized in this paper. It also remains to be seen whether marine sand and gravel mining will be encouraged or discouraged by emerging state/federal policies on marine mining. Nonetheless, if forecasts like the above can be accepted as a reasonable view of the future of marine sand and gravel mining, several broad directions for research are suggested.

Attention should be given to the development of rational state and federal management schemes. Research is called for in the legal/regulatory area relating to the design of efficient exploration, leasing and monitoring alternatives. For example, what are the relative merits of government vs. private exploration? With private exploration, should the rights be assigned on an exclusive or on an open basis? Is the cash bonus approach to leasing contained in the OCS Lands Act of 1953 appropriate for potential OCS sand and gravel, or are alternative allocative schemes--e.g., assignment of tracts based on competitive work programs or annual area rentals--more suitable? The work by Hess (M11) gives us some understanding of the experience in the United Kingdom with legal/regulatory issues such as those raised here, but the U.K.'s experience may not be appropriate for the U.S. Experience gained with a prototype leasing arrangement also would be instructive.

The economic dimensions of possible external effects of marine mining need research in terms of (1) the possible effects of mining particular deposits on the biota[2] and (2) the possible side effects of sand and gravel mining in nearshore areas on natural beach replenishment.

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[1]The same source indicates that the marine mining of crushed shells is expected to grow very slowly, increasing from 20 million tons in 1973 to an estimated 28.4 million tons by the year 2000. Virtually all of this activity is expected to continue to take place in the Gulf of Mexico(U.S.,1974, p.43).

[2]Ideally attention would aslo be given to the possible environmental consequences of substitute onshore mining sites in order to appreciate the net environmental effects of onshore vs. offshore means of meeting given demands.

In my opinion it would be desireable to attempt to quantify economically some of the environmental aspects of marine sand and gravel mining. It may be most difficult, in practice, to measure the economic effects -- perhaps the best that can be done is a "worst case" analysis. Nonetheless, I believe it is important that, if at all possible, we try to place numbers on the economic dimensions of the environmental issues involved with offshore mining, so that we can get some feeling for their importance and thereby improve the management-resource allocation process. As far as the marginal payoffs to social investment is concerned, this seems to be an area that merits research emphasis.

One final comment is in order. The problems likely to be confronted in an assessment of many marine sand and gravel operations involve elements of economics, marine biology and geology, ocean engineering, and perhaps other disciplines. In view of the multi-faceted nature of many of the issues associated with marine sand and gravel mining, it is appropriate to suggest the need for interdisciplinary research.

REFERENCE

U. S. Congress, Senate Committee on Commerce, The Economic Value of Ocean Resources to the United States, by Robert Nathan Assoc. (Washington, D.C.: Government Printing Office, 1974).

Economic and Legal Assessment of Phosphorite and Hard Rock Marine Mining

Dr. Walter J. Mead
Department of Economics, University of California, Santa Barbara

This report, consisting of an economic and legal assessment of phosphorite, hard rock, and other marine minerals, will report on four studies as follows. (1) Michael A. Almond, "Legal Aspects of Phosphate Mining in North Carolina," Sea Grant Publication UNC-SG-75-05, February 1975; (2) Elliott Dahle, Jr., "The Continental Shelf Lands of the United States: Mineral Resources and the Laws Affecting Their Development, Exploitation, and Investment Potential," Sea Grant Publication UNC-SG-73-11, June 1973; (3) James R. Woolsey, "Evaluation of Confining Strata Associated With Principal Coastal Georgia Aquifer," study currently underway; and (4) P. J. Fischer and W. J. Mead, "Evaluation and Economic Analysis of Southern California's Phosphorite and Sand-Gravel Deposits," study currently underway.

(1) "Legal Aspects of Phosphate Mining in North Carolina," by Michael A. Almond is part of the larger study being conducted at the University of North Carolina Sea Grant Program under the overall direction of Professor Seymour W. Wurfel. This study presents a brief history of phosphate mining interest in North Carolina; describes the extent of the on-shore phosphate reserve; reviews the world "need" for phosphate fertilizer; discusses three types of environmental issues including air pollution, land reclamation and ground-water damage; identifies the extent of North Carolina State Government regulation; and finally, reviews the possibility of private legal action both to protect private property rights and to protect environmental interests.

The author points out that legal control and remedies discussed in the paper depend ultimately upon the wisdom, discretion and public accountability of government officials. Protection of environmental quality similarly depends upon the behavior of public officials, upon their perception of their role, and upon their political constituency. At present North Carolina state laws grant broad discretionary powers to state officials in implementing environmental standards. An apparent high degree of legal flexibility will therefore produce different results depending upon the individuals who happen to exercise the state legal authority.

The enormity of North Carolina's phosphate reserves (the formation underlies more than 700 square miles and the deposit runs to a maximum thickness of about one hundred twenty feet) and its location (entirely on shore but forty feet below sea level at its highest point and more than 230 feet below sea level at its lowest point) create enormous legal problems. There is currently only one active mining operation in North Carolina phosphate reserves. This operation covers approximately 30,000 acres of which approximately 9,000 are on lease from the state of North Carolina. This state lease covers reserves located under the Pamlico River. The lease operator is Texasgulf, Inc. The company currently has invested approximately $175 million in phosphate production with the investment being initiated in 1963. The method of recovery is by strip-mining the **overburden,** using large drag lines to mine a 150 feet wide trench three thousand feet long. After the overburden is removed then phosphate ore will be recovered, mixed with water to form a slurry, then transformed into phosphoric acid (P_2O_5) by combining the phosphate rock with sulphuric acid.

In the process of mining operations, existing ground water rights may have been damaged leading to the possibility of legal action to recover losses in ground water rights. Owners and lessees of shellfish beds and commercial fishermen whose property rights may be affected by mining operations may also bring legal action against mining operators. Also, there is a question of ownership of phosphate deposits lying under the Pamlico River. Currently the state of North Carolina has asserted ownership rights and leased mining rights in exchange for percentage royalties and annual rental fees.

Finally, the author raises the issue of a possible "public trust doctrine" which may be asserted to prevent environmental and ground water property rights damage. According to the author, this doctrine states that

> "The state holds the land under the navigable waters of its sounds, rivers, bays, and inlets in trust for everyone. Simply stated, this doctrine of public trust says that every member of society possess such intrinsically important rights, privileges, and interests in these waters, that it is the duty of the state to protect them."

On the basis of this public trust doctrine, the state of North Carolina, or perhaps private parties might seek legal relief to prevent use of the leased river bottoms on the grounds that mining operations are inconsistent with some concept of the public welfare.

The Almond report is limited to legal aspects of phosphate mining. Its economic content is virtually nil. The report asserts that "Texasgulf's gamble has proved spectacularly successful." There is no evidence offered in support of this economic evaluation. No evidence is presented on annual profits or losses. The authors would be required to show that Texasgulf is earning a super-normal rate of return on its $175 million investment. No such evidence is shown.

(2) "The Continental Shelf Lands of the United States: Mineral Resources and the Laws Affecting Their Development, Exploitation, and Investment Potential," by Elliott Dahle, Jr., begins with a section which attempts to provide the reader with a working knowledge of the continental shelf's physical characteristics and its present boundaries. Part two of the study presents an overview of the mineral resources which are known to exist in or on the continental shelf. The third part of the report analyzes existing investments in continental shelf mineral resources made by corporations, individuals, and state and federal governments. Part four of the report provides an overview of the laws and regulations affecting investment in mineral resource development on the OCS. Finally part five analyzes current legal developments in the international arena concerning regulation and allocation of deep sea-bed mineral resources.

The Dahle report is primarily concerned with development of outer continental shelf resources in general and only passing mention is made of phosphorite and hard-rock minerals specifically. The report provides an analysis of investment interest in OCS mineral development. It points out that research is hampered by a paucity of available written material covering marine mineral development by private interests. It notes a poor performance record on past investments as reflected in stock market behavior. However, it attributes this poor performance to "the miserable management performance of mutual funds in general." The report takes an optimistic view of marine resources as "the last unexplored frontier truly accessible to man" and rejects the possibility that "individual investment in the oceans' resources and related industrial endeavors is unprofitable." No evidence is offered in the report to substantiate this forecast of future profitability and no time frame is suggested when profitability will be attained.

(3) The project entitled "Evaluation of Confining Strata Associated with Principal Coastal Georgia Aquifer," by James R. Woolsey is currently under study and no report is available. The objectives of this study are as follows:

1. "Mapping of the extent, thickness, continuity and lithology of the aquiclude which overlies the principal aquifer of coastal Georgia."

2. "Provide data on the economic geology of phosphate deposits where no drilling-sampling has been done and provide data and samples of the marsh substrate which overlies these deposits." The study was initiated in 1975. There is no estimated date of completion provided on the project summary sheet.

(4) The project entitled "Evaluation and Economic Analysis of Southern California's Phosphorite and Sand-Gravel Deposits," is a joint project by a team of geologists headed by Peter Fischer (California State University at Northridge) and by a team of economists under my own leadership. This report will be limited to an economic analysis of the phosphorite. The sand-gravel resource assessment will be provided by Panel 3-B and the economic evaluation of sand-gravel by Panel 2-B.

The principal purpose of the phosphorite economic study is to estimate the internal rate of return for an investment in marine mining of phosphorite from known deposits off-shore from Southern California. The study will provide an estimate of investment requirements for phosphorite recovery, transportation to shore, and beneficiating facilities. Operating costs and revenues will also be estimated. A demand function will be estimated in order to determine whether additional supplies from the marine environment will produce lower phosphate prices. The time flow of costs and revenues will be considered in estimating the internal rate of return on a mining investment. This analysis will update a 1969 study by Mead and Sorensen entitled "A New Economic Appraisal of Marine Phosphorite Deposits," (Marine Technology Society, The Decade Ahead - 1970-1980, 1969.) Recent dynamic changes in the fertilizer market may change substantially the 1969 conclusion which indicated that an investment in phosphorite recovery from the marine environment was likely to be unprofitable.

This economic study is hampered by the fact that no phosphorite recovery project in the marine environment exists. Therefore all investment and operating cost estimates are highly speculative. Estimates will be based on the best available engineering knowledge. This project is projected for completion June 30, 1976.

As an economist I feel hesitant to suggest the kind of legal assessment that the federal government should provide with respect to the subject minerals. Private firms are fully capable of providing their own assessment of their legal rights, obligations and liabilities, and indeed, will insist upon doing so whether a government sponsored study is available or not.

With respect to the legal rights, obligations and liabilities of the federal government, any legal aspects which can be clarified by additional research prior to ajudication should, of course, be further researched. In the absence of such research, an unnecessary degree of uncertainty is present. The economic effect of uncertainty is to reduce present values. Thus, bonus bids would be unnecessarily low when mineral leases are offered for sale at public auctions.

Additional economic analysis becomes desirable as underlying conditions change. If product prices should change drastically, or if technological breakthroughs occur which substantially reduce either the necessary investment or the operating costs, then new economic assessments may be desirable. As in the legal analysis above, firms interested in acquiring federal OCS mineral leases for the subject minerals will certainly undertake their own economic evaluations. The only reasons for government sponsored studies are (1) to identify and publicize opportunities for marine mineral recovery (a promotional function) (2) to more efficiently plan and program future lease sales and (3) to rationally evaluate bids received and exercise its legal right "to refuse any and all bids." Presumably the government as the lessee will refuse any bids that are believed, on the basis of <u>economic</u> analysis, to be below competitive values.

Economic and Legal Assessment of Marine Placers

Dr. Francis M. Schuler
Office of Marine Resources
NOAA

Introduction

NOAA, through the Office of Sea Grant, supported a limited study on the economic potential of marine placer mining on the continental shelf of California between Crescent City and the Oregon border. The study was conducted by Susan Wilcox, Walter Mead, and P.E.Sorensen. The preliminary results were presented at the 1972 meeting of the Marine Technology Society (see reference).

The study was directed at the question of whether private investment in marine placer mining would be justified. Capital requirements, operating costs, and revenues were estimated for a mining system designed to recover and beneficiate gold, magnetite, platinum, ilmenite and chromite from surficial sands. Six cases were examined, each based on a combination of dredge size and annual operating time. It was assumed that bucket line dredges would be used by the mining firm and alternative capacities of 9,18, and 54 cubic feet were selected for study. Seven and twelve months were chosen as the alternative annual operating times.

Capital Requirements

The estimates of the total capital requirements for the mining operation from exploration through beneficiation were $28.2M, $47.7M, and $102.9M respectively for the 9, 18, and 54 cubic foot dredges. The breakdown by mining system components is given in Table 1. In all three cases 55-60 percent of the capital costs went for the processing operations; 1 - 4 percent for exploration; with the remainder near evenly split between the dredging equipment and the mine site-to-shore transport vessels.

Operating Costs

Total operating costs and the breakdown by components for each case is given in Table 2 (see also Appendix I). Average total operating costs ranged from $6.00 per cubic yard of dredged material for the seven month - 9 cubic foot system to $4.28 per cubic yard for the twelve month - 54 cubic foot operation. This variance in average total operating costs per cubic yard dredged results from varying the dredge size and the annual operating period. It is not attributable to beneficiation since by definition average beneficiation operating costs were taken to be $3.00 per cubic yard dredged. In the six cases examined annual operating costs vary inversely with both the dredge size and the annual operating period.

Revenues

The estimates of annual revenues that would be generated from a marine placer mining operation ranged between $4.3M and $44.7M (see Table 2). These were based on the following prices (1971) for the recovered minerals:

Gold	$ 58.00/troy ounce
Magnetite*	$ 5.80/ton
Ilmenite	$ 20.00/ton
Platinum	$120.00/ounce
Chromite	$ 25.00/ton

(* Ore upgraded to 56 percent)

and the following assay value of the dredged materials:

Gold	1.0	(10^{-2})	PPM
Magnetite	1.0	(10^{+5})	PPM
Ilmenite	5.0	(10^{+4})	PPM
Platinum	2.3	(10^{-4})	PPM
Chromite	5.0	(10^{+4})	PPM

Study Conclusion

From Table 2 it can be seen that in each of the six cases under examination, the estimated total operating costs are in excess of estimated revenues. Simply stated the private return on investment would be negative.

The study also looked to see if there were any expected social benefits, not captured in the analysis of the private economics, which might turn the above conclusion around. But in fact the study suggests that near shore marine placer mining is more likely to inflict a social cost than produce a social benefit. Thus the authors conclude that for "a mining operation designed to recover even the highest grade U. S. mineral placer deposits it is apparent that on the basis both of private and social accounting of the costs, marine placer mining is not presently economically justified." (Wilcox, p. 503)

Future Research

Has the situation changed in the four years since the results of this study were reported? Obviously it has. You need only look at current prices for the minerals under study (see Appendix 2) to realize that some rather spectacular price increases have occurred over the last four years. The increase in current price over the 1971 price is 128 percent for gold, 68 percent for magnetite, 175 percent for ilmenite, 33 percent for platinum, and 80 percent for chromite.

Of course costs have also risen sharply. But when you look at the cost indexes you are immediately struck by the fact that they show a much slower rate of increase relative to the price increases (see Appendix 2). For example, wholesale price indexes over the same four years show increases of 40 percent for machinery and equipment, 26 percent for transportation equipment, and 48 percent for construction materials. Average labor costs increased about 30 percent. In fact, about the only costs that seemed to increase as sharply as the mineral price increases was that of fuel and power.

I am not willing to draw any inferences based solely on price and cost indexes. A more detailed study of specifics, including market outlook, is needed. However, you cannot ignore what appears to be an improving investment climate for this type of marine placer operation.

Reference:

Wilcox, Susan M.; Mead, Walter J.; and Sorensen, P. E. "A Preliminary Estimate of the Economic Potential of Marine Placer Mining" Preprints: 8th Annual Conference of the Marine Technology Society. (Washington, D. C. : 1972). pp. 499-506.

Table 1--Capital requirements for three alternative dredge sizes.

	9 cu. ft.	18 cu. ft.	54 cu. ft.
Dredge	$ 4,600,000	$ 7,800,000	$ 32,000,000
Support Vessel	250,000	250,000	250,000
Dock	5,000,000	7,000,000	10,000,000
Processing plant	15,000,000	28,000,000	55,000,000
Tugs	750,000	1,500,000	1,500,000
Barges	1,100,000	1,650,000	2,200,000
Exploration	1,000,000	1,000,000	1,000,000
Land Acquis.	500,000	500,000	1,000,000
Total capital costs	$28,200,000	$47,700,000	$102,950,000

Table 2--Estimated annual mineral production, revenue, and operating cost for alternative dredge sizes and number of operating days.

	9 cu. ft.		18 cu. ft.		54 cu. ft.	
	170 days	291 days	170 days	291 days	170 days	291 days
Production						
Yardage dredged	1,220,000	2,100,000	2,400,000	4,120,000	8,000,000	12,660,000
Tons dredged	1,830,000	3,150,000	3,600,000	6,180,000	12,000,000	18,990,000
Gold (Troy ounces)	518	819	1,019	1,789	3,396	5,374
Magnetite (Tons upgraded to 56%)	61,000	105,000	120,000	206,000	400,000	633,000
Platinum (Troy ounces)	12	20.7	24	40.5	79	125
Ilmenite (Tons)	81,690	140,600	160,700	275,900	535,700	847,800
Chromite (Tons)	91,500	157,500	180,000	309,000	600,000	949,500
Revenue						
Gold $58.00	$ 30,044	$ 51,678	$ 59,102	$ 103,762	$ 196,968	$ 311,692
Magnetite $5.80	353,800	609,000	696,000	1,194,800	2,320,000	3,671,400
Platinum $120.00	1,440	2,484	2,880	4,860	9,480	15,000
Ilmenite $20.00	1,633,800	2,812,000	3,214,000	5,518,000	10,714,000	16,956,000
Chromite $25.00	2,287,500	3,937,500	4,500,000	7,725,000	15,000.000	23,737,500
Total revenue	$4,306,584	$7,412,662	$8,471,982	$14,546,422	$28,240,448	$44,691,592
Operating cost						
Dredge wages	$ 140,000	$ 240,000	$ 175,000	$ 300,000	$ 259,000	$ 444,000
Dredge maintenance	230,000	230,000	390,000	390,000	1,000,000	1,000,000
Supplies	140,000	240,000	175,000	300,000	259,000	444.000
Power	24,400	42,000	48,000	82,400	160,400	253,000
Beneficiation	3,660,000	6,300,000	7,200,000	12,360,000	24,000,000	37,980,000
Tug operation & maintenance	109,540	187,500	200,000	342,400	219,000	375,000
Dock operation & maintenance	350,460	600,000	490,600	844,000	700,920	1,200,000
Royalties (token)	1,000	2,000	2,000	4,000	6,000	12,000
Ins. & prop. taxes	2,002,500	2,002,500	3,465,000	3,465,000	7,571,250	7,571,250
Subtotal	$6,657,900	$9,844,000	$12,145,600	$18,087,800	$34,175,570	$49,279,250
Administration (10% op. cost)	665,800	984,400	1,214,600	1,808,800	3,417,600	4,927,900
Total operating cost	$7,323,700	$10,828,400	$13,360,200	$19,896,600	$37,593,170	$54,207,150

Wilcox, et al. pp. 504-505.

Appendix 1

Operating Cost Estimates: (Annual Basis)

Dredge wages - $1,000 per man per month
Dredge maintenance - 5 percent of dredge capital cost
Supplies - 100 percent of dredge wages
Power - 2 cents per cubic yard dredged
Beneficiation - $2.00 per ton dredged
Tug operation and maintenance - 0.83% of tug and barge capital requirements per month of operation
Dock operation and maintenance - 1.00% of dock capital requirements per month of operation
Royalties - token
Insurance and property taxes - 7.50 percent of capital costs
Administration - 10.00 percent of operating costs

Appendix 2

Current Prices:

Gold	$132/tr.oz.	(Metals Week, March 1, 1976, p. 4)
Magnetite	$ 18.50/ln ton	(Commodity Data Summaries*, p. 82) 1/
Platinum	$160/tr. oz.	(Metals Week, March 1, 1976, p. 4)
Ilmenite	$ 55/ln ton	(Commodity Data Summaries*, p. 76)
Chromite	$ 45/ln ton	(Commodity Data Summaries*, p. 34)

(*U. S. Dept. of Interior, Bureau of Mines, Commodity Data Summaries, 1976.)

1/ 1971 price was assumed to be $5.80/ton when $11.00/ton was the prevailing price for high grade land ore (Wilcox, et. al., p. 499). Therefore $9.75 was taken as the current price for magnetite.

Cost Indexes:

	(1967 = 100) 1971	1975	% Change
WPI Machinery and Equip.	115.5	161.4	40
WPI Transportation Equip.	114.7	144.6	26
WPI Construction Materials	119.5	176.4	48
WPI Fuels and Power	114.2	245.1	115
Labor Costs	122.6	161.1	31

(Source: Economic Report of the President, 1976)

Appendix I

Abstracts of

NOAA Sponsored Marine Minerals Research

Note: Project numbers 1/ assigned to each abstract identify where the project orginiated by the prefix letter as follows:

S	Sea Grant Program
N	New England Offshore Mining Study (NOMES)
D	Deep Ocean Environmental Study (DOMES
M	Marine Minerals Technology Center (MMTC) 2/
A	Atlantic Oceanographic and Meterological Lab, NOAA

1/ These project numbers were assigned by the Office of Marine Minerals solely for the purpose of this Workshop.

2/ MMTC projects started prior to the establishment of NOAA are included.

Sea Grant Projects

S1. Economic Evaluation of Ocean Mineral Resource Development (1969-72)
Walter J. Mead, University of California and
Philip E. Sorensen, University of California

Objectives:

To study the economic feasibility of recovering specific minerals from the marine environment and to outline the important public policy alternatives related to marine mining.

Reports:

Wilcox, S.; Mead, W.; and Sorensen, P. E. 1972. A preliminary estimate of the economic potential of marine placer mining. Proceedings Marine Technology Society. 8: 499-506.

Mead, W. J.; and Sorensen, P. E. 1969. A new economic appraisal of marine phosphorite deposits. Marine Technology Society: The Decade Ahead, 1970-1980.

Mead, W. J.; and Sorensen, P. E. 1970. The principal external costs and benefits of marine mineral recovery. Proceedings, Offshore Technology Conference. Vol. 1.

Mead, W. J.; and Sorensen, P. E. 1970. Evaluation of technological spillovers: the case of the deep sea dredge. Proceedings, Marine Technology Society. Vol. 2.

Mead, W. J. 1970. The potential economic value of mineral production from the outer continental shelf. Outer Continental Shelf, Hearings before the U. S. Senate Committee on Interior and Insular Affairs, Part 2.

S2. An Oceanographic Inventory of the Southern California Shelf Sand and Gravel Deposits (1974-continuing)
Peter Fischer, California State University, Northridge

Objectives:

To derive information that will allow an optimal utilization of offshore sand and gravel resources with minimal effect on adjacent beaches and shore processes. Phase I - Locate and make volumetric estimates of potential sand and gravel deposits of the Southern California Shelf. Phase II - Select appropriate areas to serve as models for study of shelf sediment transport processes. These studies are needed to discriminate between Late Quaternary deposits which feed beaches and those which do not.

Reports:

Maps of Santa Barbara County submitted to California Division of Oil and Gas for publication as Special Paper. Lithologic studies and economic evaluations and preliminary reports are in progress.

S3. Evaluation and Economic Analysis of Southern California's Phosphorite and Sand-Gravel Deposits (1975-1976)

Peter J. Fischer, California State University, Northridge
Walter Mead, University of California, Santa Barbara

Objectives:

This project will involve a geological evaluation integrated with economic and socio-economic assessment of offshore *vs* onshore sand and gravel and phosphorite deposits. Questions to be addressed include:

1) Resource assessment
2) Environmental implications
3) Socio-economic considerations

Reports:

Due June 30, 1976.

S4. Sediment and Water Characteristics in the Marine District, Eastern Long Island (1971-1973)

D. J. Brennan, State University College at Cortland (New York)

Objectives:

To develop detailed baseline information for eastern Long Island waters on:

1) Area 1 distribution of sediments
2) Distribution of bottom flora
3) Interaction of sediment and waters

Reports:

Geological Society of America Abstracts, 1973
Volume 5, No. 2, Boulder, Colorado, p. 141.

Brennan, D. J. 1973. *Geological Society of America Abstracts*. 5: 141.

S5. Geology of Delaware Bay (1970-1971)
J. C. Kraft, University of Delaware

Objectives:

To apply a team effort towards applied geological investigations in Delaware Bay, and specifically to delineate the geology of the Bay and the adjacent nearshore marine area.

Reports:

Weil, Charles. 1976. A Model for the Distribution, Dynamics, and Evolution of Holocene Sediments in Delaware Bay. Ph.D. Dissertation. University of Delaware.

S6. Seismic Reflection Surveys of Sedimentary Structures of Delaware Bay (1970-1973)
R. E. Sheridan, University of Delaware

Objectives:

To study the location and distribution of oyster shell beds in the Delaware Bay basin. To initiate study of the origin and structure of the linear sand shoals of Delaware Bay.

Reports:

Moose, R. D. 1973. High Resolution Seismic Reflection Profiles in Middle Delaware Bay. Master of Science Thesis, University of Delaware.

Weil, C. B.; Moose, R. D.; and Sheridan, R. E. 1972. Structure of tidal built sand ridges in Delaware Bay (abs). Proceedings of the Annual Meeting, Geological Society of America. p. 301.

Weil, C. B.; Moose, R. D.; and Sheridan, R. E. 1974. A model for the evolution of linear tidal built sand ridges in Delaware Bay, U.S.A. Inst. Geol. Bassin d'Aquitaine Bull. 7: 343-47.

Kraft, J. C.; Sheridan, R. E.; and et al. 1974. Middle-late Holocene evolution of the morphology of a drowned estuary system. Inst. Geol. Bassin d'Aquitaine Bull. 7: 297-305.

Weil, C. B. 1976. A Model for the Distribution, Dynamics, and Evolution of Holocene Sediments and Morphologic Features of Delaware Bay. Ph.D. Dissertation, University of Delaware.

S7. Size Analysis and Heavy Mineral Distribution in Delaware Bay Sediments (1972)
B. P. Glass, University of Delaware

Objectives:

To determine the source of Delaware Bay sediments by size and heavy mineral analyses.

Reports:

See Weil, 1976 under S6.

S8. Recent Sediments of Northeastern North Carolina Estuaries: Their Relation to Plio-Pleistocene Mineral Deposits and their Implication Upon Coastal Zone Management (1970-1974)
Stanley R. Riggs and Michael P. O'Connor, East Carolina University, Department of Geology

Objectives:

To gather baseline data, to develop geological models, and to apply both the data and models towards a solution of some of the related critical coastal resource problems as outlined in the State's document "North Carolina Coastal Resources".

Reports:

Riggs, S. R. and O'Connor, M. P. 1975. Evolutionary succession of drowned coastal plains estuaries. Geological Society of America Abstracts. 7: 1247-8.

Riggs, S. R. and O'Connor, M. P. 1975. Geological Bibliography of North Carolina's Coastal Plain, Coastal Zone, and Continental Shelf. Univ. of North Carolina, Sea Grant Publication (UNC-SG-75-13) 147 p.

Riggs, S. R. and O'Connor, M. P. 1974. Relict Sediment Deposits in a Major Transgressive Coastal System. Univ. of North Carolina, Sea Grant Publication (UNG-SG-74-03) 37 p.

O'Connor, M. P. and Riggs, S. R. 1974. Mid-Wisconsin to recent sea level fluctuations and time stratigraphy of the Northern Outer Banks of North Carolina. Geological Society of America Abstracts. 6: 894.

S9. Undersea Mineral Survey of the Georgia Continental Shelf (1970-1975)
John Noakes, University of Georgia

Objectives:

1. To develop and apply a Cf252 neutron activation analysis system at sea for a) *in situ* seafloor mineral analyses; b) shipboard analysis system.
2. To determine applicability of newly developed tools and techniques to mineral exploration in the Georgia coastal area.

Reports:

Noakes, J. E.; Smithwick, G.; Harding, J.; and Kirst, A. 1971. Undersea mineral analysis with californium - 252. Proc. Am. Nuclear Soc. Meeting.

Noakes, John E. and Harding, James L. 1971. New techniques in seafloor mineral exploration. Journal of the Marine Technology Society. Vol. 5. No. 6.

S10. Geophysical Investigation of Potential Aggregate Resources in the Georgia Coastal Area (1972-1974)
James L. Harding, Skidaway Institute of Oceanography

Objectives:

To develop tools and techniques with which to investigate the occurrences of sand and/or gravel in the estuaries and on the inner shelf.

To perform reconnaissance surveys in the field.

Reports:

Harding, James L. and Woolsey, J. R. 1974. Geophysical Investigation of the Potential Aggregate Resources in the Georgia Coastal Area. Skidaway Institute Progress Report, 1973-1974.

Martin, Roger and Hicks, R. G. 1975. An Evaluation of Offshore Sand and Gravel Deposits as Construction or Specialty Materials. Georgia Marine Science Center. Skidaway, Georgia. Tech. Report 75-3. 66 p.

S11. Evaluation of Confining Strata Associated with Principal Coastal Georgia Aquifer (1975-continuing)
James R. Woolsey, University of Georgia

Objectives:

1. Mapping of the extent, thickness, continuity and lithology of the

aquiclude which overlies the principal aquifer of coastal Georgia.
2. Provide data on the economic geology of phosphate deposits where no drilling sampling has been done and provide data and samples of the marsh substrate which overlies these deposits.

S12. An Evaluation of Coastal Sand and Gravel Deposits as Construction or Specialty Materials (1975-continuing)
Richard Barksdale, Georgia Institute of Technology

Objectives:

1. Identify potential uses of coastal materials.
2. Develop aggregate and aggregate - admixture combinations for each of the potential uses.
3. Develop material specifications for use in construction or as specialty products.
4. Evaluate the economic feasibility of using these materials for the indicated applications.

S13. Evaluation and Recovery of Offshore Sand Resources (1969-1975)
Ralph Moberly, Fred Casciano, and Robert Palmer, University of Hawaii

Objectives:

1. To locate large nearshore sand deposits and to determine the quality and quantity of these deposits.
2. To develop and test a submarine sand recovery system (SSRS) capable of extracting sand either for commercial use or for recycling eroding beaches. The SSRS should recover the sand with minimal environmental damage.

Reports:

Casciano, F. M. and Palmer, R. Q. 1969. Potential of Offshore Sand as an Exploitable Resource in Hawaii. Sea Grant 69-4. Sea Grant Program, University of Hawaii, Honolulu.

Casciano, F. M. and Palmer, R. Q. 1970. Sand Coring in the Halekulani Sand Channel with the Beachcor 67 Coring System. Sea Grant 70-1. Sea Grant Program. University of Hawaii, Honolulu.

Casciano, F. M. 1973. Development of a Submarine Sand Recovery System for Hawaii. Sea Grant 73-04. Sea Grant Program. University of Hawaii, Honolulu.

Moberly, R., Jr. and Campbell, J. Frisbee. 1969. Hawaiian Shallow Marine Sand Inventory: Part 1. Introduction and Part 2. Ahuo Lake Sand Deposit, Kaneohe Bay, Oahu. Sea Grant 69-1. Hawaii Institute of Geophysics.

Campbell, J.F.; Coulbourn, W. T.; Moberly, R.; and Rosendahl, B. R. 1970. Reconnaissance Sand Inventory: Off Leeward Oahu. SEAGRANT 70-2. Sea Grant Program, University of Hawaii.

Coulbourn, W. T. 1971. Sedimentology of Kahana Bay, Oahu. UNIHI-SEAGRANT-TR-71-03. Sea Grant Program, University of Hawaii.

Campbell, J. F.; Rosendahl, B. R.; Coulbourn, W. T.; and Moberly, R. 1971. Reconnaissance Sand Inventory: Off Leeward Molokai and Maui. UNIHI-SEAGRANT-TR-71-02. Sea Grant Program, University of Hawaii.

Moberly, R.; Campbell, J. Frisbee; and Coulbourn, William T. 1975. Offshore and Other Sand Resources of Oahu, Hawaii. Hawaii Inst. of Geophysics Report (HIG-75-10).

S14. Manganese Resources (1970-continuing)
James Andrews, University of Hawaii

Objectives:

To thoroughly sample and evaluate the ferro-manganese deposits in the Hawaiian Archipelago.

Reports:

Manganese Nodule Deposits in the Pacific; Symposium/Workshop Proceedings; October 16-17, 1972; Honolulu, Hawaii.

The Origin and Distribution of Manganese Nodules in the Pacific and Prospects for Exploration; An International Symposium. Morgenstein, M. (ed); July, 1973; Honolulu, Hawaii.

Morgenstein, M.; and Andrews, J. E. 1971. Manganese resources in the Hawaiian Region. Marine Technology Society Journal. 5(6).

S15. Legal Aspects of Ocean Resources Exploitation (1971-1976)
H. Gary Knight, Louisiana State University Law Center

Objectives:

Study of national and international oceans policy concerning the use of ocean space and the exploitation of ocean resources; included in the research were issues relating to deep seabed mining.

Reports:

Knight, H. G. 1971. The draft United Nations Convention on the International Seabed Area: background, description and some preliminary thoughts. San Diego Law Rev. 8: 459.

Knight, H. G. 1973. The Deep Seabed Hard Mineral Resources Act -- a negative view. San Diego Law Review. 10: 446.

Knight, H. G. 1973. United States oceans policy: perspective 1974. Notre Dame Lawyer. 49: 341.

Knight, H. G. 1975. Jurisdictional issues in ocean management. Columbia Journal of World Business. Vol. 10.

S16. Assay of the Marine Resources of Massachusetts Bay (1973-1974)
J. B. Lassiter, Massachusetts Institute of Technology

Objectives:

To collect and to aggregate existing data relative to the sand and gravel resources of the Massachusetts Bay.

Reports:

Lassiter, J. B.; Soden, James E.; and Powers, Robert. 1974. An Assay of Marine Mineral Resources in Massachusetts Bay. MIT, Sea Grant Report 74-26. 58 p.

Soden, J. E.; Powers, Robert; and Lassiter, J. B. 1974. An assay of marine mineral resources in Massachusetts Bay. Offshore Technology Conference.

S17. The Science and Technology of Utilizing the Bottom Resources of the Continental Shelf (1969-1975)
Robert Corell; A. Yildiz; and B. Celikkol, University of New Hampshire

Objectives:

To develop an effective acoustic technology to classify and assess the coastal seafloor and sub-bottom sediments for both physical and engineering properties.

To understand the influence that exploration of offshore sedimentary resources may have upon the environment and upon society.

Reports:

Celikkol, B.; and Vogel, T. M. 1973. A New Shear Wave Velocity Measurement Technique in Ocean Bottom Soil Samples. UNH-Raytheon. Sea Grant Project Technical Report UNH-SG-112. Durham, N. H. 7 pp.

Magnuson, A. H.; and Stewart, G. K. 1973. Sound Propagation in a Liquid Layer Overlying A Multi-layered Viscoelastic Halfspace. UNH-Raytheon. Sea Grant Project Technical Report UNH-SG-105. Durham, N. H. 11 pp.

Magnuson, A. H. 1973. Sound Propagation in a Liquid Layer Overlying a Viscoelastic Halfspace. UNH-Raytheon. Sea Grant Project Technical Report UNH-SG-114. Durham, N. H. 150 pp.

Newman, A. K. 1973. A General Theory for Compensating Acoustic Transducers. UNH-Raytheon. Sea Grant Project Technical Report. UNH-SG-104. Durham, N. H. 7 pp.

Bell, D. L.; and Porter, W. J. 1974. Remote classification potential of reflected acoustic signals in physics of sound in marine sediment in L. D. Hampton (Ed.). Plenum Press. N. Y.

Porter, W. J.; and Bell, D. L. 1975. Development of quantitative remote acoustic indices for location and mapping of seafloor soil deposits. Offshore Technology Conference. (Paper 2288).

Westneat, A. S.; and Porter, W. J. 1975. Computation of compressional wave velocity in unconsolidated seafloor sediment using scaled seismic approaches. Oceans '75.

Westneat, A. S.; and Porter, W. J. 1976. Acoustic sediment classification involving gas laden soils. Offshore Technology Conference.

Azzi, V.; and Celikkol, B. 1971. Sound scattering from bubbles. Journal of Sound and Vibrations. 35: 231-252.

Celikkol, B.; and Vogel. 1973. A new shear velocity measurement technique in ocean bottom soil samples. Offshore Technology Conference (1973).

Corell, R.; Yildiz, A.; and Westneat, A. 1971. On the Science and Technology of Utilizing the Bottom Resources of the Continental Shelf. Technical Report to the National Sea Grant Office.

Magnuson, A. 1975. Acoustic response in a liquid layer overlying viscoelastic halfspace. J. Acoust. Soc. Am. 57: 1017-1024.

Magnuson, A.; and Stewart, G. 1972. Sound propagation in semi-infinite liquid overlying a homogenous viscoelastic halfspace. Proc. IEEE Conf. Ocean Envir.

Magnuson, A. 1972. Sound Propagation in a Liquid Overlying Halfspace. Ph.D. Dissertation, University of New Hampshire.

Yildiz, A. 1972. Wave propagation in an elastic field with the couple stresses. Journal of Applied Mechanics. 1146-1147 p.

Tugal, H.; and Yildiz, M. 1975. Mean square response of viscoelastic medium to nonstationary random excitation. Acoustics 33: 174-182.

S18. Developing a Management Program for Offshore Mining of Sand and Gravel (1975-continuing)
J. R. Schubel, SUNY at Stony Brook

Objectives:

To assist the State of New York in the development of a management plan for the mining of sand and gravel from New York coastal waters including: a) determination of use and needs; b) assessment of the quantity and quality of the resource; c) evaluation of environmental impacts associated with a variety of mining strategies.

Reports:

Report due Spring, 1976.

S19. Marine Resources Legal Research (1970-1975)
Seymour W. Wurfel, University of North Carolina, Law School

Objectives:

To formulate an appropriate legal regime to promote and protect North Carolina ocean exploration and development.

Reports:

Wurfel, S. W. 1974. Emerging Ocean Oil and Mining Law. University of North Carolina Sea Grant Report (UNC-SG-74-02).

Almond, M. A. 1975. Legal Aspects of Phosphate Mining in North Carolina. University of North Carolina Sea Grant Report (UNC-SG-75-05).

S20. Hydraulic Dredge Spoil Fate (1972-1974)
W. L. Schroeder, Oregon State University

Objectives:

To propose, test and confirm by field measurement an analytical model which permits a valid prediction of the area l distribution of the sediment plume and bottom deposit at the outfall of a hydraulic dredge discharging sand in water and to confirm the model by sampling.

Reports:

Schroeder, W. L.; and Pyles, M. R. 1975. Disposal of sandy pipeline dredge spoils by end dumping. Proceedings, ASCE National Convention.

S21. The Economics of the Ocean Mining of Sand and Gravel off the Coast of Rhode Island (1974-1975)
Thomas A. Grigalunas, University of Rhode Island

Objectives:

To estimate the feasibility of mining selected Rhode Island marine sand and gravel deposits under given conditions regarding geology, technology, water depth, distance from port, cost, and price.

S22. Offshore Sand and Gravel Resources in California (1974-continuing)
T. L. Henyey, and R. H. Osborne, University of Southern Calif.

Objectives:

To characterize the shelf areas off urban southern California vis-a-vis sand and gravel potential with particular emphasis on the San Pedro and Santa Monica shelves.

S23. Inventory of Mineral Resources off Chesapeake Bay (1972)
M. Nichols, Virginia Institute of Marine Science

Objectives:

This study aimed to evaluate sedimentary materials on a portion of the shelf off Virginia of the shelf floor as potential mineral resources. Specifically, to define the textural and mineralogic composition and their concentration.

Reports:

Nichols, M. 1972. Inner Shelf Sediments off Chesapeake Bay I: General Lithology and Composition. VIMS Special Science Report 64.

Thompson, G.; and Nichols, M. 1975. Inner Shelf Sediments off Chesapeake Bay II: Grain Size. VIMS Special Science Report.

1973. Inner Shelf Sediments off Chesapeake Bay III: Heavy Minerals. VIMS Special Science Report 68.

S24. Green Bay Manganese (1968-1972)
J. R. Moore, University of Wisconsin

Objectives:

1. To identify and map manganese resources of Green Bay.
2. To determine the mode of origin of manganese pellets present on the floor of Green Bay.
3. To analyze the pellets for constitutent elements.

Reports:

Moore, J. R. 1970. Manganese - rich pellets in Green Bay, an exploitable mineral resource of the Great Lakes. Proceedings Offshore Technology Conference. Paper OTC-1143. 14 pp.

Moore, J. R.; Meyer, R. P.; and Morgan, C. L. 1973. Investigation of Sediments and Potential Manganese Nodule Resources of Green Bay, Wisconsin. Tech. Report WIS-SG-73-218 Madison. 144 pp.

Morgan, C. L. 1973. The Composition of Marine Ferromanganese Deposits. Ms. Thesis, University of Wisconsin-Madison.

S25. Development of Vibratory Marine Sediment Sampler (1969-1972)
R. J. Harker, University of Wisconsin - Madison

Objectives:

The objective of this program is to develop sediment sampling equipment for obtaining undisturbed vertical cores in marine bottoms. Specifically, to design, build and test prototypes of devices which incorporate torsional vibration about the vertical probe axis for achieving penetration.

Reports:

Harker, R. J.; and Ball, J. H. 1975. Design considerations in vibratory core sampling. Proceedings of 1975 Offshore Technology Conference.

Harker, R. J.; and Shah, R. M. 1972. Design and Test of a Torsional Vibratory Core Sampler for Marine Sediments. Sea Grant Reprint.

Harker, R. J.; and Shah, R. M. 1974. Analysis of soil penetration by a whirl-excited probe. Journal of Engineering for Industry. 1974: 946-953.

S26. Marine Mineral Placers (1969-1976)
J. R. Moore, University of Wisconsin

Objectives:

To establish exploration guides for low and high energy commercial marine minerals placers (platinum, gold, chromium, tin, ilmenite, mercury, and rare earth heavy minerals).

Reports:

Everts, C. H. 1972. Exploration for High Energy Marine Placer Sites. Sea Grant Tech. Report WIS-SG-72-210. Madison. 179 pp.

Moore, J. R. 1972. Exploitation of ocean minerals resources-perspectives and predictions. Proc. Roy. Soc. Edinburgh. 72: 173-206.

Smith, P. A. 1972. Underwater mining-insight into current U. S. thinking. Mining Magazine: July, 1972: 44-49. Sea Grant College Reprint WIS-SG-72-330.

Moore, J. R. 1976. Origin of marine placers. Int. Geol. Congress, Sydney.

Wakeland, M. E. Jr. 1973. Surficial Sediments of Goodnews Bay, Alaska. Ms. Thesis, University of Wisconsin-Madison.

S27. Clean Undersea Mineral Processing (1971-1974)
T. D. Tiemann, R. W. Heins, A. Hayatdavoudi,
University of Wisconsin

Objectives:

To study by laboratory investigation the operation of completely immersed hydrocyclones on mineral deposits under simulated conditions of offshore operations at depth.

Reports:

Hayatdavoudi, A. 1974. A Theory of Hydrocyclone Operation and Its Modifications for Application to the Concentration of Underwater Heavy Mineral Sand Deposits. Ph.D. Thesis, University of Wisconsin, Madison.

S28. Lake Superior Copper Survey (1971-1975)
R. P. Meyer, University of Wisconsin

Objectives:

To develop geophysical indirect sensing methods useful in evaluating the prospects of offshore ore deposits and to use the methods developed in evaluating the Keweenaw Peninsula region.

Reports:

Moore, J. R.; Meyer, R. P.; Wold, R. J. Underwater copper exploration in Lake Superior. Proceedings, Offshore Tech. Conference. Paper OTC-1648.

Meyer, R. P.; Moore, J. R.; and Nebrija. 1975. Underwater copper exploration in Lake Superior: specific targets charted in 1974. Offshore Tech. Conference. Paper OTC-2291.

Nebrija, E.; Young, C.; Meyer, R. P.; and Moore, J. R. Electrical prospecting for copper veins in shallow water. To be presented at 1976 Offshore Tech. Conference.

S29. Pre-Mining Survey (1972-1975)
J. R. Moore, University of Wisconsin

Objectives:

To assess the critical chemical, biological, geological and coastal amenities and parameters of potential underwater mining sites.

To develop a handbook providing guidelines for such an assessment.

Reports:

Owen, R. M.; and Moore, J. R. 1974. Pre-mining surveys for underwater mining operations. Proceedings, Earth, Environment, and Resources Conference.

Owen, R. M. 1973. Pre-mining analysis of the marine environment. Fourth Underwater Mining Inst., Milwaukee.

S30. Relationship of Nucleus to Ore Grade of Marine Manganese Nodules (1972-1975)
J. R. Moore, University of Wisconsin

Objectives:

To determine the relationship between nucleus geometry and mineral composition and any relationship to the external morphology of marine nodules.

To determine if any relationship exists between copper, cobalt, and nickel values in the crust and the composition of the nucleus.

Reports:

Moore, J. R. 1970. Manganese-rich pellets in Green Bay. An exploitable mineral resource of the Great Lakes. Offshore Technology Conference. Report 1143.

Moore, J. R.; Meyer, R. P.; and Morgan, C. L. 1973. Investigation of Sediments and Potential Manganese Nodule Resources of Green Bay, Wisconsin. Tech. Report WIS-SG-73-218, Madison.

Morgan, C. L.; and Moore, J. R. 1975. Role of Nucleous in Form of Ferromanganese Nodules: Processing Guidelines for the Marine Miner. University of Wisconsin. SG-75-356.

Morgan, C. L. 1975. Nucleation and Accumulation of Marine Ferromanganese Deposits. Ph.D. Thesis, University of Wisconsin-Madison.

Morgan, C. L. 1973. Some chemical constraints in the processing of manganese nodules. Fourth Underwater Mining Institute, Milwaukee.

Morgan, C. L.; and Moore, J. R. 1975. Role of the nucleus in formation of ferromanganese nodules: processing guidelines for the marine miner. Offshore Technology Conference. Paper No. OTC-2243.

S31. Metal Extraction from Manganese Nodules (1975-continuing)
Thomas W. Chapman, University of Wisconsin

Objectives:

To identify and evaluate possible methods for commercial extraction of copper and nickel from deep-sea manganese nodules and to study specific operations experimentally.

To generate basic chemical data and engineering design procedures relevant to the hydrometallurgical processing of nodules.

S32. Marine Lode Minerals Exploration (1975-continuing)
J. R. Moore, University of Wisconsin

Objectives:

To provide basic chemical, mineral and textural exploration clues that will indicate the presence of sub-seafloor lode bodies, particularly ores of copper, zinc, lead, nickel and barite.

S33. Marine Noble Metals Exploration (1975-continuing)
J. R. Moore, Marine Studies Center, University of Wisconsin

Objectives:

1. To trace regional dispersal trends of gold and platinum.
2. To define the economic potential for gold and platinum in the area of Kuskokwim Bay and Seward Peninsula.
3. To acquire basic data on noble metal particles in order to design mining and processing systems.

Reports:

Welkie, C. J. 1976. Noble Metals Placer Formation: An Offshore Processing Conduit. Ms. Thesis (in preparation), University of Wisconsin-Madison.

Moore, J. R.; and Van Tassell, J. 1976. Exploration Research for Marine Gold Placers: Grantley Harbor-Tuksuk Channel Region, Seward Peninsula, Alaska. Sea Grant Technical Report (in preparation).

S34. Western Lake Michigan Sand and Gravel Assessment (1975-continuing)
Robert P. Meyer, University of Wisconsin

Objectives:

To identify and evaluate the distribution of accessible lake bottom sand and gravel resources which would meet the needs of urban centers along the densely populated eastern margin of Wisconsin.

S35. High Resolution Subbottom Profiling (1974-1976)
Allyn Vine, Woods Hole Oceanographic Institution

Objectives:

1. Improve geophysical reflection seismography by gaining much higher directivity and echo to noise strength through the use of very large, vertically downward-looking spherical or parabolic reflectors.
2. Reduction of interference from multiple reflections by separating very directional sources and receivers and angling them to maximize the desired reflection.
3. A 9M diameter reflector has been covered and tested briefly with a borrowed 3.5 kHz acoustic system. Results promising but very fragmentary and limited.
4. Am discussing with M. Moffett and William Konrad of U. S. Navy Undersea Center the use of non linear parametric sonars for this purpose for a much smaller physical unit to achieve narrow beams. This is a high risk venture with some very great theoretical and practical advantages. Also, high risk ventures in electronic development meet much more approval than high risk developments in sea faring techniques.

Reports:

WHOI-76-4. A Report on the Woods Hole Oceanographic Institution Sea Grant Program - July 1974 to June 1975. WHOI-76-4.

S36. Development of an Acoustic Probe for Ocean Bottom and Sub-Bottom Surveys (1974-1975)
Willard Dow, Woods Hole Oceanographic Institution

Objectives:

To redesign and reconstruct a certain precision Depth Monitoring Apparatus (U. S. Pat. #3, 174,128) into a compact, self-contained, deep-towed echo sounder (Acoustic Probe) with on-line readout aboard a surface vessel.

Reports:

Dow, Willard. DEEP PROBE (Final Report on Sea Grant Project #S-36).

Dow, Willard. Development of an Acoustic Probe for Detailed Ocean Bottom and Sub-bottom Surveys. (W.H.O.I. report in preparation.)

New England Offshore Mining Environmental Study Projects

N1. New England Offshore Mining Environmental Study (NOMES) (1972-1973)
See separate project for each principal investigator

Objectives:

To develop the capability to predict the ecological effects of marine sand and gravel mining.

Reports:

Final report, taking into account selected contracts extended past July 1973, in preparation at ERL by John W. Paden.

N2. NOMES-Geology (1972-1973)
Loren W. Setlow, Massachusetts Department of Natural Resources

Objectives:

Supplement data acquired earlier by the Commonwealth of Massachusetts by conducting sub-bottom profiling and drilling 31 sample holes up to 14 feet deep at and around the test site.

Reports:

Setlow, Loren W. 1973. Geological Investigation of the Project NOMES Dredging Site. Mass. Dept. of Natural Resources.

N3. NOMES-Physical and Chemical Oceanography (1972-1974)
A. Ippen, and Mollo-Christensen, Massachusetts Institute of Technology

Objectives:

Describe physical oceanographic conditions in Massachusetts Bay by review of literature as well as field sampling; include in field sampling currents, water chemistry, and suspended sediments.

Reports:

Bumpas, Dean F. 1974. Review of the Physical Oceanography of Massachusetts Bay. Woods Hole Oceanographic Institution Tech. Rpt. WHOI-74-8.

Christodoulou, G.; Leimkuhler, W.; and Ippen, A. 1974. Mathematical Models of the Massachusetts Bay. Part III: A Mathematical Model for the Dispersion of Suspended Sediments in Coastal Waters. Tech. Report 179, R. M. Parsons Laboratory for Water Resources and Hydrodynamics, M.I.T.

Karpen, Joseph. 1973. Dissolved Nutrient-Sea Water Density Correlations and the Circulation in Boston Harbor and Vicinity. M.I.T. Report No. MITSG-74-9, 73, Part 1.

Manohar-Haharaj, V.; and Beardsley, R. C. 1973. Spring Run-off and Nutrient-Seawater Density Correlations in the Massachusetts Bay. M.I.T. Report No. MITSG-74-9. 73-Part I.

N4. NOMES-Sedimentology (1972-1974)
C. L. Grant, University of New Hampshire

Objectives:

Mineralogical and chemical analysis of bottom sediments recovered during drill sampling of the seafloor at and around the test site.

Reports:

Grant, C. L. et al. 1974. A Study to Understand the Environmental and Ecological Impact of Marine Sand and Gravel Mining in Order to Prepare Guidelines for Mining Operations in the Sea--Chemical Characterization of Core Samples from the Dredge Site. University of New Hampshire.

N5. NOMES-Benthic Invertebrates (1972-1976)
Larry G. Harris, University of New Hampshire

Objectives:

Develop statistically reliable baseline of the benthos (mainly invertebrates) at the test site as well as at control site.

Reports:

Report due early 1976.

N6. NOMES-Phytoplankton (1972-1976)
Hugh F. Mulligan, University of New Hampshire

Objectives:

Determine spatial and temporal variability of phytoplankton in Massachusetts Bay.

Reports:

Mulligan, Hugh F. 1974. Phytoplankton Productivity in Massachusetts Bay. University of New Hampshire. (This is a report to the Commonwealth of Massachusetts on one aspect of the work; the total report is due to ERL in early 1976.)

N7. NOMES-A Test Particle Dispersion Study in Massachusetts Bay (1973-1975)
W. N. Hess and T. A. Nelson, National Oceanic and Atmospheric Administration (NOAA), Environmental Research Laboratories (ERL)

Objectives:

Development of a predictive model to estimate in advance of an actual dredging operation the ultimate fate of fines lost overboard from a sand and gravel dredge.

Reports:

Hess, W. N.; and Nelson, T. A. 1975. A test particle dispersion study in Massachusetts Bay to simulate a dredge plume. Offshore Technology Conference. Paper No. 2160.

Mayer, Dennis A. 1975. Examination of Water Movement in Massachusetts Bay. NOAA Tech. Report, ERL 328-AOML-17.

Deep Ocean Mining Environmental Study Projects

D1. Deep Ocean Mining Environmental Study (DOMES) (1975-continuing)
See separate project for each principal investigator

Objectives:

Identify potential marine environmental impact problems to be expected from the commercial-scale mining of deep ocean manganese nodules.

Progress Report:

Obtained replicate water column and seafloor samples at each of three sites in the N. E. Pacific Ocean typical of those expected to be mined in the future.

Reports:

Draft MESA Technical Project Development Plan. 1975. Deep Ocean Mining Environmental Study, Phase I - Marine Environmental Assessment. NOAA, ERL.

D2. DOMES - The Benthos (1975-continuing)
Allen Z. Paul, Lamont-Doherty Geological Observatory

Objectives:

See D1.

Progress Report:

Obtained samples at site C in Spring 1975 as well as samples at all three sites in Fall 1975.

The benthic baseline study has utilized bottom photographs to enumerate the larger epifauna and intensive replicate box cores to determine quantitatively the bottom dwelling community. Over 8,000 photographs and 75 box cores have been taken, but more are required in 1976 to have enough samples to allow appropriate statistical treatment of the variability at each site.

Approximately 2200 photographs from site A have been analyzed. They show that tracks, trails, fecal casts, and nodules were common and that the large epibenthonont were sparsely distributed (about 1 organism per $100m^2$ as compared to 8-16 organisms per $100m^2$ recorded from the floor of the oligotrophic Sargasso Sea). Elazipod holothurians comprised 62% of the fauna.

Ten box cores from site C have been partially analyzed. The density of organism ranges from 116-272 individuals per m^2 with an average biomass of 0.87 gm/m^2, not unusual values for the deep sea. Cnidaria made up customarily less than 2% numerical of deep sea fauna, but at site C they contributed over 23%. The nodules provide a substrate available for attachment of these sessile organisms which probably accounts for their increased abundance in the area.

D3. DOMES - Sedimentology (1975-continuing)
James L. Bischoff, U. S. Geological Survey

Objectives:

See D1.

Progress Report:

Obtained samples at site C during Spring 1975 and at all three sites during Fall 1975.

The project involves study of the geological and geochemical properties of the seafloor sediment in the DOMES sites. To date, the effort has focused on a single box core taken at site C during the spring of 1975. By concentrating the entire early effort on a single core, results are being inter-calibrated in such a way as to arrive at an optimum sampling plan for studies on all remaining cores.

The sediment is classified as a massive, mottled, siliceous brown clay (manganese nodules cover about 25% of the sediment surface). Pleistocene to recent age meiofossils were identified in the upper 4 centimeters of sediment. The clay minerology is mainly illite. Bulk chemical composition and interstitial water chemistry were found to be normal for the area.

Resuspension experiments with refrigerated bottom sediment and warm (surface) seawater revealed no significant release of heavy metals; toxic heavy metals were below the detection limits of 5 parts per billion.

Settling tests in sea water indicated that over half of the sediment will settle out of the photic zone (in upper 100 meters) within 140 days. Median grain sizes were found to be 4 microns or less, with no significant variation with depth in the core.

Although the mining system is not expected to excavate deeper than about 10 centimeters, it is interesting that the sediment characteristics changed somewhat below 20 centimeters in this 32 centimeter deep core. While no environmental problems were revealed by study of the deeper sediment, it is clear that the sediments at site C are neither as homogeneous nor simple as earlier thought.

D4. DOMES - Phytoplankton and Primary Productivity (1975-continuing)
Sayed Z. El-Sayed, Texas A&M University

Objectives:

See D1.

Progress Report:

Obtained samples at all three sites in Fall 1975.

Analysis of the biological productivity data collected at 45 stations enabled drawing the following conclusions: Phytoplankton standing crops (in terms of chlorophyll a) at the stations occupied at each site were low; the average value for surface water samples was 0.141 mg/m^3 and 13.19 mg/m^2 for values integrated from the surface to the depth of 0.01% of surface light intensity. Chlorophyll a maximum values were consistently found between 60 and 110 m. These values, in general, occurred at depth corresponding to the thermocline or the nutricline or both. Primary production, using the *in situ* ^{14}C uptake method was also low at each site. Surface and integrated values were 1.59 mg C/m^3/day and 0.244 g C/m^2/day respectively. Maximum primary productivity generally occurred at 25% of surface light intensity (corresponding to 30-50 m depth). Below the depth of 1% of surface light intensity, chlorophyll a values average 17% of total phytoplankton standing crop in the water column. Primary production below the 1% light depth on the other hand contributed an average of 8% of total production in the water column. It is evident from the data collected during this cruise that the nanoplankton (organisms smaller than 20 um) contributed an average of 92% of the phytoplankton standing crop in the water column studied. Also, as part of the phytoplankton investigations, detailed measurements have been made of both incident and subsurface radiation in energy units.

D5. DOMES - Zooplankton (1975-continuing)
Jed Hirota, University of Hawaii

Objectives:

See D1.

Progress Report:

Obtained samples at all three sites in Fall 1975.

Preliminary results are available for the standing stock of macrozooplankton captured in surface deployed neuston net samples and in horizontal, stratified Bongo net samples for the upper 1000 m. In addition, abundances and patterns in the vertical distribution of microzooplankton from the upper 200 m in pump samples are available. Selected samples at each site from both neuston and Bongo net tows have been analyzed for species composition and numerical abundance of larval fishes; counts of copepod species have also been made from a few selected Bongo net samples. Most of the larval fish species are from midwater taxa (Myctophids and Gonostomatids), but commercially important species are also present(Skipjack and Yellow Fin Tuna).

The neuston standing stock data showed that site A had lower average stocks than either sites B or C, and the night time abundances were higher than corresponding daytime values. Patterns in the vertical distribution of macrozooplankton show that most of the stocks occur in the upper 200 meters of the water column without vastly different distributional patterns day versus night. As with the neuston data, sites B and C had larger stocks than site A but not at every station or depth. The distribution of macrozooplankton stocks to the deepest depth sampled with Bongo nets (about 1000 m) showed the highest value at the site station at site B (11°N, 138°W) with the gradiest axis from lower values in the northwest to higher values in the southeast.

The vertical distribution of microzooplankton from samples analyzed thus far show that different taxa have maximum abundance at different depths (1) near-surface or at shallow depth (Tintinnids), (2) below about 100 m (Onceaea sp.) (3) intermediate depth (total copepod nauplii). The most abundant microzooplankters numerically are copepod nauplii, tintinnids, and sarcodine protozoans (Radiolaria and Foraminifera).

D6. DOMES - Nutrient Chemistry (1975-continuing)

Francis A. Richards and James J. Anderson
University of Washington

Objectives:

See D1.

Progress Report:

Obtained samples at all three sites in Fall 1975.

Features of thermocline depth to the oxygen minimum zone and to nutrient distributions have been revealed. A relatively shallow thermoridge is developed along 12°N and in comparison with historical data appears to be most evident during August and September. The oxygen minimum zone, beneath the thermocline, is most intense in the east and diminishes in development to 150°W at 15°N; a zone of extremely low oxygen concentration associated with relatively high concentrations of nitrite was present and is apparently a westward extension of the oxygen minimum zone developed along the coast of Central America. Microbial biomass in general was 100 times greater in the surface than at 1,000 m, was greater in surface layers along the thermoridge, and showed a small increase in the oxygen minimum zone compared to deeper waters. The structure of plant nutrient distributions in the upper 100 m showed significant variation over 24 hours periods. Variations may be due to biological activity or to patchiness or to a combination of both. Nitrate concentrations were low or not detectable above the thermocline.

D7. <u>DOMES - Suspended Particulate Matter</u> (1975-continuing)
Edward T. Baker and Richard A. Feely
NOAA - Pacific Marine Environmental Laboratory

Objectives:

See D1.

Progress Report:

Obtained samples at all three sites in Fall 1975.

Examination of data indicates that the highest concentrations of suspended particulate matter are found in the upper 100 m throughout the DOMES region, with the maximum concentrations occurring between 40 and 100 m. Only in the eastern portion of the mining area (at site C) were there any substantial particle accumulations below 200 m. These accumulations are apparently correlated with the most intense development of the regional oxygen minimum zone, between 180 and 350 m deep.

Simultaneous measurements of phytoplankton populations in the near-surface waters ($<$ 150 m) suggest that most of the particulate mass is due to living phytoplankton. In the deeper waters, the suspended particulate matter is probably a combination of inorganic particles, mostly supplied by air-borne dust, and the remains of dead plankton.

Maximum particulate concentrations in the upper 100 m are on the order of 50 ug. Below 300 m, the concentration is relatively constant, varying between about 15 and 5 ug/*l*. The total amount of naturally occurring particulate matter in the upper 100 m is roughly 2.5 g/m^2.

D8. DOMES - Physical Oceanography of Upper Waters (1975-continuing)
David Halpern, NOAA - Pacific Marine Environmental Lab.

Objectives:

See D1.

Progress Report:

Obtained about three month long current meter measurements at site C; additional STD measurements at all three sites -- all in Fall 1975.

During September 1975, vertical profiles of conductivity (i.e., salinity) and temperature were obtained from about 12°N to 18°N along 126°W. The depth of the upper mixed layer varied from 40 m to 10 m; a representative thickness of the mixed layer was 20 m.

A surface buoy mooring was deployed at DOMES site C (15°N, 126°W) on 28 August. The wire cable between the two uppermost current meters broke on 28 October. During the 60.5-day period when upper ocean measurements were obtained, the vector-mean direction of the current within the upper 100 m was towards west and northwest (which was representative of the North Equatorial Current); whereas the vector-mean direction of the current between 200 m and 300 m depth was towards the east. The occurrence of the subsurface undercurrent was not expected. Daily vector-mean values of current speeds and directions were not steady and large fluctuations, especially at the inertial and semidiurnal periods, were observed.

D9. DOMES - Plume Modeling (1975-continuing)
Takashi Ichiye, Texas A&M University

Objectives:

Initial prediction of fate of plumes caused by mining system dredge head, near seafloor, as well as that caused by discharge of waste sediments at or beneath ocean surface.

Progress Report:

Turbulent diffusion of sediments in the upper layer of the ocean is discussed from Eulerian and Lagrangian points of view. The latter model provides some simple estimation of width and depth of a plume of waste sediments discharged near th e surface. A simplified version of the Eulerian model is the Fickian diffusion equation with eddy diffusivity variable with time and space. Analytical solutions of the Fickian equation are obtained for different boundary conditions in the interface (thermocline) with a steady state diffusion-advection of sediments discharged as a vertical line source. Vertical profiles of sediment concentration are plotted in the non-dimensional form for different current speed, discharge rate, vertical eddy diffusivity and settling rate. The effect of the thermocline is that the sediment has a tendency to accumulate above the thermocline at a distance from the source if the thermocline inhibits the vertical diffusion due to its strong stability.

D10. DOMES - Literature Search, Benthic Smothering (1975)
Bruce C. Heezen, Lamont-Doherty Geological Observatory

Objectives:

Document historical cases of benthic smothering caused by rain of fines from natural disasters.

D11. DOMES - Work Up of Spring 1975 Cruise Data (1975)
Oswald Roels, Lamont-Doherty Geological Observatory

Objectives:

Work up, analyze, and report on measurements made and samples acquired at site C during Spring 1975.

D12. DOMES - Literature Search, Fish (1975-1976)
Maurice Blackburn, Scripps Institution of Oceanography

Objectives:

Review existing information on fishes, including eggs and larvae, in and adjacent to the DOMES area.

Progress Report:

This project is on schedule with most of the writing done. Four principal sources of information were available: results of commercial fishing, results of experimental fishing by research vessels, samples of fish larvae, and samples of micronekton. The annual fish catch is about 95,000 tons and consists mostly of tuna. The boundaries of principal fisheries were shown. A rough estimate of average fish biomass in the top 1200 meters of ocean is 2.17 g/m^2, all ultimately dependent upon zooplankton. About 1.70 g/m^2 of this biomass is Cyclothone, which lives permanently below 500 meters. Turbidity from the hydraulic dredge is likely to be unfavorable locally to certain fish.

D13. DOMES - Benthic Community Analysis and Prediction (1975-continuing)
Peter A. Jumars, University of Washington

Objectives:

See D1.

Progress Report:

Provided statistically sound procedure for obtaining replicate benthic samples during Fall 1975 cruise to all three sites.

There are, in general, two ways to improve the statistical reliability of a baseline. Either a larger number of samples can be processed, or more powerful statistics can be used to extract more information from the same number of samples. The time constraints of DOMES Phase I do not permit the former approach for the benthos. Hence, the latter method, cheaper both in time and in manpower requirements, is being pursued. Statistics capable of dealing with the low densities and high species diversities of deep-sea faunas are being developed or modified from existing procedures and tailored to the sample density and pattern achieved in the DOMES benthic baseline. When summarized, these baseline findings will be compared with the baseline and deep-sea community. This comparison will permit at least a limited predictive ability of the effects of nodule mining.

Marine Minerals Technology Center Projects

M1. Alaska Marine Heavy Metals (1966-1967)
Staff, Marine Minerals Technology Center (MMTC)

Objectives:

Work with the U. S. Geological Survey to evaluate the potential for the recovery of gold in Norton Sound, Alaska.

Reports:

Lense, Alvin H. 1968. Drilling for submerged gold placers off Nome, Alaska. 97th Annual Meeting of Americal Institute of Mining, Metallurgical, and Petroleum Engineers.

M2. MMTC Vertical Test Tank (1966-1967)
Staff, Marine Minerals Technology Center

Objectives:

Develop, design, and fabricate vertical test tank to test seafloor sampling as well as devices and diver operated tools.

Reports:

Reports noted elsewhere, involving the development of seafloor sampling devices, involved the test tank.

M3. Heavy Mineral Placer Sampling Techniques (1966-1970)
Staff, Marine Minerals Technology Center

Objectives:

Define errors introduced into the evaluation of seafloor mineral deposits as a result of the failure of sampling devices to recover perfectly undisturbed samples.

Reports:

Jenkins, R. L.; Cruickshank, M. J.; and Duncan, J. M. 1971. Disturbance of placer materials during sampling. Offshore Technology Conference. Paper 1363.

Terichow, Oleg, 1970. Mechanics of Seafloor Penetration by an Axisymmetric Tube: Static Penetration Studies. U. S. Bureau of Mines Report of Investigations 7451.

M4. Coronado Bank Phosporite Deposit (1968-1969)
Burton B. Barnes, Marine Minerals Technology Center

Objectives:

Study methods of evaluating a typical offshore phosphorite deposit.

Reports:

Barnes, Burton B. 1970. Marine phosphorite delineation techniques tested on the Coronado Bank, Southern California. Offshore Technology Conference. Paper 1259.

M5. Real Time Electronic Positioning and Navigation at Sea (1968-1971)
B. B. Barnes and R. Newman, Marine Minerals Technology Center

Objectives:

Develop an electronic system for on-line, real-time, digital and graphical conversion of coordinates derived from a range-range mode electronic precision positioning and navigation system.

Reports:

Barnes, B. B.; and Newman, R. 1971. A subsystem for electronic positioning and navigation at sea. IEEE Conference on Engineering in the Ocean Environment.

M6. Slurry Flow in Vertical Pipes (1969-1971)
Robert H. Wing, Marine Minerals Technology Center

Objectives:

Investigate problems associated with the hydraulic transport of solids in long vertical pipes relative to deep ocean manganese nodule mining.

Reports:

Wing, Robert H. 1972. Slurry Flow in Vertical Pipes. NOAA TR ERL 273-OD8.

M7. Marine Mining Environmental Impact, Literature Search (1969-1970)
Staff, Battelle Memorial Institute
Marine Minerals Technology Center (Contract)

Objectives:

Search the literature and annotate references of potential application to ocean mining environmental impact.

Reports:

Staff, Battelle Memorial Institute. 1971. Environmental Disturbances of Concern to Marine Mining Research, A selected Annotated Bibliography. NOAA Technical Memorandum ERL MMTC-3.

M8. Lab Studies on Effects of Suspended Sediments on Marine Organisms (1969-1972)
John W. Paden, Clyde R. Davis, and Floyd A. Nudi, Jr.
Marine Minerals Technology Center

Objectives:

Construct a laboratory facility in which simultaneous replicated experiments could be conducted on the impact of long term exposure of suspended sediments on marine organisms.

Reports:

Davis, C. R.; and Nudi, Jr., F. A. 1971. A turbidity bioassay method for the development of prediction techniques to assess the possible environmental effects of marine mining. Offshore Technology Conference. Paper 1414.

M9. Marine Geophysics: Self-Potential (1969-1971)
Robert F. Corwin, University of California, Berkeley (Marine Minerals Tech. Ctr. Cooperative Project)

Objectives:

Develop technique to detect the self-potential field generated in the ocean by seafloor metallic ore bodies.

Reports:

Corwin, R. F.; Ebersole, W. C.; and Wilde, P. 1970. A self-potential detection system for the marine environment. Offshore Technology Conference. Paper 1258.

M10. Geophysical Identification and Classification of Sea Floor Sediments (1969-1973)
Burton B. Barnes, Marine Minerals Technology Center

Objectives:

Try to relate geophysical measurements to the mass physical properties and engineering properties of seafloor sediments.

Reports:

Barnes, B. B.; Corwin, R. F.; Beyer, Jr., J. H.; Hildenbrand, T. G. 1972. Geologic Prediction: Developing Tools and Techniques for the Geophysical Identification and Classification of Sea-Floor Sediments. NOAA Technical Report ERL 224-MMTC 2.

Barnes, B. B.; Corwin, R. F.; Hildenbrand, T. G.; Jackson, L.; Kessler, R.; Takeyama, W.; Hornick, M.; and Jenkins, R. 1972. Geophysics Applied to Geotechnical Problems in a Marine Environment; A case Study: Monterey Bay, California. NOAA/ERL Report to ARPA.

M11. United Kingdom Offshore Sand and Gravel Mining (1970-1971)
Harold D. Hess, Marine Minerals Technology Center

Objectives:

Investigate nature and magnitude of sand and gravel industry working in North Sea and other areas off the United Kingdom; learn if environmental impact problems were being encountered and/or studied.

Reports:

Hess, Harold D. 1971. Marine Sand and Gravel Mining Industry of the United Kingdom. NOAA Technical Report ERL-213-MMTC 1.

M12. Anchor Blocks and Laterally Loaded Piles (Literature Search) (1970-1972)
Gordon R. Keller and James M. Duncan
University of California (Marine Minerals Technology Center support)

Objectives:

Review and summarize the literature on the passive resistance of objects embedded in soil.

Reports:

Keller, G. R.; and Duncan, J. M. 1972. A Review of Literature on Anchor Blocks and Laterally Loaded Piles. NOAA TM ERL MMTC-5.

M13. <u>Diver-Operated Seafloor Sampler</u> (1971-1972)
Richard L. Jenkins, Marine Minerals Technology Center

Objectives:

To develop and fabricate a sampling device capable of acquiring relatively undisturbed samples of the upper 2-3 feet of seafloor sediment.

Reports:

Jenkins, R. L.; and Takeyama, W. M. 1972. <u>A Bottom Sitting Diver-Operated Sampler for Engineering Properties</u>. NOAA Technical Report ERL 237-MMTC 3.

M14. <u>Effects of Suspended Sediment on the Eastern Lobster</u> (1971-1972)
David A. Cobb, Marine Minerals Technology Center

Objectives:

Investigate effects of suspended quartz and kaolin particles on the survival of larval stages of the eastern lobster, Homarus Americanus.

Reports:

Cobb, David A. 1972. Effects of suspended solids on larval survival of the eastern lobster, Homarus Americanus. <u>Marine Technology Society 8th Annual Conference</u>.

M15. <u>Environmental Impact of Manganese Nodule Mining</u> (1972-1975)
Oswald A. Roels, Lamont-Doherty Geological Observatory and City University of New York

Objectives:

To provide guidance to NOAA in its early involvement in the environmental considerations associated with deep ocean mining.

Reports:

Roels, O. A.; Amos, A. F.; Anderson, O. R.; Garside, C.; Haines, K. C.; Malone, T. C.; Paul, A. Z.; and Rice, G. E. 1973. <u>The Environmental Impact of Deep Sea Mining</u>. NOAA Technical Report ERL 290-OD 11.

Amos, A. F.; Daubin, S. C.; Garside, C.; Malone, T. C.; Paul, A. Z.; Rice, G. E.; and Roels, O. A. 1975. Report on a cruise to study environmental baseline conditions in a manganese nodule province. <u>Offshore Technology Conference</u>. Paper No. OTC 2162.

M16. <u>Lab Studies on Effects of Suspended Sediments on Marine and Estuarine Organisms</u> (1972-1976)
Richard K. Peddicord, University of California Bodega Marine Laboratory

Objectives:

Study biological effects of long term (10 day) exposure of suspended sediments on estuarine organisms.

Reports:

Peddicord, *et al*. 1975. *Effects of Suspended Solids on San Francisco Bay Organisms*. U. S. Army Corps of Engineers, San Francisco District. Dredge Disposal Study, Appendix G.

M17. <u>Manganese Nodules--Infrared Microanalysis</u> (1972)
Patricia A. Estep, U. S. Bureau of Mines (Marine Minerals Technology Center and NSF support)

Objectives:

Study structural-compositional determinations for minerals isolated from ferromanganese nodules obtained from diverse geographic localities.

Reports:

Estep, Patricia S. 1973. *Infrared Microanalysis for Deducing the Formation History of Ferromanganese Deposits*. NOAA Technical Report ERL 282-OD-10.

A1* Metallogenesis at Dynamic Plate Boundaries (1976-1980)

P. A. Rona, National Oceanic and Atmospheric Administration,
Atlantic Oceanographic & Meteorological Laboratories

Objectives:

1. Determine the processes and define the special physical and chemical conditions that lead to the concentration of metals at sites along the axial region of an active oceanic ridge (divergent plate boundary).
2. Determine patterns of mineralization in oceanic crust produced by axial processes.
3. Develop criteria to predict sites of active and relict hydrothermal mineral deposits in oceanic crust.
4. Develop guidelines for exploration for hydrothermal metal deposits in oceanic crusts.

Reports:

Metallogenesis at Dynamic Plate Boundaries (NOAA)

Betzer, P. R.; Bolger, G. W.; McGregor, B. A.; and Rona, P. A. 1974. The Mid-Atlantic Ridge and its effect on the composition of particulate matter in the deep ocean. EOS (Am. Geophys. Union Trans.) 55: 293.

McGregor, B. A.; and Rona, P. A. 1975. Crest of Mid-Atlantic Ridge at 26° N. Jour. Geophys. Research. 80: 3307-3314.

Rona, P. A. 1976. Criteria for recognition of seafloor hydrothermal mineral deposits. EOS (Trans. Am. Geophys. Union). 57: (in press).

Rona, P. A.; Harbison, R. H.; Bassinger, B. G.; Scott, R. B.; and Nalwalk, A. J. 1976. Tectonic fabric and hydrothermal activity of Mid-Atlantic Ridge Crest (lat. 26° N). Geol. Soc. Am. Bull. 87: 661-674.

Rona, P. A.; McGregor, B. A.; Betzer, P. R.; and Krause, D. C. 1975. Anomalous water temperatures over Mid-Atlantic Ridge Crest at 26° North latitude. Deep-Sea Research. 22: 611-618.

Scott, M. R.; Scott, R. B.; Rona, P. A.; Butler, L. W.; and Nalwalk, A. J. 1974. Rapidly accumulating manganese deposit from the median valley of the Mid-Atlantic Ridge. Geophysical Research Letters. 1: 355-358.

Scott, R. B.; Rona, P. A.; McGregor, B. A.; Scott, M. R. 1974. The TAG hydrothermal field. Nature 251: 301-302.

*Marine Geology and Geophysics Laboratory, NOAA Atlantic Oceanographic and Meteorological Laboratories, Environmental Research Laboratories.

Appendix II

MARINE MINERALS WORKSHOP/NOAA
March 23 - 25, 1976
Participants List

Amos, Anthony F.
Lamont-Doherty Geol. Obs.
Palisades, N. Y. 10964
(914) 359-2900

Amuedo, Curt
Amuedo & Ivey
Consulting Geologists
155 So. Madison, Suite 230
Denver, Colorado 90209
(303) 321-0242

Andrews, James E.
Department of Oceanography
University of Hawaii

Austin, Thomas
NOAA/Environmental Data Service

Ballentine, Tom
Conservation Foundation

Barnes, Burt
Federal Energy Administration
Federal Bldg. (Rm. 3439)
1200 Pennsylvania Avenue
Washington, D. C. 20461

Bischoff, James L.
U. S. Geological Survey

Boller, Jack W.
National Research Council
2101 Constitution Avenue
Washington, D. C. 20418
(202) 389-6602

Burns, Robert
NOAA/Pacific Marine Environmental Lab.

Burns, Roger G.
Massachusetts Institute of Technology
Dept. of Earth & Planetary Sciences
Cambridge, Massachusetts 02139
(617) 253-1906

Carey, Andrew
School of Oceanography
Oregon State University
Corvallis, Oregon 97331
(503) 754-2525

Chapman, Thomas W.
Dept. Chemical Engineering
University of Wisconsin
Madison, Wisconsin 53706
(608) 262-1092

Corell, Robert W.
Sea Grant Program
University of New Hampshire

Corrick, John
Division of Ferrous Metals
U. S. Bureau of Mines
2401 E Street
Washington, D. C. 20241
(202) 634-1025

Courtenay, Jr., Walter R.
Dept. of Biological Sciences
Florida Atlantic University
Boca Raton, Florida 33431
(305) 395-5100

Davin, Edward M.
National Science Foundation
1800 G Street, N. W.
Washington, D. C. 20550
(202) 632-4334

Dill, Robert F.
West Indies Laboratory
Fairleigh Dickinson University
P. O. Box 4010
Christiansted, St. Croix
U. S. Virgin Islands 00820
(809) 773-3339

Duane, David B.
NOAA/Sea Grant
3300 Whitehaven Street, N. W.
Washington, D. C. 20235
(202) 634-4125

Eger, James D.
University of Rhode Island
Marine Affairs Office
Kingston, Rhode Island 02881
(401) 792-1000

Fischer, Peter J.
Department of Geosciences
California State University
Northridge, California 91324
(213) 885-3541

Flittner, Glenn A.
NOAA/National Weather Service
Silver Spring, Maryland 20910
(301) 427-7278

Garrand, Leonard
Garrand Corporation
53 East Fourth South
Salt Lake City, Utah 84111
(801) 359-5042

Gazdik, Bill
U. S. Geological Survey
1725 K Street, N. W. - Suite 316
Washington, D. C. 20244
(202) 343-4589

Gillespie, Jim
North American Trailing Co.
Great Lakes Dredge & Dock Co.
228 North La Salle Street
Chicago, Illinois 60601
(312) 782-2690

Grigalunas, Thomas A.
Dept. of Resource Economics
University of Rhode Island
Kingston, Rhode Island 02881
(401) 792-2471

Gunnerson, C. G.
NOAA/Environmental Research Lab.
Marine Ecosystem Analysis
Boulder, Colorado 80302

Halpern, David
Pacific Marine Environmental Lab.
University of Washington WB-10
Seattle, Washington 98195
(206) 543-5284

Harding, James
Skidaway Institute of Oceanography
P. O. Box 13687
Savannah, Georgia 31406
(912) 352-1631

Harris, Larry G.
University of New Hampshire
Zoology Department
Durham, New Hampshire 03824
(603) 862-2100

Hayes, Murray L.
NOAA/Nat'l. Marine Fisheries Ser.
Northwest Fisheries Center
Seattle, Washington 98177
(206) 442-0171

Heins, Robert W.
Dept. of Met. & Mineral Engineering
University of Wisconsin
1509 University Avenue
Madison, Wisconsin 53706
(608) 262-5760

Herbich, John B.
Texas A&M University

Hess, Harold D.
U. S. Geological Survey
Conservation Division
345 Middlefield Road
Menlo Park, California 94025
(415) 323-8111

Holser, Alexander F.
Ocean Mining Administration
Department of Interior
18th and E Streets
Washington, D. C. 20240
(202) 343-9231

Hoskin, Charles
University of Alaska
Institute of Marine Science

Hughes, Kent
NOAA/Environmental Data Service

Inderbitzen, A. L.
University of Delaware
P. O. Box 286
Lewes, Delaware 19958
(302) 645-4320

Johnson, Henry S.
Intn'l. Mineral & Chemical Corp.
P. O. Box 877
Charleston, South Carolina 29402
(803) 884-2597

Jugel, M. Karl
NOAA/Office of Marine Minerals
Rockville, Maryland 20852
(301) 443-8323

Kaufman, Raymond
Deepsea Ventures, Inc.
Gloucester Point, Virginia 23062
(804) 642-2121

Keene, Donald
Pacific OCS Office
Bureau of Land Management

Keller, George H.
School of Oceanography
Oregon State University
Corvallis, Oregon 97331
(503) 754-3079

Kimrey, Leal
NOAA/Pacific Marine Environmental Lab.

Klaver, Anton
Mobil Oil Corporation

Knight, H. Gary
Louisiana State University
Law Center
Baton Rouge, Louisiana 70803
(504) 388-8701

Lane, Amor
NOAA/Office of Marine Minerals
Rockville, Maryland 20852
(301) 443-8323

Lill, Gordon
NOAA/National Ocean Survey

Livesay, Bill
Ocean Mining Laboratory
Kennecott Copper Corp.
10306 Roselle
San Diego, California 92121
(714) 453-3751

MacInnes, David
Sierra Club
1251 Gilbert Road
Meadowbrook, Pennsylvania 19046
(215) 884-7293

Manheim, F. T.
Dept. Marine Science
University of South Florida
St. Petersburg, Florida 33701
(813) 898-7411

McKenzie, Mike D.
Office of Sea Grant, NOAA
Washington, D. C. 20235
(202) 634-4125

Mead, Walter J.
Department of Economics
University of California

Mero, John L.
Ocean Resources, Inc.
P. O. Box 2244
La Jolla, California 92038
(714) 459-2907

Meyer, Robert P.
Dept. of Geology and Geophysics
University of Wisconsin
Weeks Hall - 1215 W. Dayton St.
Madison, Wisconsin 53706
(608) 262-1698

Moore, Robert
Marine Research Laboratory
University of Wisconsin

Nelson, Hans
Office of Marine & Arctic Geology
U. S. Geological Survey

Newhouse, Edgar
NOAA/Office of Marine Minerals
Rockville, Maryland 20852
(301) 443-8323

Noakes, John
Geochronology Laboratory
University of Georgia

Padan, John
NOAA/Pacific Marine Environmental Lab.
3711 15th Avenue, N. E.
Seattle, Washington 98105
(206) 442-1964

Paine, Roland
NOAA/Office of Public Affairs
Rockville, Maryland 20852
(301) 443-8243

Pajaclich, Walter
Division of Non-metalic Minerals
Bureau of Mines

Pauli, Denzil C.
Marine Board
National Academy of Sciences
2101 Constitution Avenue, N. W.
Washington, D. C.
(202) 389-6602

Pearce, Bryan R.
Dept. Civil Engineering
Massachusetts Institute of Technology
Building 48-325
Cambridge, Massachusetts 02139
(617) 253-7823

Peter, George
NOAA/Marine Ecosystem Analysis
Environmental Research Laboratory
Boulder, Colorado 80303
(303) 499-1000

Pickles, William
Lawrence Livermore Laboratory

Reichert, Guenter
Lockheed Missiles & Space Co.
1111 Lockheed Way
Sunnyvale, California 94088
(408) 743-2251

Richards, Adrian F.
Lehigh University
Marine Geotechnical Laboratory
Bethlehem, Pennsylvania 18015
(215) 691-7000

Rona, Peter A.
NOAA/Atlantic Oceanographic &
Meteorological Laboratories
15 Rickenbacker Causeway
Miami, Florida 33149
(305) 361-3361

Rossfelder, Andre
Geomarex/ECOsystems Management
1010 Pearl Street
P. O. Box 1466
La Jolla, California 92038
(714) 459-2420

Rothman, Sam
George Washington University
Tompkins Hall
Washington, D. C. 20052
(202) 676-7409

Saucier, Roger T.
U. S. Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, Mississippi 39180
(601) 636-3111

Schuler, Francis
Office of Marine Resources
NOAA
6010 Executive Blvd.
Rockville, Maryland 20852
(301) 443-8053

Sentfle, Frank
U. S. Geological Survey
Reston, Virginia 22092
(703) 860-7662

Sheary, G. W.
INCO Ocean Development

Shiels, E. F.
Zapata Corporation
P. O. Box 4240
Houston, Texas 77001
(713) 222-9051

Silver, Irving
George Washington University
707 22nd Street, N. W.
Washington, D.C. 20052
(202) 676-7068

Stang, Paul
NOAA/Coastal Zone Managemennt
Washington, D. C.

St. John, Jos. S.
Erie Sand & Gravel Co.
Box 153
Erie, Pennsylvania 16512
(814) 453-6721

Stoeffler, August G.
Construction Aggregates Corp.

Stowasser, Bill
Bureau of Mines
2401 E Street, N. W.
Washington, D. C. 20241
(202) 634-1190

Tirey, George B.
Woodward-Clyde Consultants
5120 Butler Pike
Plymouth Meeting, Pennsylvania 19462
(215) 825-3000

Vadus, Joe
NOAA/Manned Undersea Science and Technology

Van Horn, Bill
Bureau Land Management
U. S. Department of Interior
Washington, D. C. 20240
(202) 343-6264

Willard, Robert J.
U. S. Bureau of Mines
P. O. Box 1660
Twin Cities, Minnesota 55111
(612) 725-4573

Williams, S. Jeffress
Coastal Engineering Research Center
Kingman Building
Ft. Belvoir, Virginia 22060
(202) 325-7560

Wojcik, Joe
ASARCO Incorporated
3422 South 700 West
Salt Lake City, Utah 84119
(801) 262-6621

Appendix III

Agenda
NOAA Marine Minerals Workshop

<u>March 23 (Tuesday)</u> -- Summaries of NOAA Sponsored Research

8:00 - 8:30	Registration
8:30 - 9:00	Opening Remarks • Amor Lane, Acting Director, Office of Marine Minerals
9:00 - 10:30	Environmental Assessment Summaries • Panel Moderator: Dr. Larry Harris - Manganese Nodules (R. Burns for G. Anderson) - Sand and Gravel (L. Harris) - Phosphorite and Hard Rock (P. Fischer) - Placers (R. Moore) - Discussion
10:30 - 10:45	Coffee Break
10:45 - 12:15	Resource Research and Assessment Summaries • Panel Moderator: Dr. Peter Rona - Manganese Nodules (J. Andrews) - Sand and Gravel (M. McKenzie) - Phosphorite and Hard Rock (P. Rona) - Placers (L. Kimrey) - Discussion
12:15 - 1:45	Lunch
1:45 - 3:15	Technology Development Summaries • Panel Moderator: Dr. John Herbich - Manganese Nodules (T. Chapman) - Sand and Gravel (J. Herbich) - Phosphorite and Hard Rock (R. Meyer) - Placers (J. Noakes and J. Harding) - Discussion
3:15 - 3:30	Coffee Break
3:30 - 5:00	Economic and Legal Assessment Summaries • Panel Moderator: Dr. Walter Mead - Manganese Nodules (H. G. Knight) - Sand and Gravel (T. Grigalunas) - Phosphorite and Hard Rock (W. Mead) - Placers (F. Schuler) - Discussion

5:00 - 6:30	Reception
6:30	Banquet Speaker: Dr. Robert Frosch Associate Director for Applied Oceanography Woods Hole Oceanographic Institute "Dreamers, Doers, and Analysts: A Technology Assessment"

March 24 (Wednesday) -- Commodity Sessions

8:30 - 12:00	Four Simultaneous Sessions - Manganese Nodules (Chairman: Raymond Kaufman) - Sand, Gravel, and Shell (Chairman: Robert Corell) - Phosphorite and Hard Rock (Chairman: Robert Dill) - Marine Placers (Chairman: J. Robert Moore)
12:00 - 1:30	Lunch
1:30 - 4:00	Continuation of Simultaneous Sessions

March 25 (Thursday) -- Report on Commodity Sessions

9:30 - 11:30	Reports by Commodity Chairmen - Manganese Nodules (R. Kaufman) - Sand, Gravel, and Shell (R. Corell) - Phosphorite and Hard Rock (R. Dill) - Marine Placers (R. Moore)
11:30 - 12:00	Workshop Wrap-Up and Adjournment

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