Manganese Nodule Deposits in the Pacific

Symposium/Workshop Proceedings

Honolulu, Hawaii
October 16-17, 1972

MANGANESE NODULE DEPOSITS IN THE PACIFIC

Symposium/Workshop Proceedings

Princess Kaiulani Hotel

Honolulu, Hawaii

October 16–17, 1972

SPONSORED BY:

Hawaii Institute of Geophysics
University of Hawaii

Office of the Marine Affairs Coordinator
State of Hawaii

Department of Planning and Economic Development
State of Hawaii

Office of the International Decade of Ocean Exploration
National Science Foundation

State Center for Science Policy and Technology Assessment
Department of Planning and Economic Development
State of Hawaii

CONTENTS

FOREWORD

The Hawaii State Department of Planning and Economic Development (DPED), the University of Hawaii Institute of Geophysics (HIG), the Office of the State Marine Affairs Coordinator, and the National Science Foundation Office of International Decade of Ocean Exploration co-sponsored a Symposium/Workshop on Manganese Nodule Deposits in the Pacific, held October 16 and 17, 1972 at the Princess Kaiulani Hotel in Honolulu. The technical program was organized by HIG; and conference details and the compilation and editing of these Proceedings were carried out by the State Center for Science Policy and Technology Assessment, which is located within DPED. The major work of compiling and editing was done by Ginger Plasch, Research Associate. The Center is jointly supported by the National Science Foundation and the State of Hawaii.

Key personnel in the field of manganese nodules were invited to present papers or attend the two-day Symposium/Workshop. The 100 or so attendees came from the Federal government, the State government, universities, local and mainland industries, and from governments, universities and industries in other countries.

This Symposium/Workshop provided a forum to discuss the latest developments and the present status of the exploration and utilization of manganese nodule resources in the Pacific. One-and-a-half days were devoted to technical sessions, and on the final half-day a Technology Assessment Workshop was held. The Workshop resulted in recommendations for future national, international and State of Hawaii policies and actions.

These Proceedings include the technical papers presented and the results of the Workshop.

SESSION I

Introduction

Chairman: **James E. Andrews**

Speakers: **George P. Woollard**

Shelley M. Mark

Edward M. Davin

WELCOMING ADDRESS

By

George P. Woollard
Director, Hawaii Institute of Geophysics
University of Hawaii

It is with real pleasure that I welcome such a distinguished group to Hawaii. I do hope you are able to see how Americans of the far far West live on their "rock," and still discuss and exchange ideas on one of nature's, until recently, totally unappreciated natural resources: manganese nodules.

As a taxpayer in Hawaii it also gives me real pleasure to know that the discussions for which you are here can have considerable economic significance for Hawaii as well as for the country and the world at large. As a member of the fraternity of hard sciences and as an engineer, it also gives me pleasure to know that this Symposium will deal with a subject on which it is possible to reach factual conclusions that are not dependent upon the fickle and unpredictable behavior of man, or related to the generation gap, the success of the UN, ecological balance, pollution, nuclear blasts, student unrest, minority discrimination, woman's rights, or public outrage. For all such blessings we, and by "we," I mean the Governor of Hawaii, his honor the Mayor of Honolulu, the President of the University of Hawaii, and the Chancellor of the Manoa Campus, as well as myself and other citizens of the Islands, are duly thankful and grateful.

The topic of this Symposium is one of great importance to the world, to the United States and particularly to Hawaii, since Hawaii is in the center of one of the world's greatest deposits of high-grade manganese nodules--a resource yet to be exploited. These deposits will have tremendous economic potential once they are effectively mapped and sampled to define their true mineral worth; legal problems for exploitation are resolved; and the problems of economic recovery from the ocean floor, ore treatment, and mineral separation are resolved.

As you will hear today and tomorrow, great strides have been made over the past few years on each of these facets influencing the economic value of manganese nodules. You will also hear that in contrast to most other natural mineral resources, this resource is constantly being regenerated and on a time scale that boggles the imagination in that it is second only to the artificial cultivation of oysters and pearls, and rates with aquaculture, raising beef, and agriculture as a process that man can exploit to meet some of his demands on nature.

Only ten years ago manganese nodules were regarded as a curiosity in the same class as petrified dinosaur eggs and gizzard stones. Then the economic value of the nodules was assessed only on the basis of their iron and manganese contents. The availability of iron on the world market and the limited demand for manganese made it appear that the nodules were not worth mining. However, with the discovery that manganese nodules contain significant accessory cobalt, nickle and copper, and with the identification of rare earth minerals, titanium, palladium, platinum and gold as component metals, the nodules are no longer something of value only to a museum or a collector of curiosities. We now have to consider them as ore; how their tenor varies with environment of occurrence; the extent of localities where they have high economic value; the most cost-effective means of recovery; and with this, the problem of ocean pollution and the effect of mining operations on the ecological balance and pelagic fish. The problems of ore treatment and mineral recovery once the nodules are mined are significant ones, as is the effect on world markets. The problem of control, both from the legal viewpoint and price support of the metals recovered, is another. A glance at the Conference program shows that most of these subjects will be discussed today and tomorrow. This Symposium represents one of the few instances when most of the aspects of exploiting a new resource will have been looked at realistically in advance of exploitation. It is a common-sense approach, and as such, the program committee and those who provided support to make the Symposium possible are to be commended.

So I welcome you on behalf of the people of Hawaii, fill a necessary puka (which is Hawaiian for a "hole") whether in lava, Swiss cheese, the street, or in this case the program , and to tell you how pleased we are that so many of you could take time off from your busy schedules to discuss what we in Hawaii feel is an important subject that could influence our economic destiny. In short I say aloha and mahalo, and if I may revert to my English heritage, say "God bless," both as it applies to this Conference and to what may develop from it.

HAWAII: A NATURAL FOR NODULES

By
Shelley M. Mark, Director
Department of Planning and Economic Development
State of Hawaii

It is a great honor for me to join Dr. Woollard in welcoming to Hawaii so distinguished a group of scientists and other leaders, gathered here for our Symposium/Workshop on Manganese Nodule Deposits in the Pacific.

Hawaii has established a tradition of inviting or organizing here many international gatherings on a great variety of subjects. They have been attended by Presidents, Prime Ministers, Queens, Princes and Princesses, philosophers and scientists, and business and industrial leaders.

We are particularly pleased to welcome those skilled in the marine sciences, since ours is a marine State. Hawaii is a "natural for nodules" and a number of research reports indicate Hawaii is the heart of a vast undersea region in which these nodules are most plentiful.

There are at least four major reasons why Hawaii is a "natural" for manganese nodule research and related work. Our geographical location in the center of a great ring of Pacific nations is the most obvious one. Second, we have a very strong educational and technical support base for nodule research, experimental expeditions and other work. A third reason is Hawaii's history of innovative use of science and technology in a variety of fields, particularly agriculture and oceanography. For example, when the Federal government published its marine science report, Our Nation and the Sea, Hawaii followed it almost immediately with Hawaii and the Sea, a Plan for State Action, which has brought significant practical results.

The fourth reason why Hawaii is ideal as a world center for manganese studies and possibly mining is found in our Foreign Trade Zone, one of only seven in the United States. Let me discuss these four points in a little more detail.

First, Hawaii's unique location: Hawaii once was a great center for whaling fleets. We have been, since the dredging of the channel into Pearl Harbor and the development of the Naval shipyard, a major military and naval base. We were, before the age of fast ships and faster planes, an important coaling and oiling station for Pacific voyages. Today, we are increasing our marine services with a new oil refinery serving foreign bottoms, and encouragement of the use of our harbors for more economical transshipment of goods by surface and air to other world ports.

We have seen a significant increase in the number of scientific vessels on exploratory cruises, prospecting for manganese nodules. These ships have been put into Hawaii's harbors for various services.

The distribution of nodules in the Pacific puts Hawaii in a strategic location in relation to these "lodes of nodes," if you will forgive the phrase.

In addition, during the past few years deposits of manganese nodules and plates have been discovered very close to our Islands, notably in the Kauai Channel. It is worth noting that Pacific Ocean nodules have higher concentrations of those metallic elements having economic demand and value compared with nodules found in the Atlantic.

Because of its central location, Hawaii is a logical point for providing services to vessels and their crews, research and development, and possibly processing of nodules. I might add here that as you know, we have active volcanoes in Hawaii, and there are indications that the formation of nodules is somehow related to the presence of volcanic material.

We recognize that industry and government must take a long-range view with respect to costs of any needed industrial support, land support bases, transportation facilities, processing, and power supply related to a manganese nodule industry. We believe that now is the time that many of these factors should be considered while the international and other legal, jurisdictional and political aspects of mining and processing particularly as they relate to Hawaii's resource management concerns, are being resolved and clarified. It is worth emphasizing here that Hawaii has very deep waters relatively close to shore, a factor to be considered in test dredging and other experimentation.

The second reason Hawaii is important as a manganese nodule base is that we have a strong foundation of technical expertise and facilities in our Islands. Many people think of Hawaii only as a tourist center and an agricultural State. However, a recently published Directory of Hawaii's Scientific Resources shows 345 organizations and more than 25,000 people are engaged in science and technology activities in the State. This is far greater than the 17,900 people employed by the hotel industry. Hawaii has a number of internationally known research centers such as the Hawaii Institute of Geophysics, the Hawaii Institute of Marine Biology, the Institute for Astronomy, and the Bishop Museum. The University of Hawaii has several research ships that are in continuous use for oceanographic and geophysical exploration and studies. The State of Hawaii has supported practical exploration for, and studies of, manganese nodules in the Pacific. This strong technical base makes Hawaii an ideal research and development center for manganese nodules, especially for the study of the causes of nodule formation, for deep-sea testing, and for processing technology.

The third favorable factor about Hawaii is our tradition of using science and technology in exceptionally innovative and sophisticated ways. In agriculture, for example, Hawaii has been a leader in the development of new varieties of sugar cane and very advanced methods of growth and harvesting. This technology has been exported throughout the world. The University of Hawaii is presently operating an experimental satellite educational system, linking various Islands of the Pacific. Students in Fiji, Samoa and New Zealand may take courses for credit at our University via satellite with a two-way exchange between the professor and the students.

We are continuing studies of ways to convert volcanic magma heat to useful power. This is of particular importance as a potential low-cost power source.

Cheap geothermal power would lead to new possibilities in processing manganese nodules. Environmental studies of ocean mining may also lead to new approaches such as the tracking of sediment clouds in the sea by remote sensing from earth resources satellites. Hawaii is a logical center for such studies.

The fourth factor favoring Hawaii as a center for manganese nodule work is our Foreign Trade Zone, part of our Department of Planning and Economic Development. It is one of seven such Zones in the United States. Material may be landed and processed, and the original or processed products shipped to other countries without payment of import duties. The Trade Zone has other special attractions and incentives for international commerce. It has already attracted a number of industries, taking advantage of its special benefits.

The four factors I have mentioned are only the more obvious ones favoring the Islands as a center for manganese nodule prospecting, mining, processing and distribution, as well as for the scientific studies and technological development upon which such practical work must be based. I need not mention to all of you the finer points of living and working in Hawaii, where the air is balmy, the nights clean and cool, the ocean beaches clean and inviting, the people lovely and charming, and the research and education climate second to none.

We are hopeful your conference activities today and tomorrow will lead to recommendations for policy and action which can benefit our State, our nation, and the world.

Mahalo.

U.S./IDOE RESEARCH PROGRAMS IN RESOURCE GEOLOGY

By
Edward M. Davin
Office for the International Decade of Ocean Exploration
National Science Foundation
Washington, D.C.

The International Decade of Ocean Exploration (IDOE) was proposed to examine major scientific problems on man's relationship to the sea through the concerted efforts of many institutions and many nations.

The National Science Foundation has the responsibility for management and funding of the U.S. participation in IDOE. The Office is under the Assistant Director for National and International Programs--along with Deep Sea Drilling and Polar Programs.

There are four program areas: environmental quality, environmental forecasting, seabed assessment and living resources.

Seabed assessment programs are oriented primarily toward resource-geology; i.e., the results should assist the exploration geologist in planning more detailed investigations. The projects considered for funding investigate those processes which operate both on the sea floor and along the continental margins which generate the raw materials of industrial civilization-petroleum and heavy metals.

These projects can be divided into three broad areas of investigation. The three areas of investigation are: (1) passive continental margins, (2) active mid-oceanic ridges, and (3) ocean mineral deposits, particularly in the abyssal plains of the ocean.

At present, there are two major studies of the continental margins, one on the East Atlantic Ocean, the other on the Southwest Atlantic; a third study includes the framework of the continental margins of the Gulf of Mexico, Caribbean and the coastal waters off Monrovia (West Africa). In the second area, a major study is already underway on the Nazca Plate, off the west coast of South America and a new program is beginning this year to investigate the mid-Atlantic Ridge. In the area of ocean minerals, a new project is now being defined in manganese nodules.

Almost all of these projects were proposed and defined at major international scientific meetings of organizations such as the Scientific Committee on Ocean Research and the Pan-American Institute of Geography and History.

K. O. Emery summarized our knowledge--the extent to which continental margins are known--of the best known and moderately known areas, these are mostly from the economically more advanced countries around the North Atlantic. From these limited data we have established general principles on the structure and characteristic of continental margins through geologic history.

Concentrating on the coastline around the South Atlantic Ocean; i.e., off the coasts of Africa and South America, has broad scientific appeal. Considering the currently accepted "fit" of the continents made by Bullard, the process of separation and spreading must have been relatively straight-forward here, and, therefore, the most logical place to reconstruct the phases of sea-floor spreading and the changing conditions through geological time. The South American coastline has numerous fractures and open-ended basins trending normal to the coastline with counterparts at conjugate positions on opposing margins off Africa. Results and interpretations gleaned from carefully conducted investigations on the South Atlantic margins are applicable to other passive continental margins where existing measurements await fresh perspective. The potential here is great for international cooperation.

The Atlantis II from WHOI began its survey off South Africa last February and completed the first cruise off the north coast of Angola in June. Next year's survey will extend the coverage north and include lines off Portugal. The 1972 survey concentrated on the continental margin and extended out to the mid-Atlantic Ridge. Scientists from South Africa, Portugal and France participated in the cruise; scientists from Nigeria, Gabon, Ghana, Senegal, Liberia, will participate in next year's survey.

Preliminary results are available. Two areas were outlined where conditions are favorable for oil accumulation. One is a thick sedimentary section off the delta of the Orange River, S.W. Africa; the other is a large salt basin off Angola. Illustrations in Emery's operational report show the area near Luanda and show that highly plastic salt domes have folded the overlying sedimentary layers.

This project will extend seaward the geological picture of West Africa and serve as a framework for later more-detailed work by groups within these countries. The benefit to the U.S. is more long-term. By understanding better how continental margins are formed, criteria can be developed for locating older margins in the geological column. This will improve the risks in searching for new oil provinces which are becoming increasingly harder to find.

Simultaneously a complementary survey is being carried out in the Southwest Atlantic off the coasts of Argentina and Brazil. Both Lamont and WHOI are working with marine scientists from both countries. The results will become available in the same time framework as the East Atlantic Continental Margin.

Here again the potential for international cooperation is excellent. We have had discussions with Brazil, France and the Netherlands.

Both Brazilians and Argentinians are providing second ships to Lamont. Meanwhile, under guidance of WHOI scientists, Brazil is outfitting its own marine research vessel. The first cruise will start this November. Similar discussions are taking place with Argentinians.

Le Pichon (CNEXO/France) who has been studying the Walvis Ridge off West Africa plans to do a similar study off Brazil--a trend known as the Rio Grande Rise. Collette from the Vening Meinesz Laboratory in the Netherlands has indicated plans to survey the coastal area off Surinam.

The surveys off South America and Africa will be tied together by a series of regional lines from the coasts out to the MAR. Emery plans to do this work once the work off Africa is complete.

From October 29 to November 2, 1972, the Brazilian Geological Congress will be held at Belem: The participants in the SWACM Study will meet there and discuss, among other topics, the present status of our knowledge of the continental margins and identify problems which can be approached on a cooperative basis.

In addition to programs in the Atlantic, other parts of the world's continental margins remain largely unexplored. Several sites in the Gulf of Mexico, Caribbean and Northwest Africa were surveyed by the U.S. Geological Survey. These data are now being analyzed.

IDOE has been invited to participate in the technical meeting of the Coordinating Committee for Offshore Production (CCOP), part of the UN Development Program. A key agenda item is the possible IDOE program for the continental margins and small ocean basins in the area which extends from Korea and Japan, south to Philippines and the Malaysian Peninsula. Scientists from these countries will define their problems, describe their current plans and the resources available.

Turning now to the subject of mid-oceanic ridges and active trenches, their resource potential is not as apparent as it is along the continental margins. Nonetheless, it represents an intriguing scientific problem which may hold the answers to how the world's mineral deposits are formed.

A consideration of the map of world seismicity is a logical place to begin. The worldwide occurrence of earthquakes as recorded during the sixties forms a pattern. There is a continuous line of earthquakes down the middle of the Atlantic Ocean and around the Pacific Ocean.

When studied in detail, this pattern reveals that the surface of the earth is made up of several major plates and some minor ones. Along some of the margins of these plates, evidence suggests that new crust of the earth is continuously being formed and along others that it is being consumed. The two processes balance each other out. The size of the earth remains the same.

IDOE is interested in the active mid-oceanic ridges, such as the Mid-Atlantic and the East Pacific Rise and the active ocean trenches such as the Peruvian-Chilean Trench. We are testing the hypothesis that heavy metals rise with the new crust, that it moves toward the trenches where complex distillation processes concentrate the metals into rich ore deposits.

The Nazca Plate has been recognized as an excellent example for detailed investigation of the complete cycle from crustal formation along the East Pacific Rise to its consumption in the Peruvian-Chilean Trench. The major copper deposits of the Andes are considered to be a significant end-product of this process.

The University of Hawaii in cooperation with Oregon State University and the Pacific Oceanographic Laboratory of NOAA are conducting a study of the margins of the plate using geophysical methods and extensive sampling. Scientists from Colombia, Ecuador, Peru and Chile are all actively participating through the Pan-American Institute of Geography and History, both on the cruises and in the data analysis. Ecuador and Chile are contributing on the cruises and in the data analysis. Ecuador and Chile are contributing ships. Considering the travel-time to reach the Nazca Plate from Oregon and Washington this will be a significant contribution to the investigation.

During 1972 the Soviets carried out an extensive sampling program along the East Pacific Rise. Russian scientists will work with the HIG group next year. Their extensive sampling program will complement the U.S. detailed geophysical surveys.

Dr. Woollard, Director of Nazca Plate Study, is carrying out a major study of transition between the continental and oceanic crust under the Andes. Although this study goes beyond the scope of IDOE, the data on subduction zone has obvious implications for the Nazca Plate metallogenesis studies.

The East Pacific Rise extends northward into the Gulf of California where it is accessible for study relatively close to the surface. Scientists from Scripps and the University of Mexico are making a detailed study of this rift valley which is believed to be analogous with the Red Sea Rift Valley where heavy metals have been detected in the hot brines.

Better understanding of this same phenomena is also the basis of our interest in the Mid-Atlantic Ridge. During the past few years it has been the subject of study by scientists from many countries surrounding the North Atlantic.

In order to obtain a clear picture of the nature and scope of the problem a workshop was held last January which brought together scientists from Canada, the U.K., France, the Netherlands, and Iceland, as well as several institutions in the U.S. The report entitled "Understanding The Mid-Atlantic Ridge, A Comprehensive Program" gives a broad review of our present knowledge, includes recommendations for future investigations. The program goes far beyond the scope of IDOE and will be supported by NOAA, ONR, as well as other offices in NSF.

Investigating the Mid-Atlantic Ridge will begin with Project FAMOUS (Franco-American Mid-Ocean Undersea Study). Scientists from France and the U.S. are planning extensive explorations using manned submersible crafts. If you consider that studies to date from surface ships are analogous to making geophysical surveys on land from elevations of 15,000 feet, then our present understanding of the ocean floor is very coarse indeed. WHOI is now gathering data, developing instrumentation and training scientists in preparation for dives in 1973-74. Firsthand observation, sampling, and photography will be obtained along walls of the rift valley, crestal mountains and fracture zone scarps. This will make it possible to determine the geology to a scale of a few meters. Selection of actual site for dives will be based on detailed survey to be carried out this fall. Finer details will be obtained by means of U.S.-British deep tow devices. In addition to the French and British, Canada, the Netherlands, Iceland and Portugal plan to participate.

The third general area of investigation is ocean minerals. Until recently the nodules were regarded as a geologic curiosity like the Green River Oil Shales and the tachonite deposits of Minnesota. With changing technology, however, these deposits are now being exploited. Similarly, during the past few years there has been an increase in interest in the nodules for their economic potential.

A major workshop/conference was held at Lamont last January. The proceedings are now in press and will be available later this year. Here again the purpose was to determine the state of knowledge and prepare recommendations for a research program. There was general agreement among the participants that a lot of information in core labs and files should be inventoried and published. From the 30 scientific-technical papers presented and the ensuing discussions, roughly four major themes seemed to stand out: (1) the chemistry of formation; i.e., rates, habitats, geologic ages, etc.; (2) the technological problems which must be solved before mining becomes economical; (3) the environmental impact of stirring up the sediments on the deep ocean floor must be assessed; and (4) little is known about the legal status of mining operations far beyond the limits of any claims to offshore sovereignty.

We are currently supporting a definition study covering these four areas. Lamont-Doherty Geological Observatory is serving as a coordinating office. Ten separate studies are being done at Lamont and another ten at other U.S. institutions. Close to $300,000 is going into this one-year effort which is substantial for a definition study. The results, however, should provide a broad basis of research for other interested groups. The environmental impact of ocean mining, for example, and the technology of recovering the nodules is of interest to NOAA. When the definition study is complete and the recommendations available, IDOE will then have a basis on which to begin Phase II.

SESSION II

Legal Aspects

Chairman: **Agatin T. Abbott**

Speakers: **John P. Craven**
Leigh Ratiner
Myron H. Nordquist
Francis M. Auburn

HAWAII'S RELATIONSHIP TO THE DEVELOPMENT OF SEABED RESOURCES AND TO THE DEVELOPING LAW OF THE SEABED

By
John P. Craven
Dean of Marine Programs, University of Hawaii
and Marine Affairs Coordinator
State of Hawaii

In 1969 before coming to Hawaii, I presented a paper on the question of developing jurisdiction of the seabed with exploitation of resources. This paper argues that for purposes of both conservation and economic exploitation a single jurisdiction (whether it is international, national, or municipal) which has a resource of identifiable geographic entity, must insure that the resource was both economically utilized and wisely conserved. At the time, the presumption was made that manganese nodules were of fairly uniform composition and uniformly distributed across the ocean. As such, they were considered not identifiable as a geophysically defined geographical entity. Under such an assumption any attempt to exert a single jurisdiction over manganese nodule ore fields would be very difficult indeed.

But it now appears that this is not true. The composition of any manganese nodule field may be highly dependent upon geophysical properties which relate to geographical or geophysical features which can be identified geographically. Thus we may find that the manganese nodule fields, while of considerable extent, are as yet unidentifiable in terms of economic significance. Certainly we know now that the economic significance of manganese nodules is going to be highly dependent upon a multiplicity of factors. These include the chemical composition of manganese nodules and the proximity to port and harbor areas where they can be beneficiated and reduced. The resulting economic equation is rather complicated, but if one can find nodules rich in other minerals which are close to islands, then those islands will have a high probability of being involved with the recovery and processing of such nodules. If we look at the latest information about the nodules in the vicinity of the Hawaiian Archipelago, it is already clear that there is some relationship between the activities that formed the Hawaiian Archipelago and the distribution of mineral content in the manganese nodules.

We can therefore partially identify manganese nodules in terms of geographic entities, if we look at their geophysical properties. With this in mind, if we re-examine the points that were made in the earlier paper, we can conclude that attempts by nations to establish jurisdiction over large areas of the seabed will be frustrated by the very extent of the sea floor and the seabed and the fact that economic interests will center on a relatively small area. To this extent doctrines which attempt to exert jurisdiction over large areas of the world, over continental shelves, or over large areas of seabed, are going to be very much like the papal bull of 1494, in which it was declared that all of the oceans of the world were divided between Spain and Portugal. It was therefore suggested that one must look for a doctrine which is related to the resource and a jurisdiction which again is related to the resource.

This last summer a group of students examined the Hawaiian Archipelago in this regard. The initial examination was focused on the current status of the seabed in the Hawaiian Archipelago under current international law and international doctrine. The students discovered that contrary to popular belief, the presumption that the State of Hawaii has well-defined physical boundaries is incorrect. It is true only for limited purposes. In fact, the boundaries of the State of Hawaii are, in terms of legal documentation, very loosely defined. Current legal research indicates that the boundaries of the State of Hawaii are identified as the boundaries of the Territory of Hawaii and the boundaries of the Territory of Hawaii are identified as the boundaries of the Kingdom of Hawaii. If one examines the claims of the Kingdom of Hawaii, at least one monarch, King Kalakaua, declared that the Kingdom of Hawaii consisted of all of Oceania. The terms of the Statehood Act do eliminate certain areas (I think Palmyra, Johnson, and Midway) from the State. With those exceptions King Kalakaua's claim could include Catalina and San Clemente Islands off the coast of California, and perhaps the New Zealand islands where Dr. Francis Auburn comes from.

On the other hand there have been a number of legal cases which indicate more limited boundaries. The most significant is the case relating to the definition of Hawaii in terms of interstate commerce. Here, the courts ruled that a plane flying from one Island to another passes over international waters as defined by the Interstate Commerce Act. Fairly recently a number of archipelago nations, particularly Indonesia, have made claims that an archipelago includes not only the land mass, but also the intervening areas between the land masses. Acting on the presumption that the Islands of Hawaii are defined in a somewhat conventional way with respect to high-water marks, then one can indeed draw a very unusual patchwork quilt around the Hawaiian Islands in terms of State, Contental-Shelf, and national jurisdictions. (This is, however, difficult in the area of the French Frigate Shoals and other reef areas of the Leeward chain, since it is not quite clear which of the protruding rocks are indeed islands in the archipelago and which are just merely projecting coral reefs.)

The student study project concluded that a new doctrine was required for the conservation and economic exploitation of the resources of the Hawaiian Archipelago. The study project therefore suggests a new doctrine which, while it may not be promulgated by any agency of the State, is at least suggestive of some changing possible view of jurisdiction over resources. This doctrine essentially suggests that one might attempt to establish a property right in the mineral resource. Since the student study was not confined to manganese nodules, but to all the resources, it includes an attempt to establish a property right in the biological resources. Excerpts of this proposed doctrine are:

WHEREAS, the Hawaiian Archipelago is an integral geophysical and biophysical configuration and the conservation and utilization of the resources thereof are inseparable; and

WHEREAS, the Constitution, Laws and Treaties of the United States vest jurisdiction over said resources to a limited extent viz to the twelve-mile contiguous area for fisheries and to the limit of the Continental Shelf, as defined by the 1958 Convention on the Continental Shelf for resources of the sea bed; and

WHEREAS, the vast majority of sea bed resources of the Hawaiian Archipelago are in water depths substantially greater than 200 meters or in international waters as currently defined by such Treaty; and

WHEREAS, the vast majority of biologic resources are in international waters as defined by the 1958 Convention on the Law of the Sea as further defined by unilateral assertions of sovereignty by the United States; and

WHEREAS, the exploitation or interference with such resources of the Hawaiian Archipelago which are in international waters poses a threat to the biological and physical resources of that portion of the seabed and ocean waters in the jurisdiction of the State of Hawaii; and

WHEREAS, a substantial portion of the biological resources of the Hawaiian Archipelago experienced a significant part of their life cycle (said life cycle including ancestral, embryonic, larval, or progenal phases) in part or in whole in waters within the jurisdiction of the State of Hawaii; and

WHEREAS, a substantial portion of the mineral resources of the Hawaiian Archipelago are the result of geophysical processes of accretion and deposition related to the geophysical configuration of the State of Hawaii; and

WHEREAS, the uncontrolled exploitation or interference with such resources of the Hawaiian Archipelago poses a threat to the environment, economy, and wise management of said resources; and whereas said threat amounts to a danger to the public health, safety, and welfare of the people of Hawaii; and

NOW THEREFORE, it is concluded that those biological resources where life cycles, including ancestral, embryonic, larval and progenal phases which occur in part or in whole in waters under the jurisdiction of the State of Hawaii, and those mineral resources of the Hawaiian Archipelago whose deposition and/or accretion are the result of processes which interact with the geophysical configuration of the State of Hawaii, have been and are by virtue of said life cycles or said geophysical process, the property of the State of Hawaii; and inasmuch as the state of scientific knowledge does not admit of precise definition of the relationship of the resources to the geophysical and biophysical configuration of the State of Hawaii; it is deemed that this claim shall apply to all of the biological and mineral resources known to exist in the Hawaiian Archipelago, or later discovered to exist, within an area bounded by parallel lines drawn generally north and south from a line connecting the highest elevation location of the islands known as Kure, Pearl and Hermes Reef, Lisianski, Laysan, Maro Reef, Gardner Pinnacles, French Frigate Shoals, Necker, Nihoa, Niihau, Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii. The end extremes of this shall be fixed a point 200 miles north beyond the end of the Island of Kure at the northern extreme and south beyond the Island of Hawaii at the southern extreme. This description is meant to claim all biological and mineral resources within a corridor 400 miles wide, generally centered at the highest points of elevation along the Hawaiian Archipelago; beginning and ending about 200 miles beyond the northern and southern extremities of the island chain.

HOWEVER, said declaration of property right is not deemed to vest in those pelagic fish whose presence in or near the Hawaiian Archipelago is, or may be found to be, wholly independent of the existence of the Hawaiian Archipelago.

This declaration of property right is absolute and entire except for (1) that portion of the Continental Shelf which is covered by the 1958 Treaty on the Continental Shelf and thereby reserved to the Federal Government, (2) those biologic resources which are beyond the three-mile limit but within the twelve-mile contiguous zone as defined by the 1958 Treaty on International Fisheries, and (3) the area reserved to Federal jurisdiction at or near Midway Islands.

Whether this proposed doctrine or similar doctrine is promulgated, it is clear to all of us that the nations of the world must find some way of vesting single jurisdiction over resource fields which are defined as an entity. If the nations of the world adopt such an approach, they will discover that archipelagos are one such geophysical entity and that the biological and physical resources of archipelagos will be related to the existence of the archipelago and therefore warrant archipelago management. Unless this happens, any other patchwork-quilt division of mineral resources will result in the kind of pollution and inefficient exploitation that we have seen in the past, in the development of oil fields and minerals and other competitive exploitations.

PUBLIC POLICY AND THE DEBATE ON U.S. SENATE BILL S 2801

By
Leigh Ratiner
Director for Ocean Resources
U.S. Department of the Interior
Washington, D.C.

We are all familiar with U.S. Senate Bill S 2801 and its companion bill in the House, HR 13904, so I will mention only its principal features. First, it is a bill prepared by the American Mining Congress and introduced by Senator Metcalf. Its avowed purpose is to promote the conservation and orderly development of the hard-mineral resources of the deep seabed beyond the limits of national jurisdiction pending adoption of an international regime by treaty. Its actual purpose is to establish promptly a legal and operational climate which will give United States mining companies guarantees sufficient to justify major investments now in deep-sea mining, and reduce to an inconsequential degree the political risk which results from international negotiations which may alter the legal status of the deep seabed from what it is today--an area subject to the high-seas regime--to another more restrictive international regime yet to be negotiated.

Just as our tuna fishermen in California might be reluctant at this particular time to build new fishing vessels at a cost of say one million dollars each if those vessels were tailor-made to fish exclusively for tuna within 200 miles of Peru, our mining industry is reluctant to spend 250 million dollars for each company to develop mining systems, metallurgical processes and prototype and production plants tailor-made for a mineral resource which as a result of negotiations now in progress could conceivably become legally inaccessible. The net result, if four U.S. companies made the necessary investment, might be perhaps a billion dollars "sunk" into the Pacific Ocean.

As an official of the Department of our Government which is responsible for the development of mineral resources, I find it difficult to fault either the avowed purpose of the bill or its actual purpose as I have described it. However, as an official of the United States Government charged first with a responsibility to assure rational management of resources which may fall under the jurisdiction of the United States and second (and not in order of importance), having the responsibility to help assure the negotiation of a global treaty governing virtually all uses of ocean space for perhaps several hundred years, my sympathy for our minerals industry must be tempered by a variety of other considerations such as national defense and foreign policy. I will, however, present to you the key issues which must be considered in the development of a domestic policy on deep-sea mining.

Industry's principal arguments in favor of S 2801 are:

First, the United States ia mineral-importing country--at least with respect to the minerals found in manganese nodules. While there is not a metal shortage, industry believes, particularly in light of the proclivity of some developing countries for expropriation of investment and control over production and prices, that it is in the U.S. interest to reduce American dependence as much as possible on foreign sources of supply. This argument seems faultless: our country cannot survive without secure and dependable sources of minerals. To the extent we must find such mineral resources beyond our own borders, it seems to me incumbent on the Government to attempt to help create, through international law, conditions of stability, fairness, and security which will, to the maximum extent possible, reduce the risks inherent in reliance on minerals found under foreign sovereignty or in the oceans.

Nevertheless, these are objectives which in the abstract need not be gained by unilateral action and can be achieved through international negotiations and embodied in a new treaty. Apparently industry is concerned that these objectives may be sacrificed in the negotiations to achieve other objectives. I do not believe the U.S. negotiators will do this. Accordingly, taken alone, I do not regard this as an overriding consideration requiring passage of S 2801 or similar legislation.

Second, industry apparently believes that the Law of the Sea negotiations will take several more years to complete and possibly, it will be an additional five to ten years after that before the treaty has the requisite ratifications to come into force. This delay, they argue, will make it necessary to put off investment for so long that capital will move toward land mining rather than ocean mining, and the capital-intensive, technological effort to create this new industry will not take place. They fear that other countries will engage in the enterprise anyway, with governmental assistance and encouragement. The result they say, will be that by the time a treaty comes into force, others will have a substantial technological, prospecting, and site-identification lead over the United States--a lead not to be easily regained.

On the other hand, there are cogent arguments that the Law of the Sea treaty, when completed in the next several years, can be implemented immediately by national governments, provided they allow for the requirements of the treaty when it comes into force. The United States need not await the actual treaty before implementing it. The United States has not accepted the moratorium resolution of the United Nations General Assembly, and holds the view that until a new regime comes into force, we are entitled to mine the seabed under the high-seas convention. Hence, we could enact interim legislation closely geared to the treaty, once we had signed it, which would give industry the necessary assurances so that they could make their investments in about two years from now. Moreover, the short delay inherent in the approach I have just discussed would probably not result in the substantial risk of foreign countries closing the technological gap. My observation is that industry still has additional work to do before it can make the very large investment necessary to build production plants.

Nevertheless, we must seriously question whether the foregoing scenario is realistic. Can the United Nations be expected to negotiate a satisfactory treaty of universal appeal by the end of 1974? I will return to that question at the end of my statement.

Third, industry has closely watched the U.N. Seabeds Committee and has noted not only a disturbing reluctance on the part of many countries to get on with the job but a "sheep-herding syndrome." A few countries (whose economies are closely related to the mining of certain of the metals found in manganese nodules) are intensively pushing for an international regime which can control both production and prices of minerals through an organization that would be dominated by developing countries and legally empowered to have the exclusive authority to mine and market seabed minerals.

In the interest of "developing country solidarity"--an important political reality in U.N. politics--many other countries are giving tacit support to this international-regime approach. Industry concludes then that, even if we could speed up the negotiations to meet their timing needs, the result will be unacceptable to them; they lack confidence in the treaty-making process. This lack of confidence is not tied to the skill of the negotiators. Rather, industry fears that it may be necessary for the United States to accept a fundamentally harmful treaty on the deep seabeds in order to obtain other objectives in the treaty, such as the freedom of transit of U.S. warships through international straits. Industry has watched our negotiations and has concluded that they might be "sold out" if the United States could achieve other interests. To correct this erroneous impression (which is not only held by industry but also by several foreign delegations) the chief U.S. negotiator, John R. Stevenson, made the following statement on August 10, 1972, in Geneva at the plenary session of the U.N. Seabeds Committee, and repeated it in no uncertain terms in testimony before the House Merchant Marine and Fisheries Committee only two weeks ago.

> "The views of my delegation on resource issues have also been stated on a number of occasions. Unfortunately, some delegations appear to have the impression that maritime countries in general, and the United States in particular, can be expected to sacrifice in these negotiations <u>basic elements of their national policy on resources. This is not true</u>. The reality is that every nation represented here has basic interests in both resources and non-resources uses that <u>require</u> accommodation.
>
> "Accordingly, we believe it is important to dispel any possible misconceptions that my government would agree to a monopoly by an international operating agency over deep seabed exploitation...."

It is clear then that while the United States is following the "package-deal approach" in these negotiations, it has made clear in major policy statements that it cannot and will not trade off its basic resource objectives to achieve other equally important objectives such as those concerned with the mobility of U.S. forces at sea.

Fourth, industry holds the view that if it has a right to mine the seabeds under present international law, it is patently unfair to ask it to mine while the United States is negotiating a treaty which will almost certainly do away with the regime of the high seas for deep-sea exploration and exploitation. Investing 250 million dollars knowing the law may soon require surrender of mine sites which justified the investment, would I am sure be regarded as a rather poor investment decision.

I must confess that I see a great deal of logic in favor of industry on this point. As I said earlier, if the treaty could be completed and implemented by U.S. interim legislation fairly soon, I would not want to add a new and possibly divisive issue into the debate in the U.N. and would conclude that a short wait for a treaty would be reasonable. The real question then is whether it is possible to negotiate a treaty which is sound from the viewpoints of both the investor and the miner and also a treaty which will be completed in the very near future.

I am pessimistic that this can be done, but I still have some hope.

Negotiations on a legal regime for the deep seabed have been slow, despite the insistence by the developing countries that priority be given to that very aspect of the Seabed Committee's work. The United States has warned repeatedly that technology would not wait for the U.N. to finish interminable debate. We have shared with the developing countries a sense of urgency about these negotiations. Yet despite our best efforts, the world does not appear to be ready to grapple with its current opportunity to write law before mining begins. We urged a 1973 Law of the Sea Conference and the U.N. General Assembly agreed to call one in 1973. It is now obvious that if the General Assembly (currently meeting in New York) does convene a 1973 Conference this will merely be an organizational and procedural meeting--the substantive work would not begin until 1974. Moreover, we have thus far seen no emerging consensus that would allow the Conference to finish its work by 1974. What, then, can we tell our Congress and our industry when they ask us how long the United States should wait? We don't know--and that is not really a satisfactory answer.

Perhaps an even more important reason for pessimism is the serious communication gap in these negotiations. In any negotiation it is critical for both sides to remain keenly aware of the bargaining flexibility available to each. Within limits, that flexibility should be obvious to all parties. A careful review of United States' speeches in the Seabeds Committee would give other delegations a good idea of the extent of our flexibility. Yet we seriously run the risk right now of being misunderstood. Many of the developing countries are still making new far-reaching proposals which exceed our own negotiating scope--at a time when we are coming quite close to our final negotiating positions. It is in some respects like negotiating the sale of a car. Let us say the asking price for the car is $5,000 and the dealer's cost is $3,000. If we want to buy we would offer $3,500 and work up from there. But if we offer $1,500, the dealer will quickly lose interest in the negotiation. The same thing is occurring in the U.N. on a larger and more complex scale and our industry is losing hope that a fair legal regime can be negotiated.

The plain truth is that a few developed countries have the capital and technology to mine the deep seabeds. If the common heritage of mankind is to be realized in any concrete way they must be enticed into making that capital and technology available to all. But so far the developing countries' proposals have offered very little encouragement. Can the United States and other developed countries afford to seriously contemplate making their capital and technology available on a "service contract" basis to an international organization which would monopolize seabed resources? The answer is obvious. Yet, at this late stage in the negotiations, this is precisely what the developing countries seem to be advocating. So the problem is that the negotiations lack credibility. Let us use our car example again. We should now be negotiating in a range between $3,750 and $4,250. Instead we are at about $4,500 and the developing countries are at $2,000. If there is to be a successful treaty in 1974, we should be far past the conceptual and philosophical stage by now. Negotiations today should be concerned with block sizes, royalties, work requirements and a licensing system.

For these reasons I am pessimistic. How much longer will we be able to continue to tell our Congress and our industry that if they are just a little more patient we will bring home a good treaty which guarantees a fair, reasonable and stable investment climate under which deep-sea mining can commence.

When Congress asked for our position on S 2801 last spring we withheld it. We wanted to see whether a new sense of purpose would infuse the Seabed Committee's work in the summer. We also wanted to see whether the U.N. General Assembly now in session would make definitive decisions as to the timing of a conference so that we could tell our Congress when they might expect to see a final treaty.

We did see a new work ethic emerge in the Seabeds Committee. The meeting was businesslike, marked by a lack of rhetoric, and was encouraging. But industry has been quick to point out--and they are not wrong--that despite our efforts and our "sense of purpose," very little substantive work was accomplished on the negotiation of treaty articles. Trying hard is not good enough for the large investor. At the minimum he needs to see measurable results which suggest that success is in his grasp within a reasonable time period. While I believe we made important progress in the negotiations this summer, I am not comfortable defending that progress as the "measurable results" our industry and Congress seek.

As to the work of the U.N. General Assembly and a decision on the timing of a Law of the Sea Conference, we will have to wait to know the decision. Only then can we intelligently evaluate whether a Conference will take place in time for us. I hope it does.

Mankind needs a success in the law of the sea very badly. In my judgment this Conference will be an important signal as to whether the world is capable of dealing with its problems rationally. If ever an area was suited for international regulation, revenue sharing for community purposes, technical assistance and technology sharing, it is the deep seabed. It is possibly man's last significant opportunity to build viable international, multilateral institutions which deal not just with an area but an area rich with resources. If man can deal reasonably with resources of great value--can apportion and manage them cooperatively in an international framework--then I think we will have reason to look ahead with hope and some satisfaction that we have begun to conquer some of our more base instincts.

I do not detect, however, that this sentiment is widely shared in the U.N. Seabed Committee. If it were, I suspect we would now be moving at breakneck speed toward the conclusion of a treaty on seabed resources rather than flirting with the disaster which further delay will bring.

Seabed mining will occur soon. The choice is whether a few developed countries will reap its benefits or whether many countries rich and poor, big and small, landlocked and coastal will also benefit. If the former is the result of our labors rather than the latter, I do not believe it will be due to the fault or lack of concern for the common good of the United States. For we have been trying very hard.

The head of the U.S. delegation to the U.N. Seabeds Committee, State Department Legal Advisor, John R. Stevenson, has advised Congress that we will take a position on S 2801 in January after the U.N. General Assembly decision calling the Conference has been studied and evaluated. I am sure we will all look forward with considerable interest to that decision.

INTERNATIONAL LAW APPLICABLE TO DEEP SEA MINING

Myron H. Nordquist
Office of Legal Advisor
U.S. Department of State
Washington, D.C.

Mr. Chairman, fellow panelists and participants, geographical and cultural. I appreciate being invited to this Symposium/Workshop and I am delighted to be here in Hawaii--a land of fascinating contrasts and unique beauty. For those of us having an interest in the law of the sea, latent law-of-the-sea problems and potentials seem to loom everywhere. I was interested to learn, for example, that in the United States, only Alaska, Florida and, perhaps California have longer coastlines than Hawaii. Due to its location in the mid-Pacific and its standing as the cultural and commercial center for Polynesia, Hawaii is destined to be the focal point for some of the long overlooked issues in law-of-the-sea negotiations. Islanders do have an intimate relationship with the sea which surrounds them, and I think it is wise of you to be monitoring law-of-the-sea developments quite closely. The University of Hawaii has already established an outstanding reputation as one of the six Sea Grant institutions, and those of you responsible are to be sincerely congratulated on that achievement. With the inauguration of your new Law School and the on-going activities of the world-renouned East-West Center, one can certainly expect increasing emphasis in Hawaii on scholarly aspects of the oceans, on both the scientific and social levels.

My task this morning is to discuss some of the international law problems which arise in connection with the exploration and exploitation of manganese nodules in the deep seabed. Perhaps the most efficient way to highlight the main issues will be to discuss the existing rules of international law and then to venture a few remarks about prospective issues in a legal regime for the deep seabed.

EXISTING RULES OF INTERNATIONAL LAW

With regard to existing rules, the threshold question is, What area constitutes the "deep seabed?" Limits questions have been the most troublesome in past law-of-the-sea negotiations. Indeed, it may be said that the principal failures of the 1958 and 1960 Conferences on the Law of the Sea were that the limits for fisheries jurisdiction, the territorial sea and the Continental Shelf were not satisfactorily resolved. Limits problems still plague us, particularly where islands are used as basepoints. To avoid these difficulties, we shall assume for our discussion this morning that the seabed area under examination is beyond the limits of national jurisdiction.

In so doing we reject by implication one theory regarding the legal status of the deep seabed and its resources. Under the Continental Shelf Convention, coastal states have exclusive exploration and exploitation rights over the natural resources of <u>adjacent</u> submarine areas. These rights extend out to the 200-meter isobath or beyond that, to where the depth of the superjacent waters admit of exploitation. The relevant legal issue is: To what extent does the term "adjacency" limit the exploitability criterion? There are sophisticated arguments which can be made to support either a narrow or a wide interpretation of what is "adjacent." It is sufficient for us to note that by the inclusion of the words "adjacency" and "Continental Shelf" in the Continental Shelf Convention, national jurisdiction was not intended to extend indefinitely seaward. That is, existing law encompasses a deep-seabed area beyond coastal-state exclusive natural-resource jurisdiction.

What rules of international law apply to this area beyond national jurisdiction, which for brevity, we shall call the "deep seabed?" In the absence of seabed treaty law, such as the Continental Shelf Convention, customary rules apply. Evidence of international custom is found in general community practices accepted as law. Unfortunately, there are no direct precedents for clear guidance as to national practice, because manganese nodules have never been commercially mined. However, the deep seabed is subject to general high-seas principles. What does this mean in more concrete terms?

The Convention on the High Seas, which is generally declaratory of established principles of international law, confers rights and imposes duties on high-seas users. The foremost rule is that no nation may assume sovereignty over high-seas areas. Specific freedoms such as navigation, fishing, laying of submarine cables and pipelines and "....others which are recognized by the general principles of international law," are provided. The exercise of these freedoms, however, is subject to the condition that reasonable regard be given to the interests of other nations in their exercise of the freedom of the high seas.

What relevance is high-seas doctrine to manganese nodule miners? In brief, it means that until accepted rules emerge governing the miner's activities, he has an international obligation to pay "reasonable regard" to other high-seas users, including navigators and fishermen. For example, irresponsible degradation of the marine environment from his activities would be prohibited. The criterion of reasonableness must be measured against the facts of the particular case. Firmer guidelines would evolve with experience. This process of case-by-case legal development in international law is well known to the common law. For example, the abstract concepts of "due process" or "negligence" are given precise meaning as they are applied to specific cases.

Some nations have recently asserted that the deep-seabed <u>area</u> and its resources are the common property of all mankind. The United States has consistently rejected that contention. Would, for example, the common-property approach imply that the consent of <u>all</u> mankind would be required before exploration and exploitation of deep-seabed manganese nodules could be undertaken?

Under high-seas customary law, the deep-seabed <u>area</u> cannot be seized as national territory. But who has title to the manganese nodules resources themselves? The point is a controversial one among nations, and international law is not as clear as we would like. There is not time to develop the technical arguments on this subject. Those having the technological capability to exploit the resources might find it in their interest to maintain that the manganese nodules belong to the first possesser. Nations without deep-seabed mining capital and expertise might argue that the nodules are a non-renewable resource of the world community and should not be subject to appropriation in the absence of a general agreement.

The question of whether deep-seabed manganese nodules belong to no-one or to everyone is not satisfactorily resolved. A similar situation exists with regard to possible interference with mining activities by outsiders. All one can say is that existing high-seas doctrine would permit some protection of one's right to exercise high-seas freedoms. Again, reasonable criteria would have to be marked against specific facts. It is the future which holds more precise answers to these and interference questions--whether in the form of a widely ratified multilateral agreement or by the accepted practice of nations if a generally supported international agreement is not concluded.

For the short term, international law does not provide the miner or his banker with the type of security of tenure they are accustomed to having on land. Fishermen have been faced with somewhat similar problems for centuries. Often they have resolved the difficulties through the evolution of de facto practices. Of course, mining is not fishing; nevertheless it may be worthwhile to continue to investigate the possibility of similar pragmatic solutions, given the confines of existing international law and politics.

Time, of course, is of the essence and delays are not in the interest of any of the concerned parties. The technology is probably close at hand for developing a mining recovery and processing system which is commercially feasible. Eventually, experimental efforts will be proven to be economically sound--but when?

Uncertainty is probably the hallmark of the existing legal, technical, and economic circumstances regarding the mining of manganese nodules in the deep seabed. Indeed, this is the very reason why the United States has taken a lead in attempting to find multilateral solutions to the many unanswered questions, for a treaty can be concluded more quickly than generally accepted customary practices can emerge. Perhaps now we should briefly look at some aspects of a prospective seabed regime, based on the activities in the U.N. Deep Seabed Committee.

PROSPECTIVE ISSUES IN A LEGAL REGIME

Of course, a legal regime for the deep seabed is merely one of several major subjects which are currently being negotiated in the Law of the Sea preparatory meetings. The United States has many important interests to balance and accommodate and it is a demanding task to negotiate the optimum combination for all of them.

In 1970, the United States put forward the first detailed and comprehensive proposal for a regime which would apply to the mining of manganese nodules in the area beyond national jurisdiction. The United States' draft Convention on the International Seabed Area made a significant contribution towards moving the U.N. Seabed Committee from the stage of engaging in general debate to making specific proposals. In the U.S. draft, an "International Seabed Resource Authority" would have the power to license the mining of manganese nodules and would carry on certain supervisory activities in connection therewith. Essential to the U.S. proposal are the international standards to protect the ocean from pollution, to protect the integrity of investment, and to prevent unreasonable interference with other uses for the ocean. In addition, the United States strongly supports sharing revenues for international community purposes and compulsory settlement of disputes.

A number of developing nations have proposed an international agency having the exclusive right to exploit the resources of the deep seabed. In their view, the international agency itself could carry on exploration and exploitation activities. While sympathetic to developing countries' efforts to improve their relative economic positions, the United States and many other nations have rejected this monopolistic suggestion. The reasons for opposition are clear. Multinational political organs do not make efficient business enterprises, especially in cases where high risk, huge capital and extensive expertise are required. Such are the circumstances surrounding deep-seabed mining ventures. It is simply unrealistic to expect these resources to be available for the general benefit of mankind without full support and cooperation among those having a demonstrated commitment to development.

Several related important issues have emerged. One primary question is who would control an international authority? Obviously, the well-accepted principle of sovereign equality in U.N. affairs implies that each nation is entitled to be treated as a sovereign. This concept works well in most circumstances but not when carried to extremes. For deep-seabed mining some reasonable relationship should exist between control and responsibility. The United States has proposed a governing council composition and voting structure for its proposed International Seabed Resource Agency which would accommodate both the one-nation-one-vote principle and the legitimate concerns and expectations of those nations having the greatest responsibilities for mining manganese nodules. Other nations have put forth proposals, and more can be anticipated in the negotiations before this question is finally settled at the Law of the Sea Conference.

Another contentious issue concerns the economic implications surrounding mining manganese nodules. The U.N. Secretariat has made several studies of the potential effects of deep-seabed mining on the land-based producers of the metals which might have to compete with minerals from the deep seabed. A study of the potential effects of lower metal prices on the large number of consuming countries might also be useful. However, the entire subject of economic implications is a highly speculative one and too often facts have been confused with highly tenuous opinions. There are too many variables, such as the prospective world supply and demand for the extracted metals, the relative cost projections of mining and processing manganese nodule metals vis-a-vis land-based sources, and whether, in any event, controls on prices and production from the deep seabed would be effective without having similar controls on prices and production from national sources (including those which might be found in off-shore areas). It does seem clear that if there are to be benefits or revenues for the international community from exploitation of a common-heritage area, it is not in the international community's interest to curtail experimental activities. This seems particularly true when the expense of these activities is borne by entities from developed countries.

The most relevant document regarding prospective international law concerning deep-seabed manganese nodules is the Declaration of Principles adopted by the U.N. General Assembly in December, 1970. These Principles will provide the starting point for the multilateral treaty terms on the deep seabed to be negotiated at the upcoming Law of the Sea Conference. The Principles provide that the area beyond national jurisdiction shall not be subject to appropriation and that no state shall claim or exercise sovereignty or sovereign rights over any part of it. This is consistent with the United States' view that the deep-seabed area is subject to the regime of the high seas. The Principles go on to state that no claims or rights may be acquired with respect to the area (and these are the key words) or its resources, incompatible with the international regime to be established. In other words, on the question of title to the manganese nodules, the Declaration of Principles looks to the future international regime for clarification. Paragraph 14 of the Declaration of Principles imposes a similar obligation upon every nation regarding activities in the international seabed area, including those relating to resources. Such activities are to be carried out in conformity with the international regime to be established. Here again, the Declaration of Principles is fully consistent with President Nixon's May 23, 1970 oceans policy statement where he suggests that all permits for exploration and exploitation of the seabeds beyond the 200-meter isobath be issued subject to the international regime to be agreed upon.

What will be the nature and character of the international regime? Many concrete ideas have now been presented in the U.N. Seabed Committee but no one knows the outcome. That is what the laborious negotiations are all about. Four preparatory sessions have been held for the Conference. Detailed regimes for the deep seabed have been submitted, the international seabed regime has been receiving priority attention in the deliberations, and the general outlines of an agreement are emerging. Or, at the minimum, key areas of disagreement have been identified.

A timely, acceptable and equitable regime for the deep seabed is in everyone's interest. In the United States' view, the legitimate expectations of all the parties involved can be accommodated if nations will face the difficult political decisions which must now be made regarding the oceans and their use. It is only after those judgments have been made at the highest levels of government that the legal rules, which will provide order in the deep seabed, can be derived. This is what is so badly needed. In spite of the present frustrating uncertainty, I am confident that in the long run, we are headed in the right direction--for negotiation is superior to confrontation, and stability is better than chaos.

INTERNATIONAL LAW ASPECTS OF OCEAN MINING

By
Francis M. Auburn
Faculty of Law, University of Auckland
Auckland, New Zealand

In this paper I shall briefly examine some recent legal developments of relevance to manganese-nodule exploitation. In 1972, the focus of international law interest in ocean minerals shifted from the United Nations Seabed Committee to the practices of various nations.

General Assembly Resolution 2881/XXVI added little to the two resolutions on the seabed of 1970. The 1971 resolution noted "....with satisfaction the encouraging progress...." of the U.N. Seabed Committee. Such satisfaction was justified for the year 1971 on account of the large number of working papers representing marked progress. This was not the case, however, in 1972.

On March 30, 1972, the last day of the first session of the year, Kuwait presented draft resolution A/AC.138/L.II calling on all nations to desist from commercial activities on the seabed before the establishment of an international regime for the area. The draft was co-sponsored by Algeria, Iraq, Kenya, Libya, Mauritania, Pakistan and Yemen. A similar resolution was passed at the Third Session of the United Nations Conference on Trade and Development at Santiago, Chile, in May 1972. These two moratorium moves raise once again the problem of Resolution 2574 D/XXIV. The effect of the adoption of the Kuwait proposal by the General Assembly can be predicted. The State Department will hold that General Assembly resolutions are recommendatory, and not legally binding on the United States. The Department would therefore not discourage United States nationals from manganese-nodule exploration. So much is predictable from past statements. What is not clear is the State Department's views on the exploitation of manganese nodules. When this stage is reached the conflict between the various moratorium proposals and State Department policy will become clear.

The U.N. Seabed Committee also prepared a vast list of topics covering the whole range of the international law of the sea. It is difficult to categorize this list as other than a disaster. It would be quite impossible to reach agreement and to draft useful conventions on even a small number of these topics. Unless this list is drastically reduced the Law of the Sea Conference will be highly confused.

The date of the Law of the Sea Conference is an essential matter when considering the fast-approaching exploitation stage for manganese nodules. There are already suggestions in the U.N. Seabed Committee that the initial session of the Conference will take place in 1973, substantive work is expected to begin early in 1974 if possible and, if not, by 1975. This is only the Conference itself. The Seabed minerals provisions of a convention would then come into force, at the earliest, in 1980. Well before then, on the current views of active ocean miners, exploitation will be in full swing. With regard to manganese nodules time has almost run out for the U.N. Seabed Committee.

As stated earlier the focus of interest has shifted to national practices. This is exemplified by the American Mining Congress' Deep Seabed Hard Minerals Bill introduced by Senator Metcalf in November 1971. The Bill gains importance with the slowing up of the work of the U.N. Seabed Committee. The basic concept is that manganese nodules can be mined under the existing international law of the sea, with an interim regime which would develop customary international law. The Bill covers only the "deep seabed," seaward of the Continental Shelf, but does not define the deep-seabed/Continental Shelf boundary. Under the Bill U.S. nationals could only develop the seabed under license. A licensee would gain exclusive use of the mine site for a 15-year development period. Exploitation would be permitted so long as commercial recovery continued. An international registry would be created, but only as a clearinghouse. The minimum annual expenditures to prohibit speculation and claim freezing would be $1,350,000 over a 15-year period for each licensed block. An escrow fund, formed of a percentage of United States license fees, would be distributed to developing nations having similar legislation or practice, as Congress would direct. The United States government would reimburse for increased costs or lost assets over 40 years resulting from any future international regime.

A number of points may be raised in regard to the Bill. The lack of a definition of the deep-seabed/Continental-Shelf boundary raises the possibility of licensing the same area, such as the Kauai Channel manganese deposits of Hawaii, under this Bill and under the Outer Continental Shelf Lands Act. The boundary between the deep seabed and the overlying high seas is far from clear, leaving open the question whether superficial deposits do indeed come within the Bill. The legislation does not make provision for non-development uses, such as strategic reserves of nodules. To provide that "....any person subject to the jurisdiction of the United States may be enjoined from violating this act," is very wide in view of the generous scope given by the U.S. Supreme Court to extra-territorial anti-trust laws. The President is to designate "reciprocating states (nations)" having interim policies comparable to that of the United States. If Shakespeare could compare his love to a summer's day this leaves wide scope to the President of the United States. The elements of compatability must be stated. The problem is basic as there could be wide differences between national practices sanctioned under the Bill.

Licenses may be revoked for "wilful substantial failure to comply" with the Bill. There can be little doubt that a multi-million-dollar investment would require litigation of such revocation to the bitter end. This might take a decade and is not sufficient to provide the urgent action required for environmental protection. The United States government's insurance against interference causing loss to a licensee points out that it is difficult to conceive any realistic premium. This is not really insurance, but a shifting of the total risk to the United States government. The insurance provisions, taken with the indemnity against loss from a future international regime and the commercial recovery license in force until recovery ends, tend to make this regime permanent rather than interim. Finally, the lack of decision functions for the international clearinghouse and the permanence of tenure to be given are contrary to Resolution 2749/XXV prohibiting national appropriation of the seabed. In default of decisive action by the U.N. Seabed Committee, the Bill may quite closely approximate the final outcome.

Another aspect of international law relevant to ocean mining and Hawaii is that of offshore zones. In 1972, Iceland extended its fishery limits to 50 miles. In August 1972, the International Court of Justice, at the request of the United Kingdom and West Germany, laid down provisional measures by which Iceland was not to enforce its regulations, without prejudice to the final decision. The dissenting opinion of Judge Padilla Nervo is of special interest:

> "The progressive development of international law entails the recognition of the concept of the patrimonial sea which extends from the territorial waters to a distance fixed by the coastal State (nation) concerned, in exercise of its sovereign rights, for the purpose of protecting the resources on which its economic development and the livelihood of its people depends."

It is clear from Mexican government statements that the patrimonial-sea concept covers manganese nodules. Iceland's position was strengthened by an agreement with Belgium, in September 1972, permitting named ships to take a defined tonnage in six restricted areas within the 40-mile limit. This agreement contains a disclaimer analogous to that in the shrimp agreement between Brazil and the United States. But, despite the statement that the legal position of both parties is not affected in each case, it is hard to resist the pragmatist's view that the legal position is, in fact, changed. Mexico, champion of the patrimonial sea, gained a considerable degree of support from the Declaration of Santo Domingo of June 1972. That country has, through the patrimonial sea, a possible interest in manganese-nodule mine sites.

In conclusion, it may be apposite to venture some suggestions as to the interests of Hawaii in the international law of the sea. The unique geographical configuration of the Hawaiian Archipelago would seem, from a logical point of view, to require a much more generous treatment than the 3-mile territorial sea for each island prescribed by the Ninth Circuit Court of the United States Court of Appeals in Island Airlines Inc. v. C.A.B. That decision is of course open to challenge before the U.S. Supreme Court, but such litigation would not be feasible until the decision in U.S. v. Maine has been handed down. To the outsider, the case for Hawaii would appear to be at least as strong as that of some of the litigants in U.S. v. Maine, such as Virginia. The Second Act of King Kamehameha III prescribing that "....the marine jurisdiction of the Hawaiian Islands shall also be exclusive in all of the channels passing between the respective islands,and dividing them, which jurisdiction shall extend from island to island," may well be compared with similar legislation of this period. One relevant example is the Proclamation of King George Tubou of Tonga in 1887:

> "We do hereby erect as Our Kingdom of Tonga all islands, rocks, reefs, foreshores and waters lying between the fifteenth and twenty-third and a half degrees of south latitude and between the one hundred and seventy-third and the one hundred and seventy-seventh degrees of west longitude from the Meridian of Greenwich."

In a letter dated June 21, 1971, the Prime Minister of Tonga drew the attention of the Secretary-General of the United Nations to this Proclamation which, the Prime Minister stated "has been acquiesced in by all countries." This Proclamation may well prove to be the crowning glory of the diplomacy of Shirley Baker.

Additional material of assistance to Hawaii's case may well be found in what may be, for want of a better term, described as Polynesian common law. Maori law contains a vast store of learning on jurisdiction over water and offshore areas, much of it unreported. One example is the decision of the Native Appellate Court of September 20, 1944, on Lake Waikaremoana, together with the associated and extremely complex previous litigation.

Another Pacific development of considerable concern to Hawaii is the continuing dispute over the Minerva Reefs. On January 19, 1972 the Ocean Life Research Foundation proclaimed the new Republic of Minerva whose territory consisted of two reefs south of Tonga. The Republic's plans include a 2,500-acre Sea City designed by the Glass Age Development Committee of Pilkington Bros., with a population of 30,000. In June 1972, Tonga, with the use of about a hundred convicts, built artificial islands on the Reefs and annexed them under the name of Teleki Tonga and Teleki Tokelau, with a 12-mile territorial sea. Neither the Republic of Minerva nor the Kingdom of Tonga mentioned the Continental Shelf of the reefs. The implications of this dispute for Hawaii and manganese nodules are complex and far-reaching. Hawaii, which is planning a Sea City, is most concerned with manganese nodules, and has possible offshore jurisdictional claims. There can be no doubt that the Hawaii State government will follow with considerable interest the present developments in the international law of the sea and will take heed of the prescience of King George Tubou of Tonga.

SESSION III

Technology

Chairman: **Keith E. Chave**

Speakers: **David R. Horn**
James E. Andrews
George Andermann
Geoffrey P. Glasby
James Greenslate

WORLDWIDE DISTRIBUTION AND METAL CONTENT OF DEEP-SEA MANGANESE DEPOSITS

By

David R. Horn, Barbara Horn, and M. N. Delach
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York

ABSTRACT

The geographic location of the State of Hawaii is most favorable in regard to future mining of ferromanganese deposits at abyssal depths. Based on oceanographic data in hand, a broad band of nodular ferromanganese, rich in copper and nickel, lies 500 miles south of the Hawaiian Islands. A compilation of chemical analyses reveals the nodules have higher nickel and copper values over greater areas than in other regions of the oceans. As a consequence they are receiving serious study by ocean miners.

Hawaii is the closest land to many of the deposits and is located mid-way between major markets in Japan and the United States. Therefore, it would seem that Hawaii will play a role in mining this valuable ocean resource.

WORLDWIDE DISTRIBUTION AND METAL CONTENT OF FERROMANGANESE DEPOSITS ON THE OCEAN FLOOR

The widespread occurrence of ferromanganese nodules and crusts has been known for a century and our understanding of their distribution (Figure 1) can be credited to the efforts of the men who participated in many early oceanographic voyages. Included are the expeditions of *Challenger*, *Albatross*, *Vityaz*, *Eltanin*, *Vema*, *Robert D. Conrad*, *Spencer F. Baird*, *Horizon*, *Gosnold*, *Atlantis* and others. It is apparent from their reports that the major concentrations of ferromanganese deposits of the World Ocean occur in the North Pacific (Figure 1). In the Atlantic and Indian Oceans they are patchily distributed and less extensive because conditions are less favorable for nodule development.

The first conclusion is that widespread ferromanganese deposits occur in the North Pacific south of the Hawaiian Islands. They are as extensive and concentrated as any known in the World Ocean. This places Hawaii in a most fortunate geographic position in that it lies close to the primary fields of nodules on the ocean floor.

However, location is not the only factor which has to be taken into account. The vast majority of nodules contain insignificant amounts of copper and nickel and have metal values well below those which permit commercial exploitation. "Good" nodules are a far rarer commodity. They must include at least 1 percent copper and 1 percent nickel. Are the nodules in the Hawaii area rich enough in copper and nickel to represent a potential resource? In Figures 2-9 are plotted the results of 640 chemical analyses for copper, nickel, manganese and cobalt.

If we accept the minimum base-line of 1 percent for both copper and nickel, the question is--Where are nodules which have values above the base-line? The maps showing the metal content of the nodules indicate that there is only one region in the World Ocean which consistently meets the basic requirement. It is in the North Pacific and lies south of Hawaii (e.g., Figures 2 and 4).

Again Hawaii is in a favorable location. Not only is it situated close to major ferromanganese fields, but the deposits are relatively rich in metals of immediate interest to the ocean mining community. The nodular materials lie approximately 500 miles south of Hawaii and form a broad, east-west band across the Pacific (Figure 10). Nodules rich in nickel and copper are characteristic of the region.

NORTH PACIFIC FERROMANGANESE PROVINCE

Closer inspection of this province of Cu-Ni rich nodules indicates that it extends from approximately 110°W to 180°W and from 6½°N to 17°N. This is a very large area of the North Pacific and mining companies will endeavor to delineate smaller sites of high-grade nodules within the province.

The substrate is siliceous sediment dominated by radiolarian ooze and clay. Topography is gently rolling (Figure 11). Water depths are of the order of three miles. There appears to be a strong correlation between nodules rich in Cu-Ni and the distribution of siliceous sediment. However, the siliceous deposits coincide with sites of little or no sedimentation and exposures of Tertiary sediment are frequently encountered at, or close to, the surface. It is not known whether the nodules are rich in copper and nickel because they are associated with highly porous siliceous sediment, or because very low rates of sedimentation enhance enrichment of the nodules in these metals.

The vast majority of nodules in the North Pacific lie on the surface (Figure 12). Presumably mining will consist of dredging or raking of the surface to recover the deposits.

CONCLUSIONS

Hawaii is closer than any other land area to the most widespread and potentially richest deposits of commercial ferromanganese on the floor of the World Ocean. It also lies mid-way between major markets in Japan and the United States. For these reasons it would seem wise for the State of Hawaii to carefully follow developments in the ocean mining industry and to investigate further its role in what may well grow into substantial mining operations relatively close to its shores.

Acknowledgment: Compilation of data on the distribution and metal content of ferromanganese deposits was sponsored by the International Decade of Ocean Exploration, National Science Foundation Grant GX 33616.

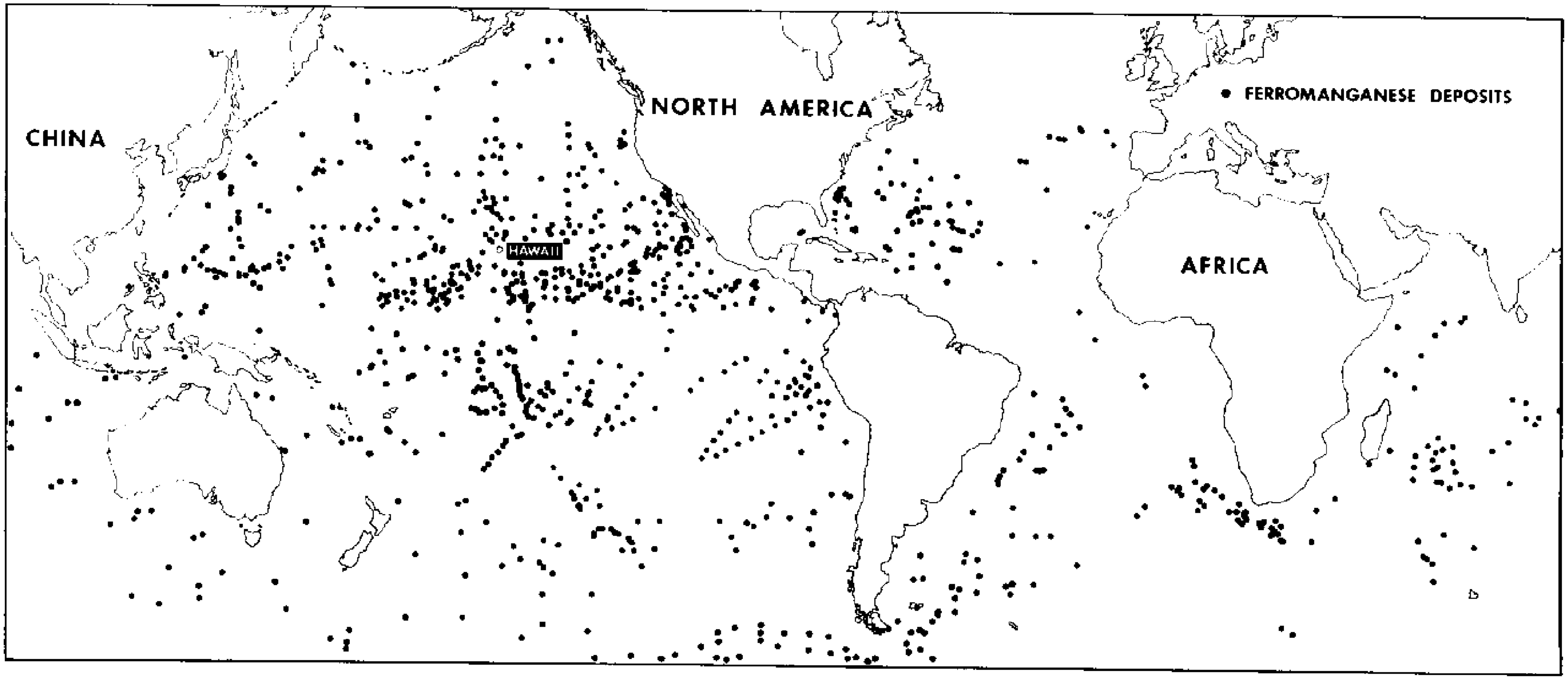


Figure 1. Worldwide distribution of surficial ferromanganese deposits on the ocean floor based on core and dredge data. The great majority of occurrences are in the North Pacific south of Hawaii.

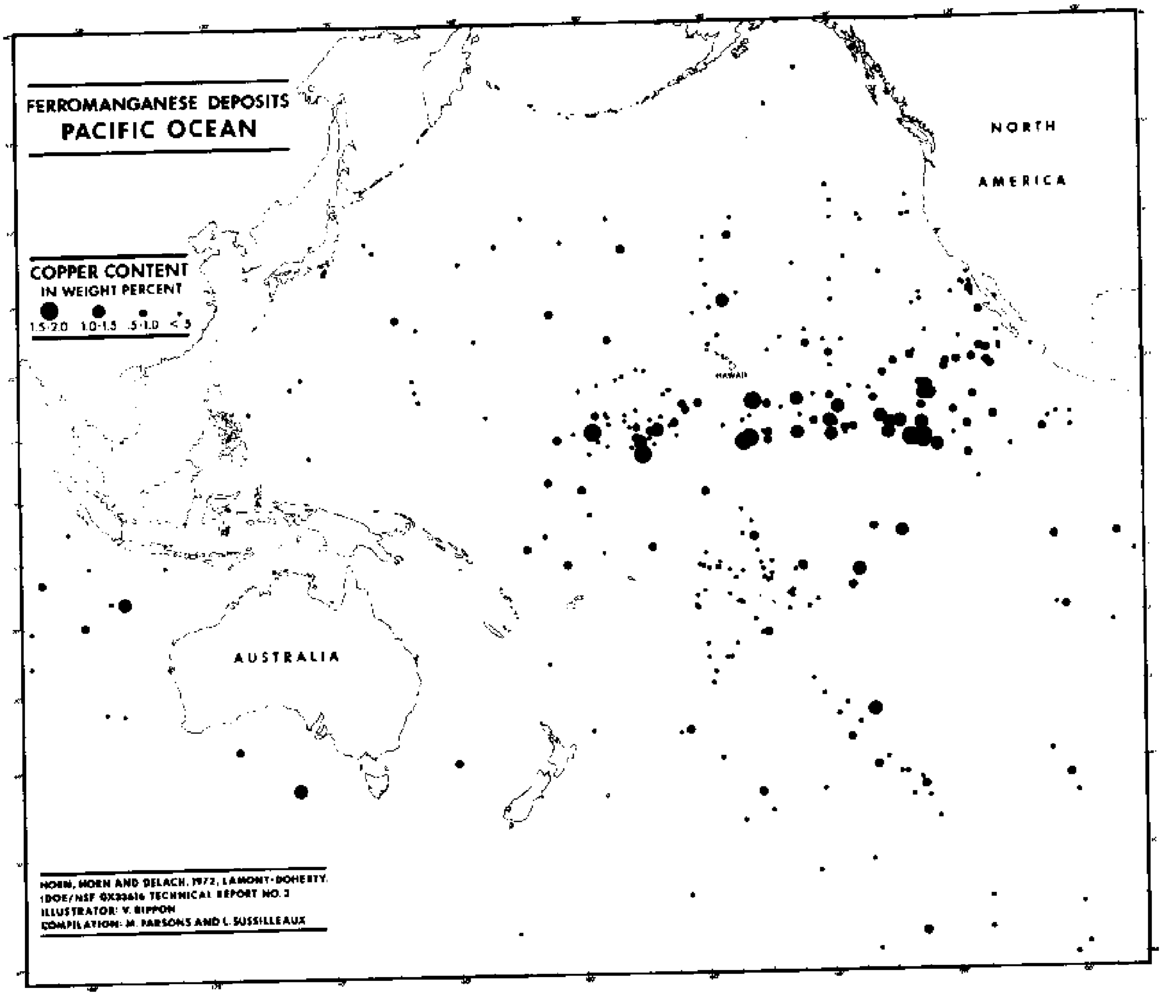


Figure 2. Copper content of ferromanganese deposits of the Pacific Ocean. Chemical analyses reveal a broad band of nodules rich in copper south of the Hawaiian Islands.

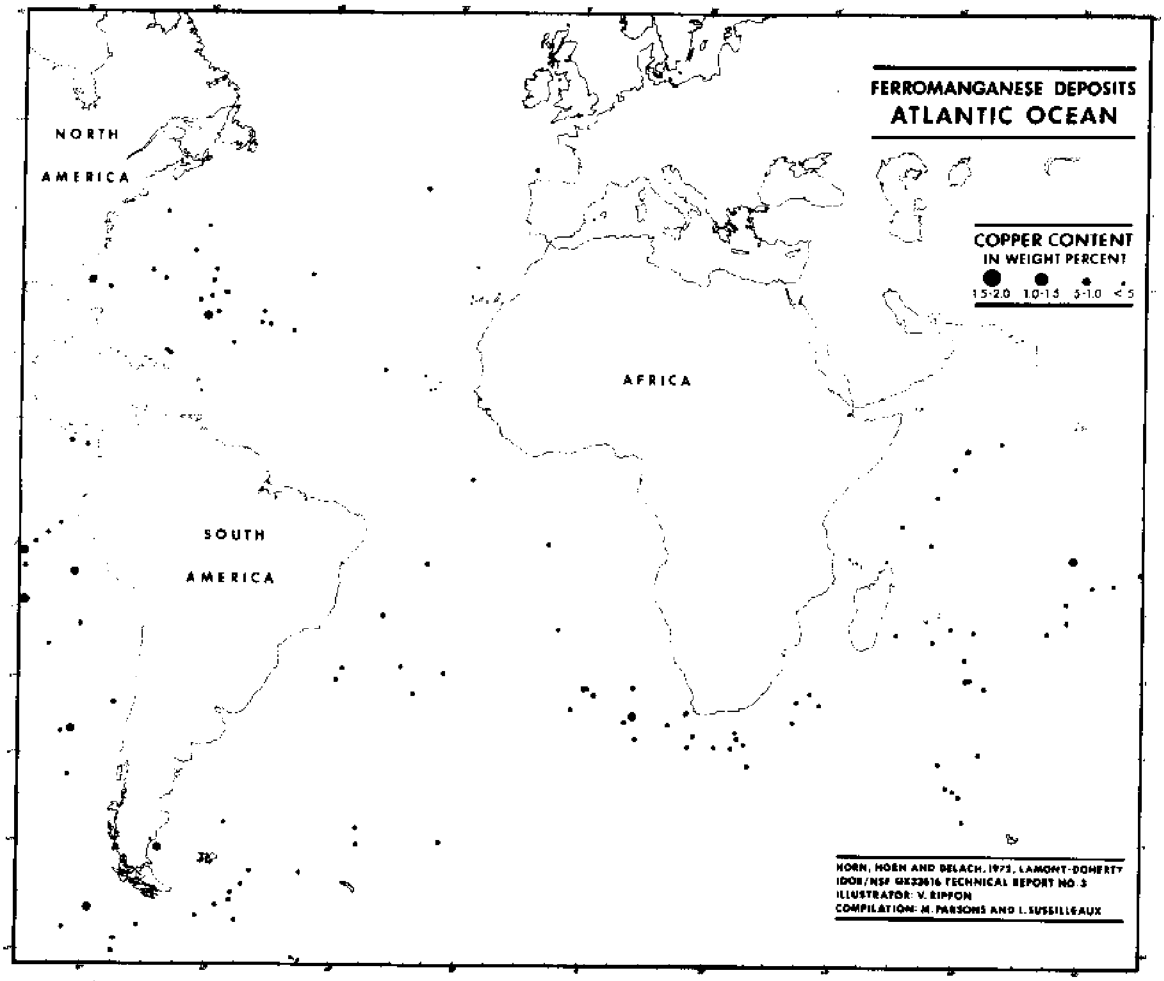


Figure 3. Copper content of ferromanganese deposits of the Atlantic Ocean. Analytical results reveal the deposits to be low in copper (generally less than 0.25%).

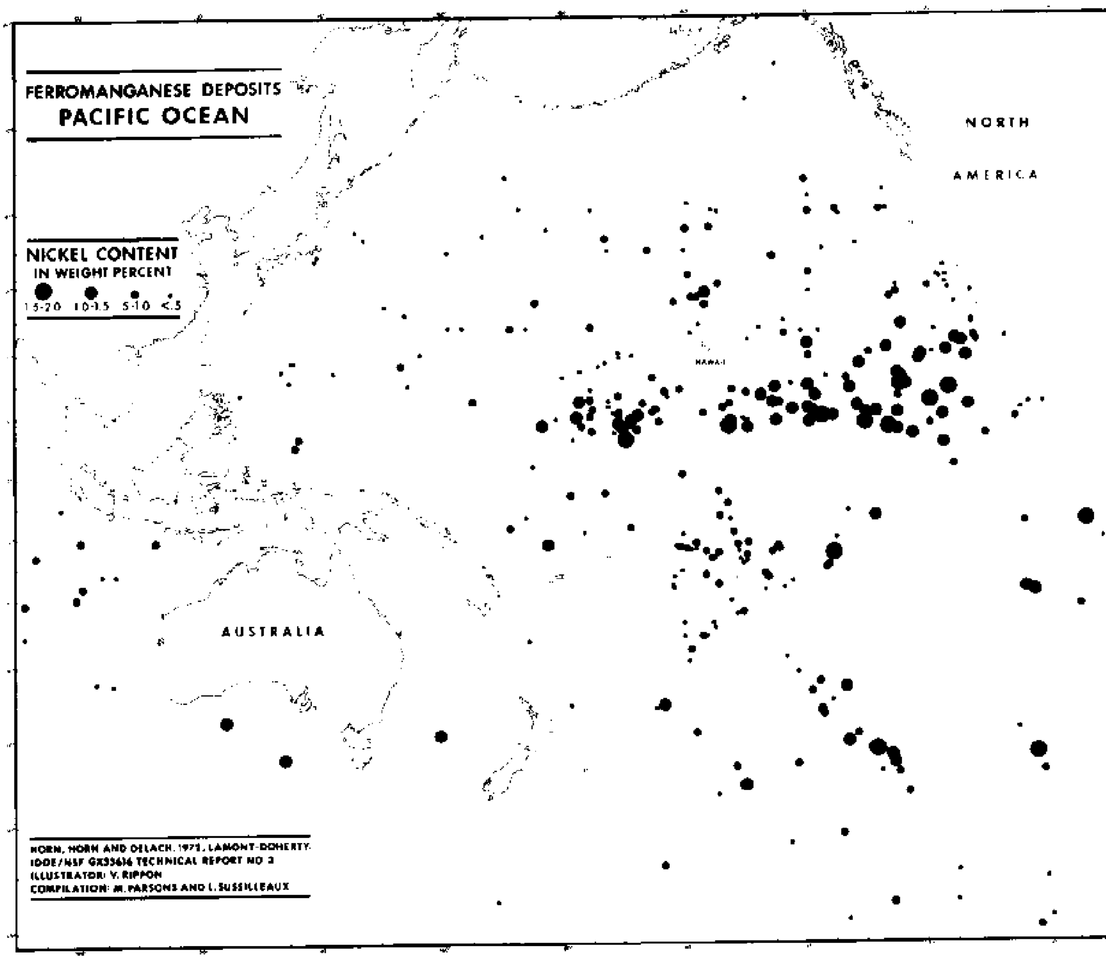


Figure 4. Nickel content of ferromanganese deposits of the Pacific Ocean. Nodules rich in nickel are widespread southeast and southwest of Hawaii.

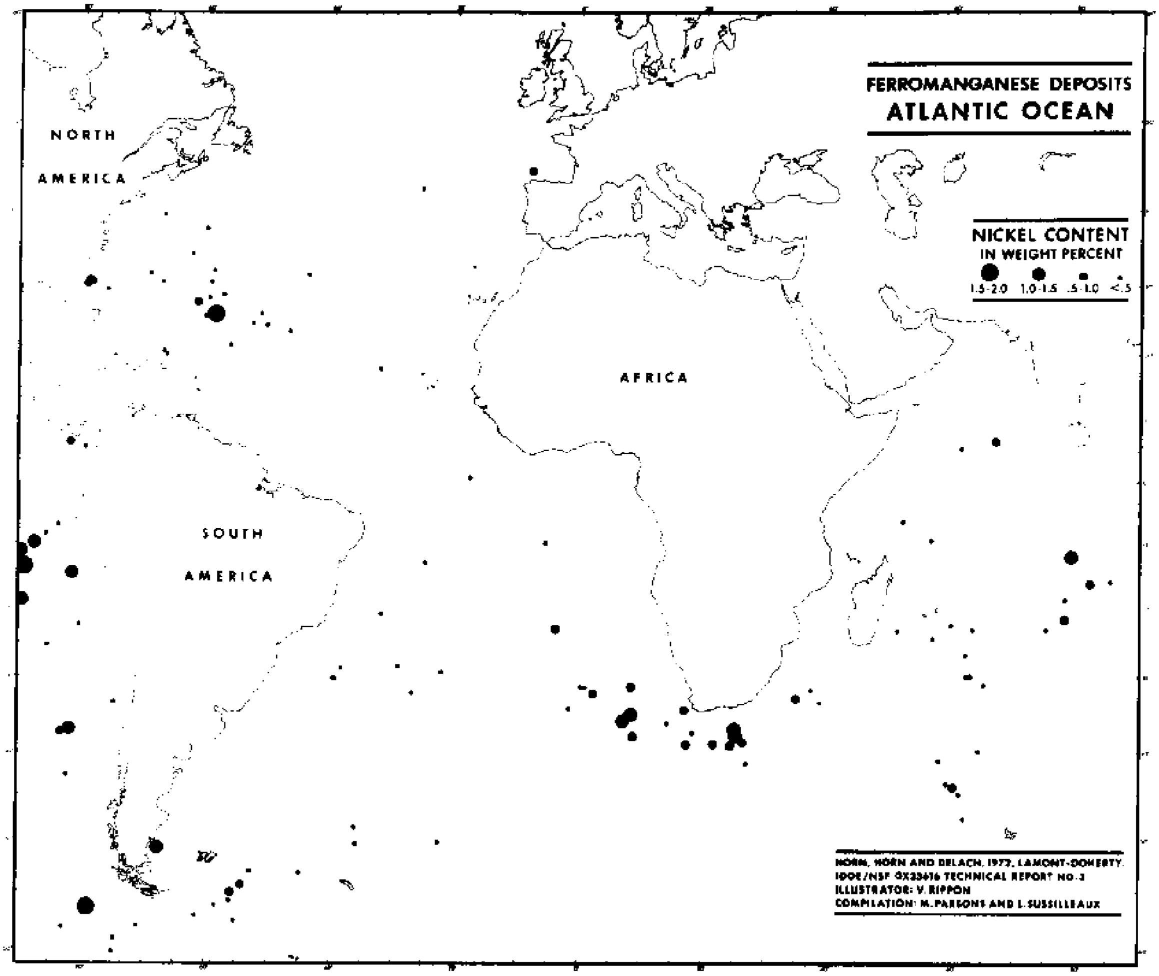


Figure 5. Nickel content of ferromanganese deposits of the Atlantic Ocean. Results of chemical analyses indicate the nickel content of Atlantic deposits to be considerably lower than their counterparts in the North Pacific. There are nodules southwest of the southern tip of Africa which contain slightly more than 1% nickel.

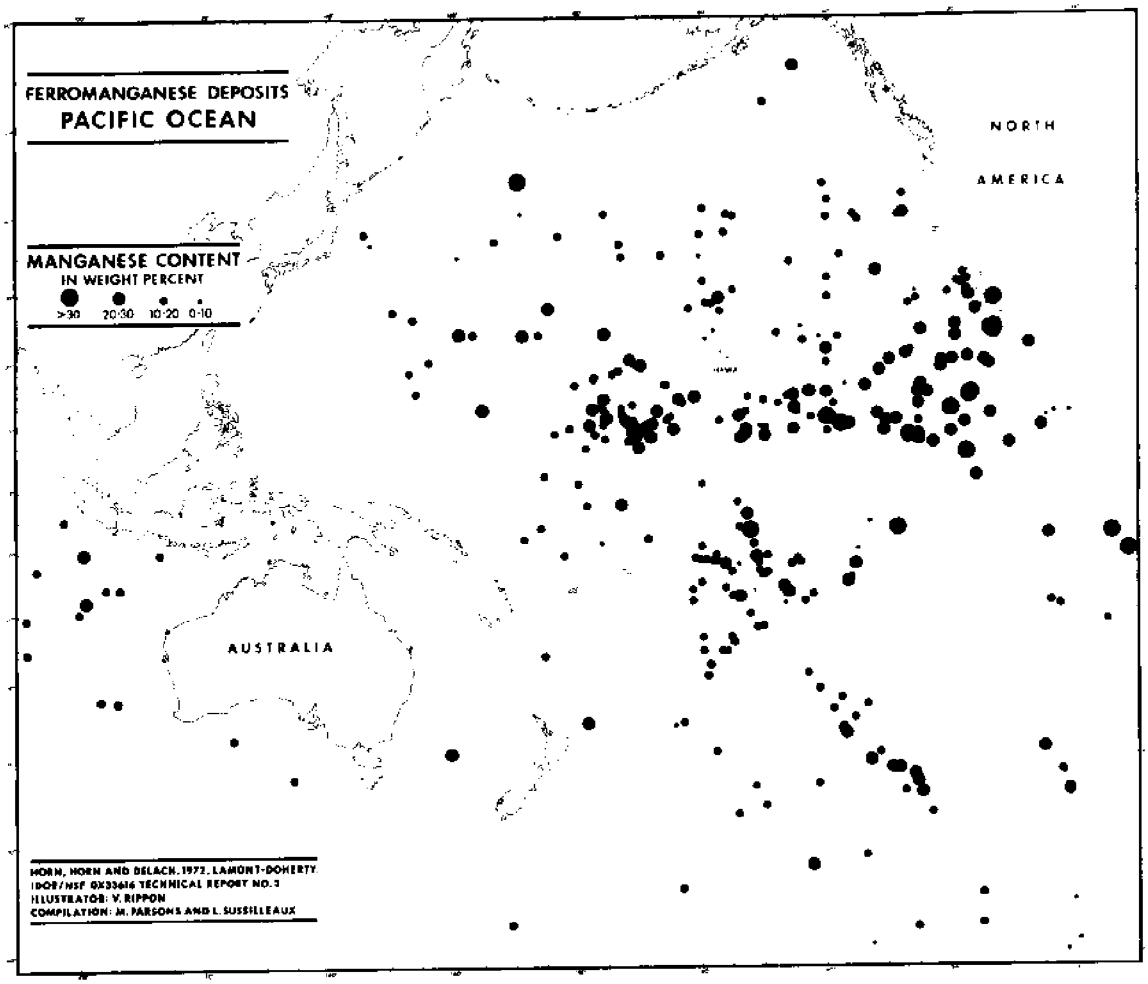


Figure 6. Manganese content of ferromanganese deposits of the Pacific Ocean.

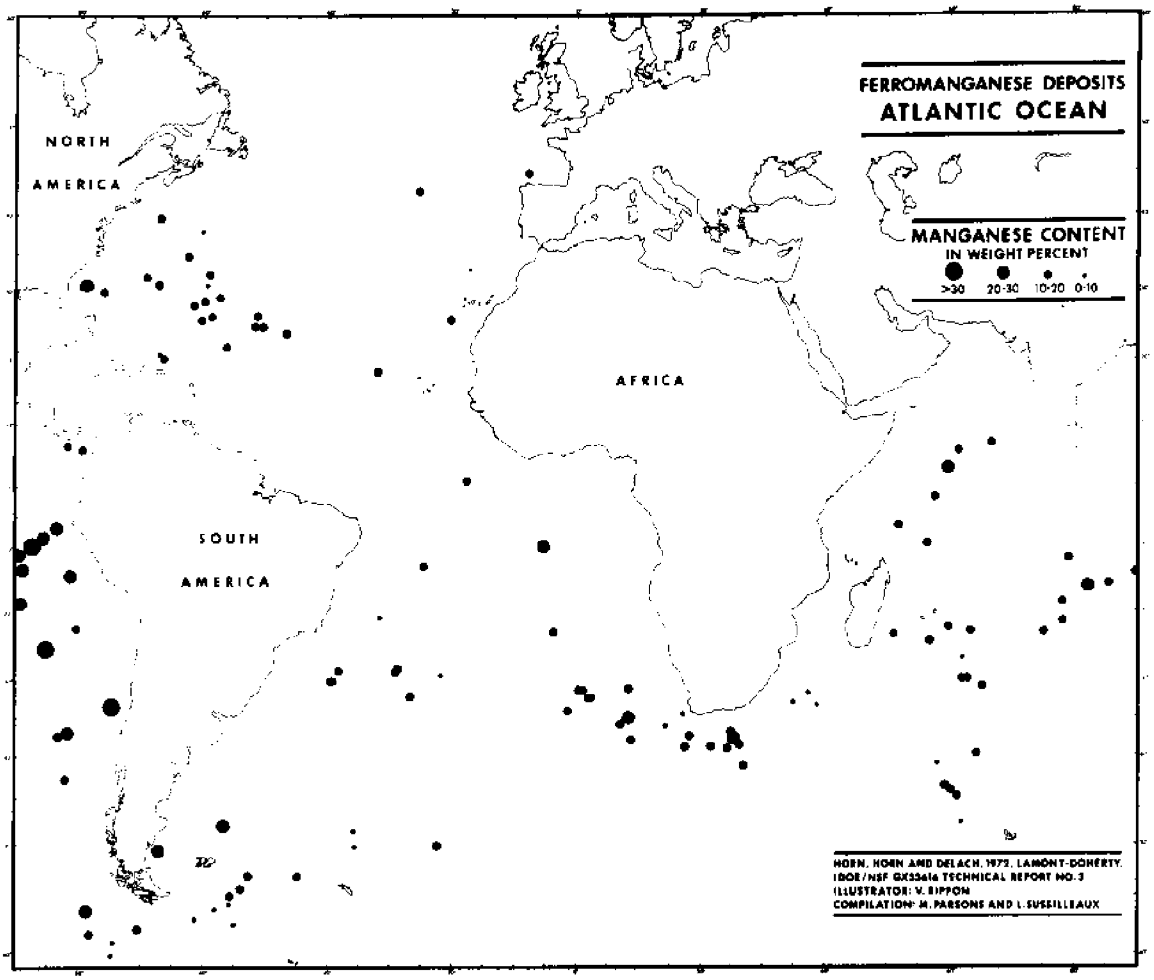


Figure 7. Manganese content of ferromanganese deposits of the Atlantic Ocean. When this map is compared with Figure 6 it is readily apparent that nodules rich in manganese are restricted to the Pacific Ocean.

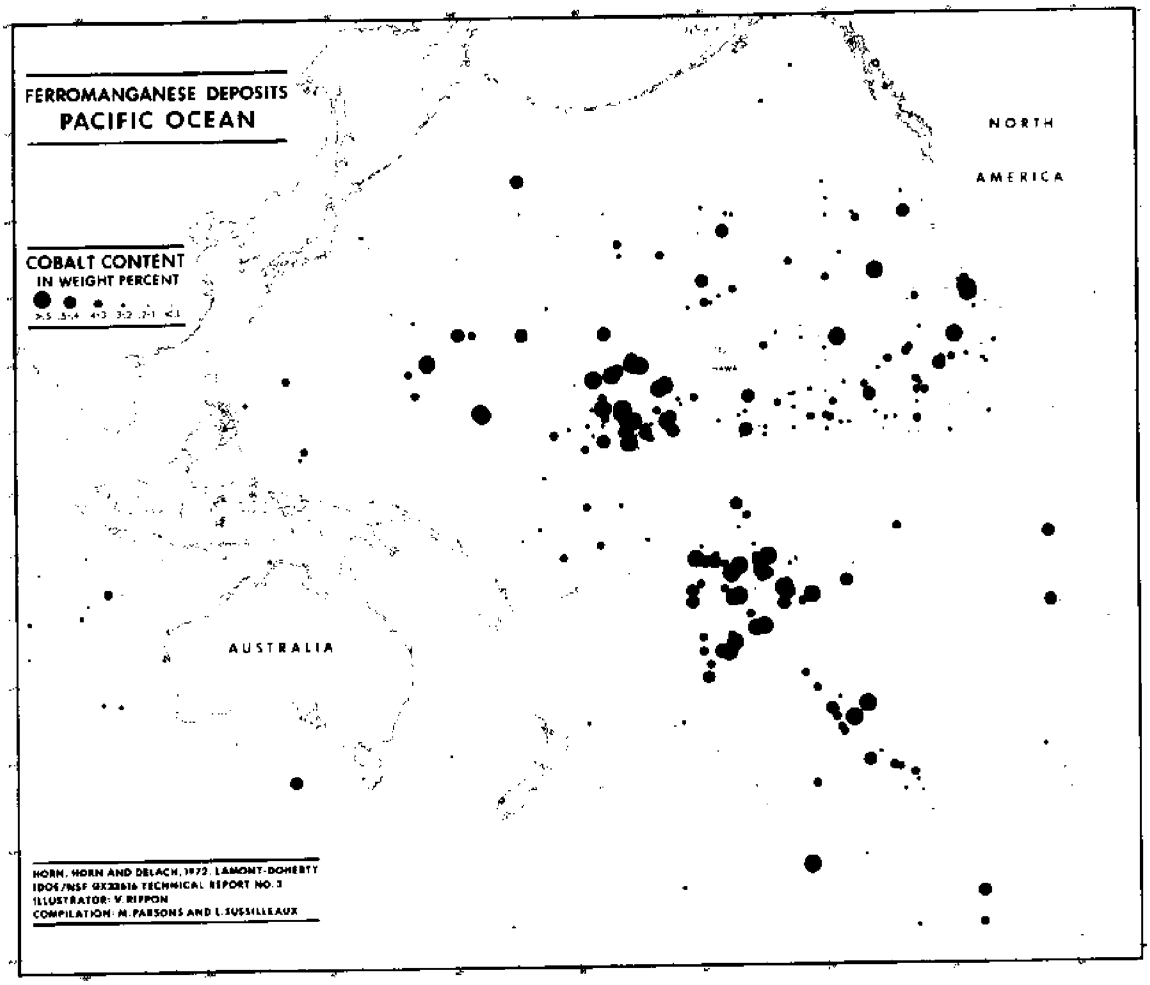


Figure 8. Cobalt content of ferromanganese deposits of the Pacific Ocean. High values of cobalt are obtained from samples of deposits which occur on crests and flanks of submarine topographic highs. The circular grouping of high cobalt values southwest of Hawaii reflects the summits of a ring of submarine mountains encrusted with ferromanganese. High cobalt values in the South Pacific are also characteristic of relatively shallow water regions of the Manihiki Plateau and Tuamoto Archipelago.

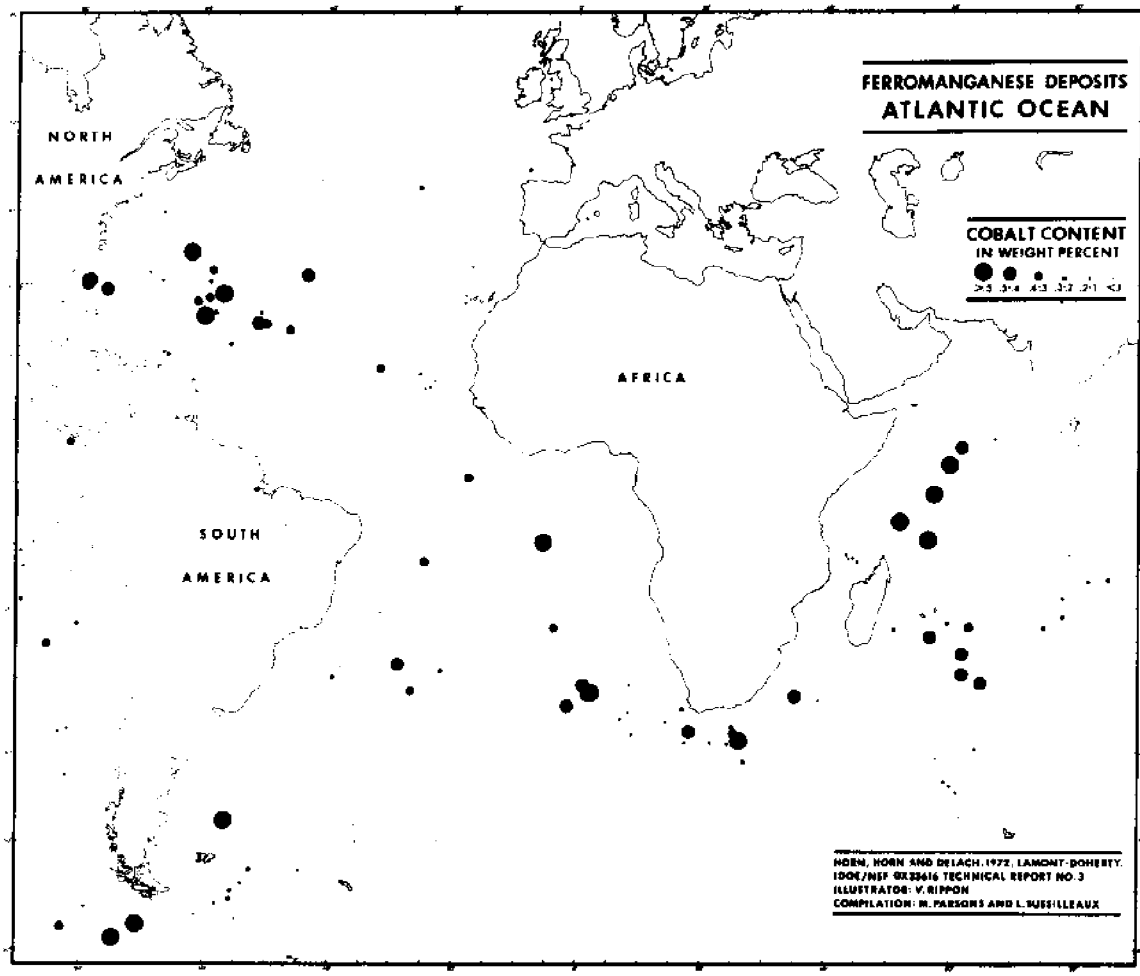


Figure 9. Cobalt content of ferromanganese deposits of the Atlantic Ocean. Cobalt values greater than 0.5% are restricted to submarine peaks and ridges.

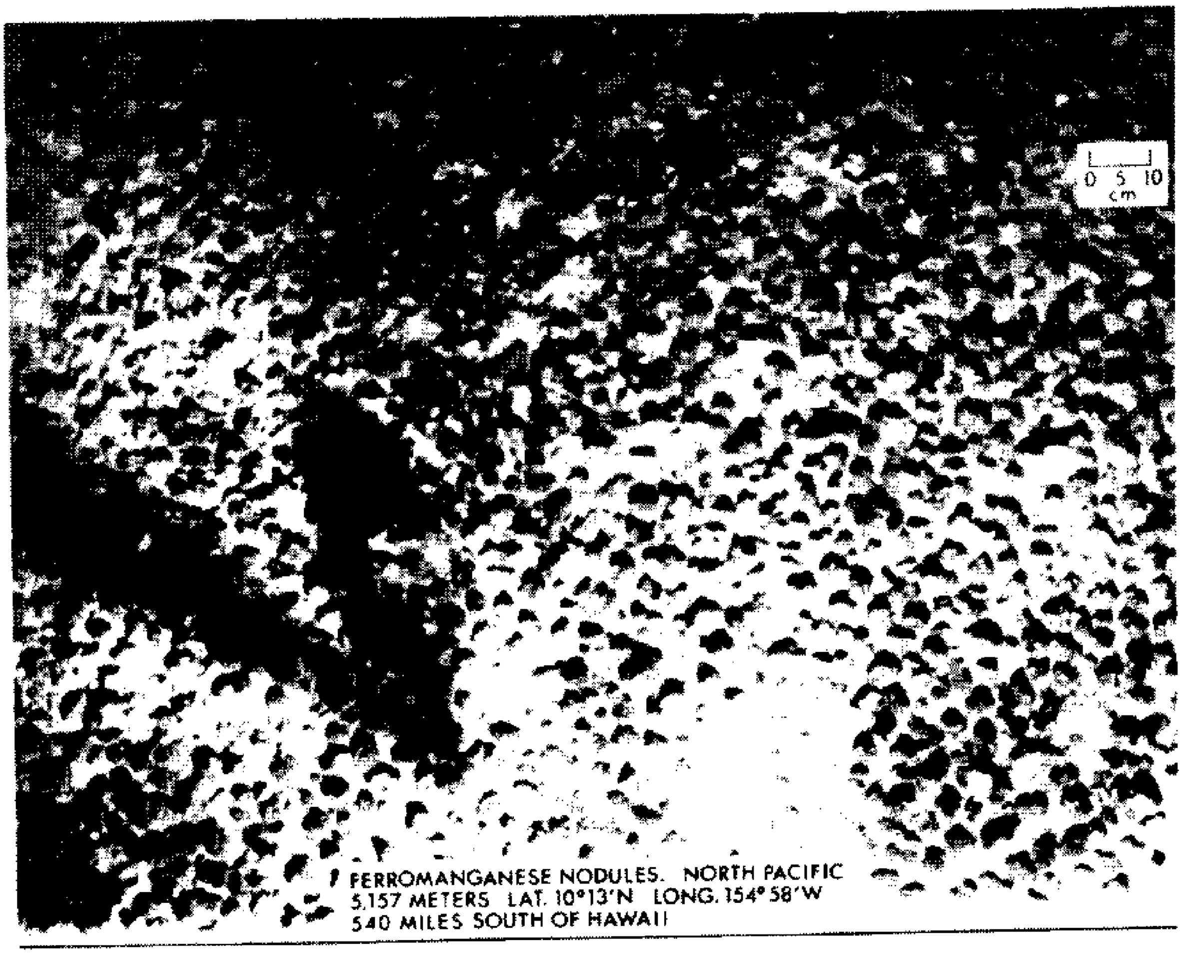


Figure 10. Photographs of the seabed taken within the band of nodular deposits south of Hawaii show fields of nodules crowded against one another.

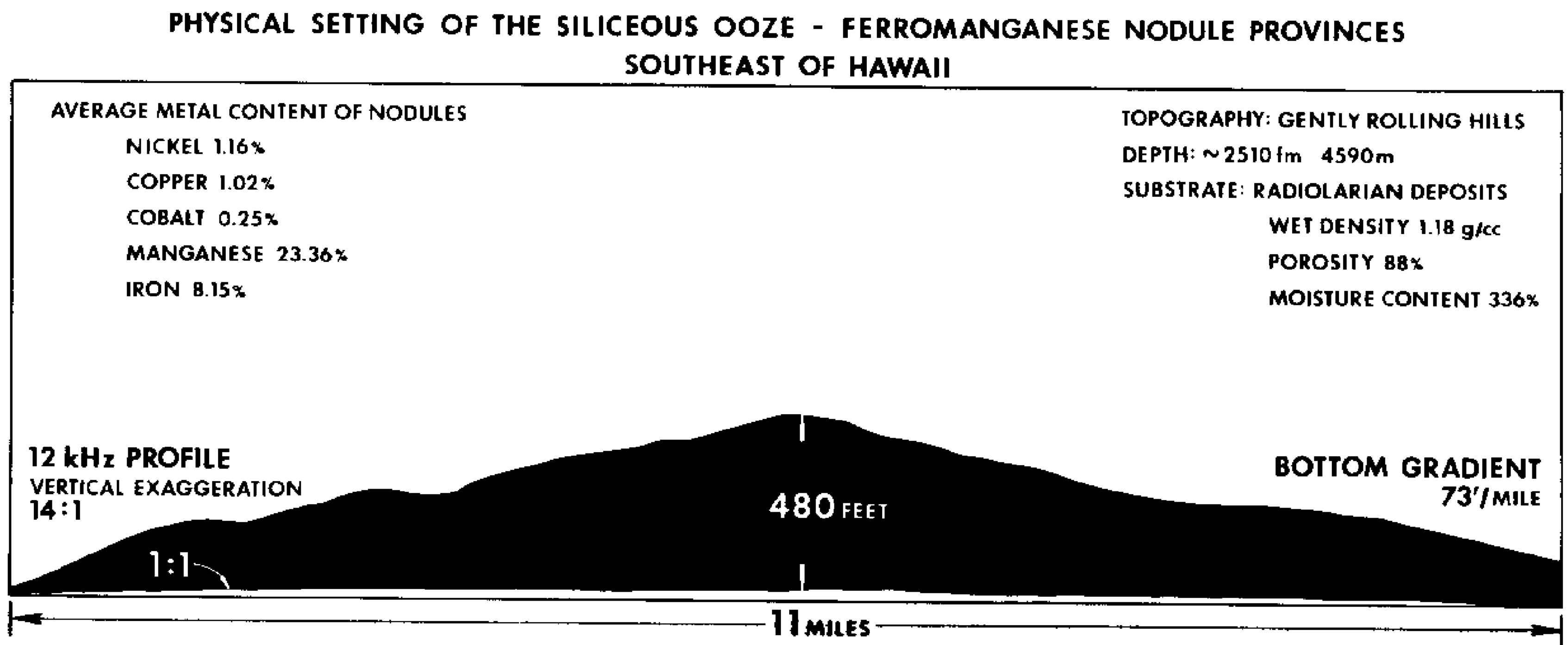
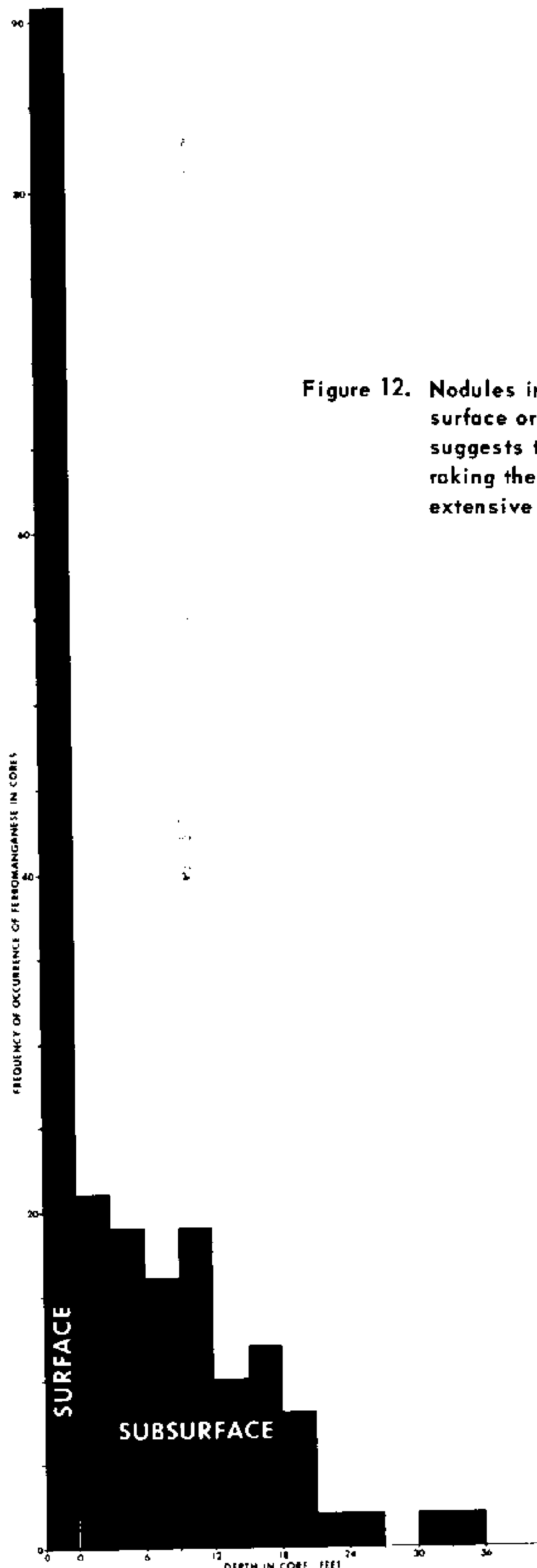


Figure 11. The seafloor within the region of nodules rich in copper and nickel is characterized by gently rolling hills blanketed with radiolarian ooze and clay. The subdued relief lends itself to successful dredging of the nodules.



SURFACE AND SUBSURFACE DISTRIBUTION OF FERROMANGANESE DEPOSITS IN CORES FROM THE NORTH PACIFIC

Figure 12. Nodules in the North Pacific occur on the surface or sediment/water interface. This suggests that mining will be confined to raking the seabed and will not include extensive dredging of the substrate.

DISTRIBUTION OF MANGANESE NODULES IN THE HAWAIIAN ARCHIPELAGO

By

James E. Andrews
Department of Oceanography
University of Hawaii
Honolulu, Hawaii

During 1970, the Manganese Research Group at the University of Hawaii, and Maury Morgenstein in particular, first recognized some of the interesting occurrences and associations of ferro-manganese deposits at relatively shallow depths in the Hawaiian Archipelago. A series of cruises was initiated on the R/V Teritu to study the nature of these accumulations, their distribution, and mode of origin.

The deposits are accreting principally on the three prominent terrace levels around all of the Islands--at 400 to 800 meters, 1200 to 1600 meters, and 2400 meters as crusts and pavements. The sediments on which they are forming are volcanogenic sands derived from Island weathering, and transported to the terraces via turbidity currents. There appears to be a distinct association between the ferromanganese crusts, their chemistry and mineralogy, and the sediments of the substrate. Ongoing work on these relationships will be presented as a doctoral dissertation by Mr. Morgenstein.

Figure 1 is a cartoon which depicts our present thoughts on the gross morphology of the deposits and the origin of the materials involved. The thickest and richest material appears to be accreting where the following environmental criteria are met: good supplies of iron-rich volcanogenic sediments (sands and silts) from the Islands; terraces to help trap and hold these sediments; and exposure to the flow of currents around the Islands--particularly where they are accelerated through channels between the Islands, or over shallow peaks. Our sampling has been concentrated between Oahu and Kauai and around Kauai and Niihau. Recently, however, the R/V Kana Keoki completed a dredging cruise up the leeward chain to Midway under the direction of Dr. Ralph Moberly of the University's Hawaii Institute of Geophysics, and demonstrated the presence of ferromanganese deposits throughout the region as had been anticipated on the basis of the model.

The importance of the current patterns should perhaps be emphasized. Any topographic feature which obstructs a current flow will increase the current velocity in its vicinity by virtue of the diversion. This in turn exposes the substrate to a great volume of water per unit of time, and at the same time maintains the exposure of growing oxide crusts by inhibiting sediment deposition. Only the rapid large-scale deposition of turbidites would interrupt this pattern, but this would in turn provide fresh iron-rich seed material to continue the growth processes with a new pavement. The effects of more rapid surface currents and the rich seed supply from the Islands are in marked contrast to the deep-sea environment where bottom currents move more slowly, and pelagic sediments routinely accumulate to help bury developing deposits. Only small areas of structural influence such as fracture zones promote acceleration of the currents, and other processes must act to keep the manganese nodules of the deep-sea floor exposed to sea water. Growth rates of deep-sea nodules are generally close to 1 mm/10^6 years (range of 1-10 mm/10^6 years). On the Waho Terrace--a 1900 Km^2 terrace at 1600-meter depth which extends northwest from Kaena Point, Oahu into the Kauai channel--sediments dated by hydration-rind techniques average 750,000 years old. These sediments normally have one or more crusts of 1 to 2 centimeters, or more, in thickness. This suggests rapid accretion rates of several centimeters, per million years--another facet of the shallow-depth formation of ferromanganese oxides. The variety of environmental interactions in the growth of the pavements, and the relatively well-defined and semi-closed system are unique phenomena which can be studied in the Hawaiian Islands.

Other examples of the rapid growth of ferromanganese oxides and the importance of seed material come from nodules growing on artificial seeds.

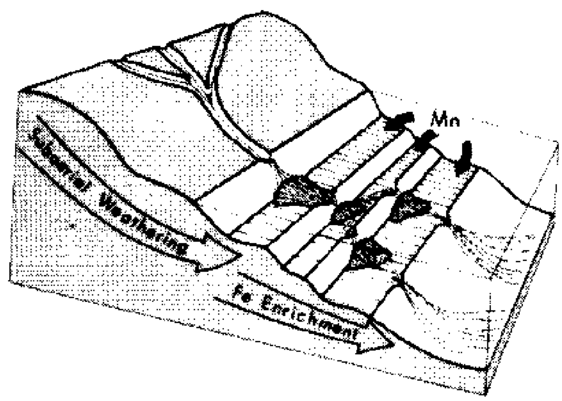


Figure 1. Schematic of Manganese Sediment Associations

A large number of iron and steel samples encrusted with ferromanganese deposits have been collected by divers during the past year off Oahu beaches. A variety of knife blades, old nails, and bottle caps with deposits may be rather old. However, ceramic-jacketed spark plugs are more recent and several of these serving as seeds for nodules have been found. The one shown in Figure 2 has a minimum of included carbonate sediment from the reef. It had obviously been used as a fishing weight, and the youth of the nodule is also attested to by the monofilament line which is still attached to the plug and included in the nodules. This nodule is about 5 centimeters in diameter, with over ½-centimeter of ferromanganese oxide--a growth rate several orders of magnitude above deep-sea rates, and a subject for continued research. In these "artificial" nodules it is interesting to note the cementing action of iron oxides migrating away from the seed--securing trapped sediment and extending the seed for manganese growth.

The German research vessel R/V Valdivia has kindly provided us with some high-resolution echo sounding records which point up some of the structures

Figure 2. Queens Beach Sparkplug Nodule. Champion J12Y with Attached Fishing Line

of the terraces we are examining, as well as showing the importance of narrow-beam sonar systems for detailed mapping of any future ocean mine sites. The Valdivia records shown in Figure 3 were obtained with two systems--one operating at 12-kHz with a 7-degree beam width, and the other operating at 30 kHz with a 1.4-degree beam width. The resolution with the narrow beam is strikingly clear, and details show considerably steeper slopes for channel walls on the terraces. The hilly channeled topography of the terraces is typical for deposits generated by turbidity currents in the nearshore. Slopes here on channel walls where cutting is taking place may be 30 degrees or greater. Resolution of the larger structural relationships is a problem that presently awaits the replacement of the R/V Teritu next year by a more fully equipped R/V Agor.

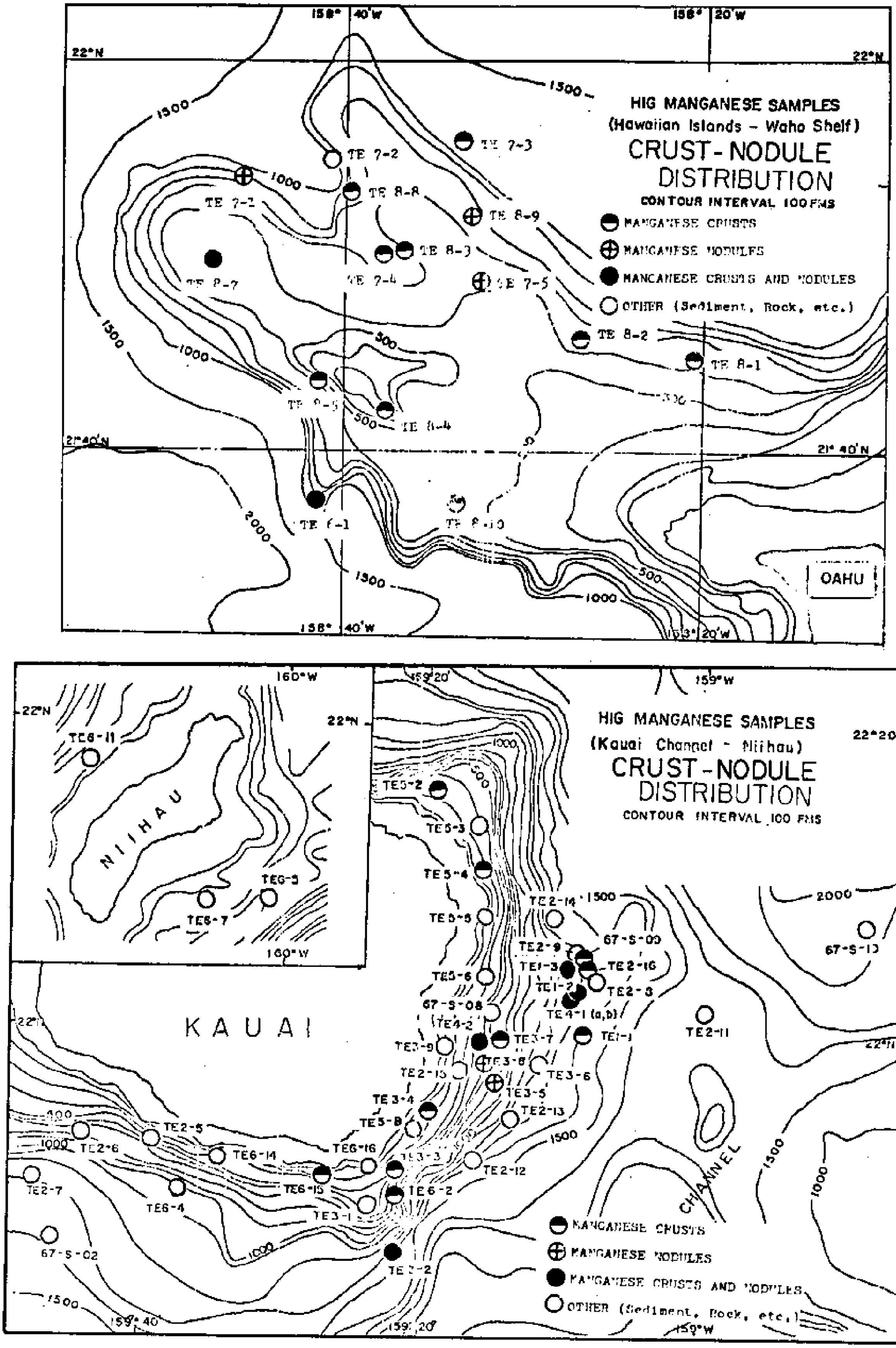


Figure 3. Bathymetry of Terraces Between Kauai and Oahu Showing Sample Locations and Type of Material Dredged

SPECTROSCOPIC ANALYSIS OF MANGANESE NODULES

By
George Andermann
Department of Chemistry
University of Hawaii

My interest in manganese nodules is the result of a discussion with Professor Goldberg of Scripps Institute. He told me that there was a very difficult analytical problem in connection with these nodules: "Just what does the manganese nodule consist of?"

Ordinary spectroscopic analysis of nodules will reveal their elemental composition, and you already know this. However, in order to understand the structure and composition of manganese nodules, we also need to know how the manganese and iron and the other transition metals chemically combine with other low atomic-numbered elements such as oxygen.

At the time of my discussion with Professor Goldberg the only reasonable analytical method for determining the structure of the ferromanganese constituents was x-ray diffraction. All of you know that this technique is simply one of using an x-ray beam to scatter from a set of unique atomic planes, but this assumes that your nodule is of purely crystalline form. Of course these nodules are not purely crystalline, so the x-ray diffraction pattern cannot provide quantitatively reliable information. Analysis by x-ray diffraction is also based on the idea that there are basically only three types of materials: MnO_2, 7-A^o manganite, and 10-A^o manganite. Thus the x-ray diffraction pattern, in fact, can be very misleading.

Our group, as well as some other groups including Geoffrey Glasby's, is looking at various other techniques, including spectroscopy. We have looked at three techniques here at the University of Hawaii. The assumption has been that we do not want to be confused by the presence or absence of crystallinity. What we really would like to look at is the transition metal element itself and the electronic structure of this atom, and thereby gain some knowledge of the oxidation state of the element. Thus far, manganese is the only metal that we have looked at. But what holds true for manganese should hold true for iron and the other transition metals.

Figure 1 shows the use of a very unique spectroscopic technique--the so-called ESCA or photo-electron spectroscopy--which provides information about the chemical combining capability of manganese. This figure shows the intensity on the vertical axis and the binding energy of the 2p electrons from manganese. There is a peak of the manganese metal $2p_{3/2}$ electron approximately at 640 electron volts and there is also another peak at the left. However, the 640 ex/region is going to be the most useful region. In Figure 2 the binding energy from MnO_2 corresponding to the higher oxidation state of manganese mainly Mn^{+4} shows a much higher value. We have observed that if we look at MnO_4^-, then the spectrum shows a higher binding energy peak corresponding to Mn^{+7}. If the permanganate is partially decomposed, then we observe a peak from MnO_2, the Mn^{+4} peak, and also the +7 peak. So we have, therefore, a calibration of the oxidation state in terms of the binding energy of the manganese $2p_{3/2}$ electron.

If you look at a particular manganese nodule sample, such as the deep-sea sample of Figure 2 you can see that just below the Mn^{+4}, but definitely above the Mn metal peak, there is a slight shoulder. This corresponds, then, to the Mn^{+2} state. This should represent the fact that this sample is rich in 10-A^{o} manganite. You can see that there is only a slight indication of the presence of Mn^{+2}. Most of the sample here would have to be considered to be composed of Mn^{+4} oxidation state. Clearly, a technique like this, and in fact all of the techniques that we have looked at (and I understand all of the techniques that Dr. Glasby has looked at) indicate that none of the spectroscopic methods will give you by inspection an exact quantitative determination of the oxidation state of one of these transition metals. The problem is that the photo-electron method consists of looking at electrons from a depth of from about 20 to 100 angstroms, and any Mn^{+2} near the surface would be heavily oxidized, so this technique would give you an under-estimate even if sophisticated computer technology were used.

We next consider another technique--another unique method called high-resolution x-ray photon emission. This

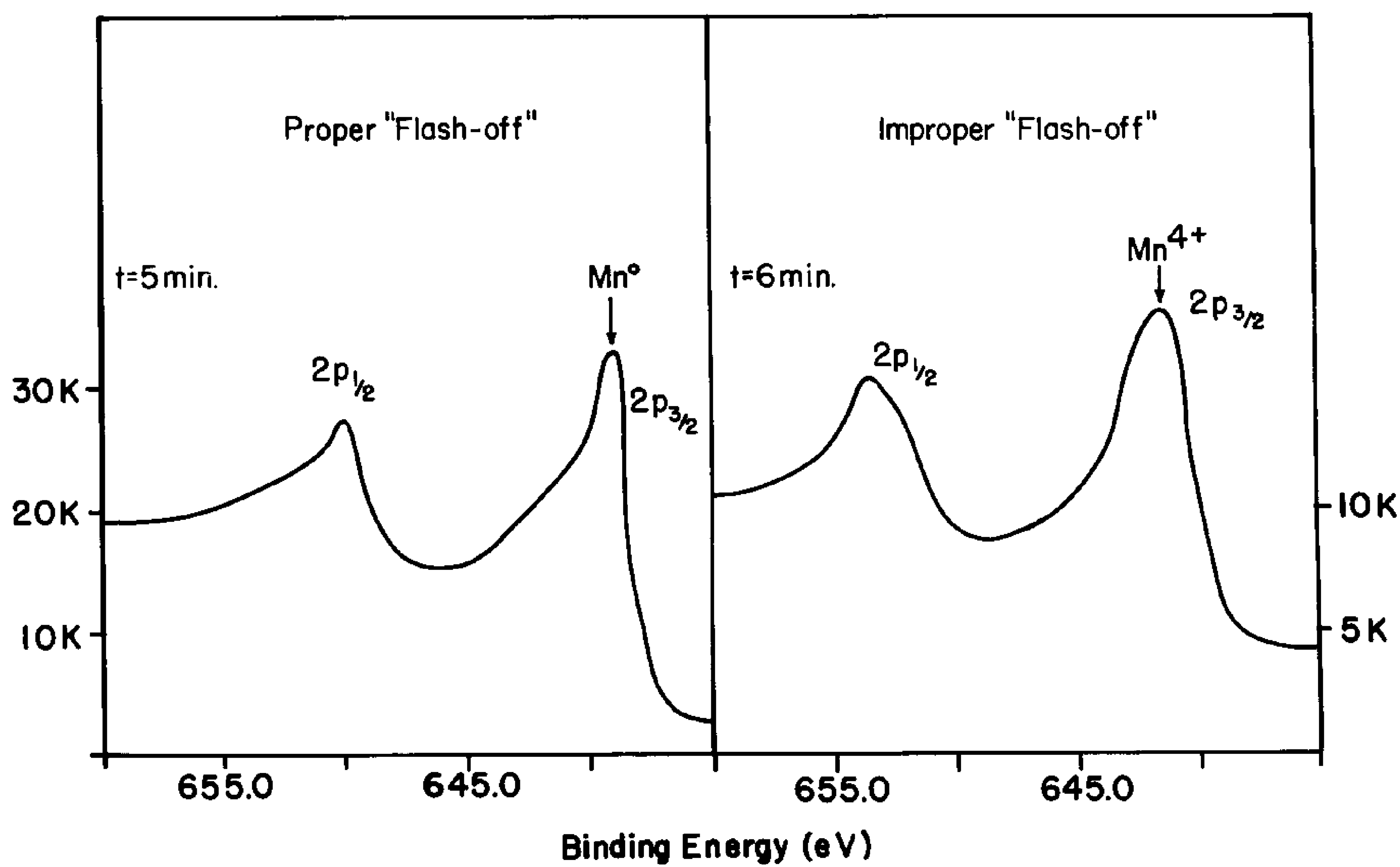


Figure 1. Photo-Electron Spectra of Manganese Metal

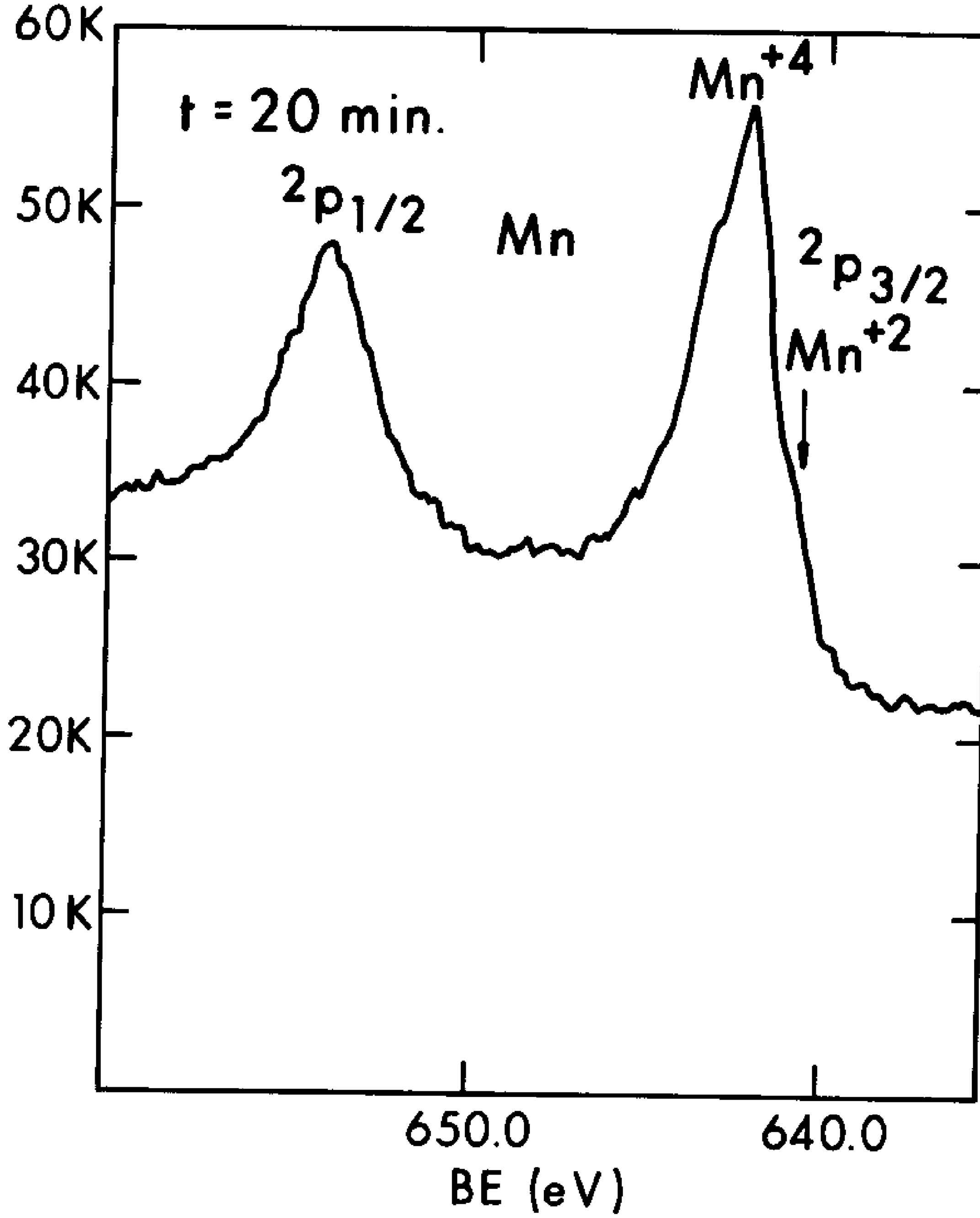


Figure 2. Photo-Electron Spectra of MagBa Nodule.

technique fundamentally would be more useful than the photo-electron method because the escape of the x-ray photon is from a depth of approximately 20 to 100,000 angstroms. Neither the photo-electron nor the photon-emission method would be disturbed by the presence of any non-crystalinity of the sample itself. We do not yet have the results on manganese nodules, but Figure 3 shows the results for manganese metal. There is a sharp peak for the manganese $L\alpha_{1,2}$ radiation, whereas the MnO_2, which is the corresponding MnO_2 phase would give you a broad peak. We have in process the development of a machine of a sort where each of the fine structures for MnO_2 would be resolved. Once again, please note that this is a very difficult analytical problem and to distinguish MnO_2 from $Mn(OH)_2$ would be very difficult by inspection. Fairly complex computer technology-curve solution methods will have to be used; that is, sophisticated games will have to be played by spectroscopists.

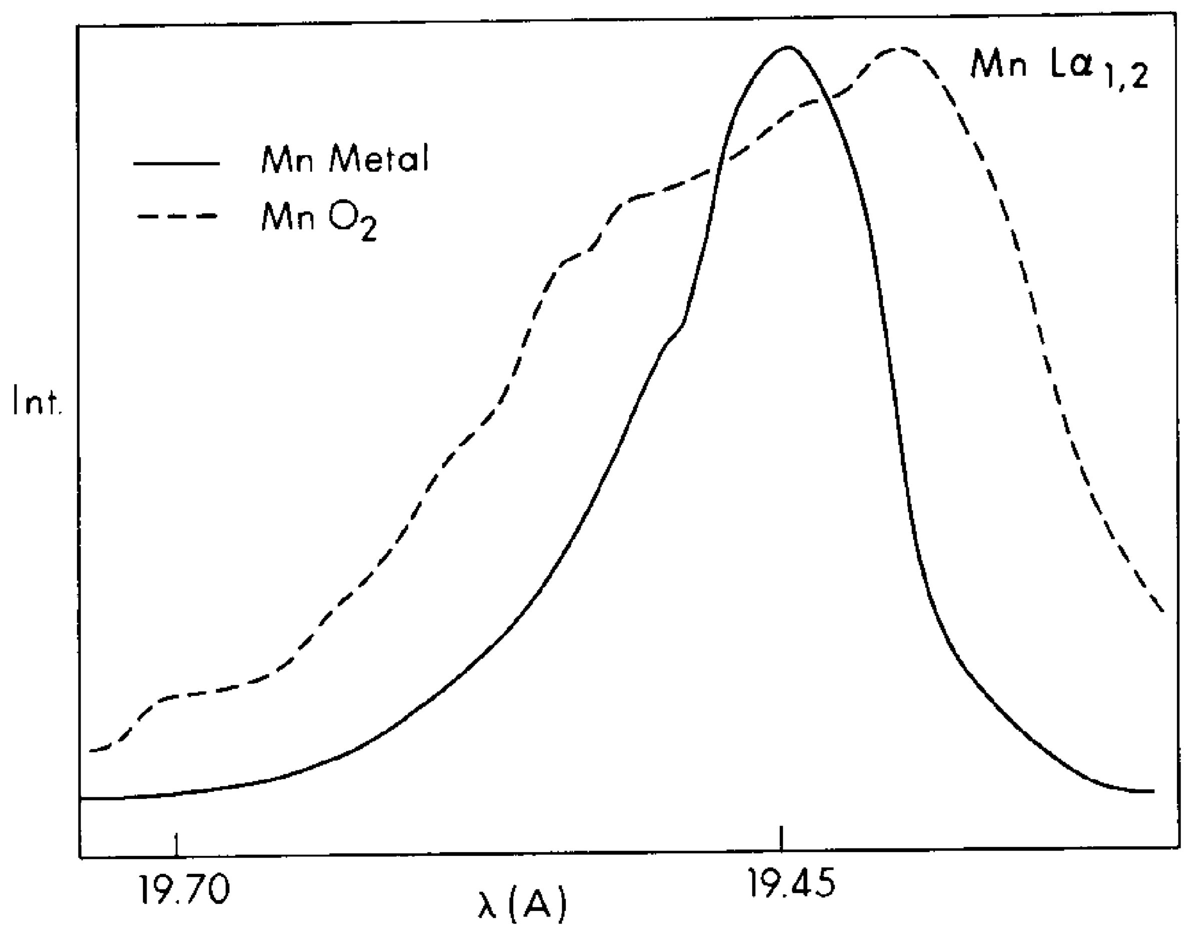


Figure 3. X-Ray Photon Emission

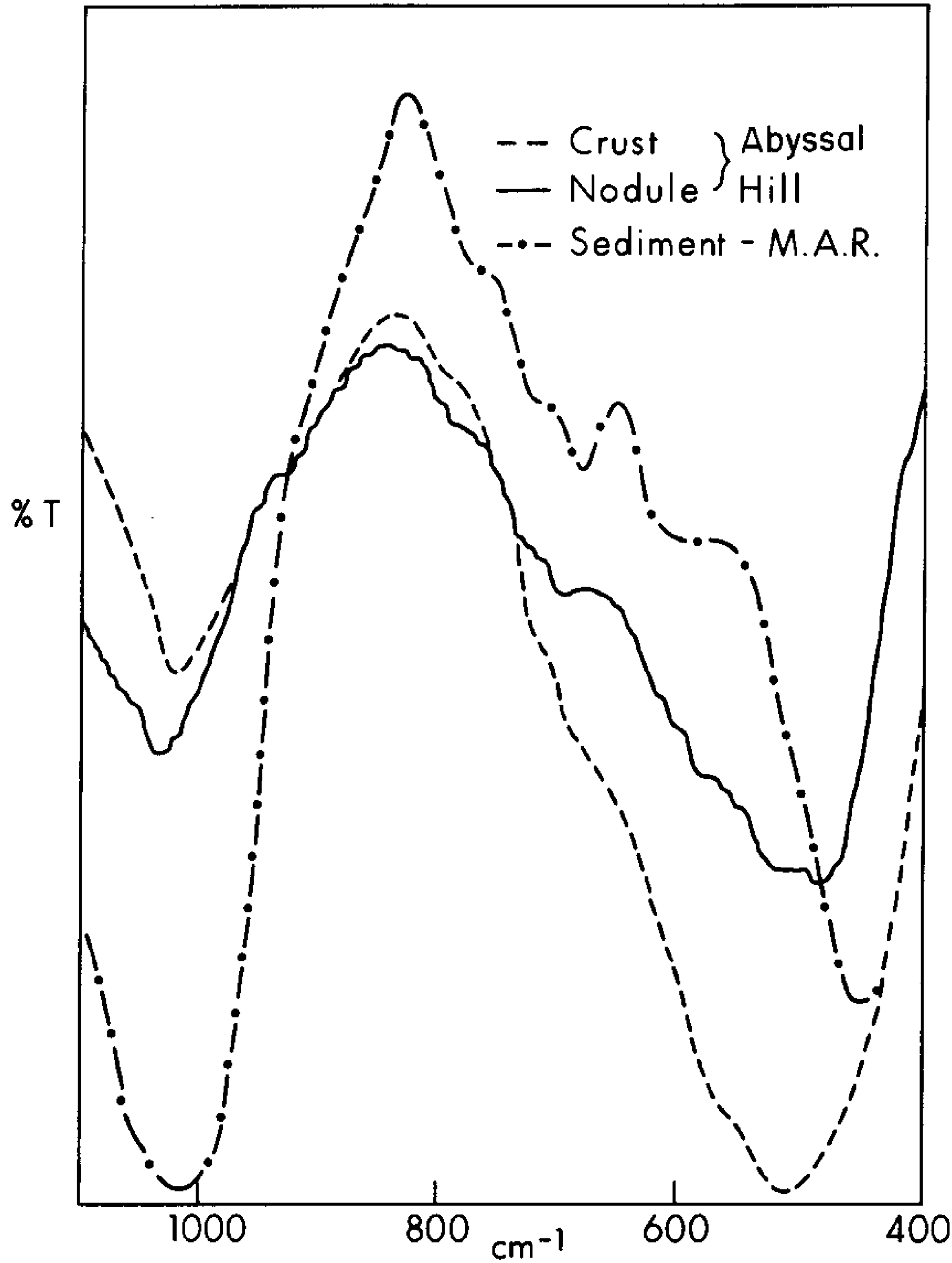


Figure 4. Infra-Red Spectra

One of the ways, then, to look at the oxidation state of manganese is to look at the electronic structure of the transition metal itself, more specifically to look at the so-called molecular electronic structure of the species. Still another way, is to look (as shown in Figure 4) at the infra-red spectrum of nodules, crust, and sediments, in order to see whether or not it would be possible to distinguish between the various oxides, since each of these oxides of manganese, for example, would have characteristic vibrational modes. This technique of looking at the specific vibrations of the transition metal with respect to the oxygen atoms surrounding the transition metal, is promising. Once again, however, the spectra are very, very complicated and one will not be able to simply run an infra-red spectrum and have the operator immediately obtain by visual inspection the amount of $Mn(OH)_2$ or the amount of MnO_2 in the sample. So we are faced with the problem that fairly complex mathematical games will have to be played in the future to be able to get exact information from this kind of spectroscopy. There are other spectroscopic techniques available, but each and every one of them is confronted with the same problem. Ordinary spectra alone will not do the job, spectroscopy plus computer technology does hold forth some promise.

INDIAN/ANTARCTIC NODULES

By

Geoffrey P. Glasby
New Zealand Oceanographic Institute
Wellington, New Zealand

INTRODUCTION

Because of their similar situation in the Pacific Basin, New Zealand's interests in marine mineral resources are essentially similar to those of Hawaii. We therefore welcome the opportunity to attend this Conference and exchange ideas on Pacific nodule sources. In this talk, I would like to review very briefly those aspects of the distribution of manganese deposits in the Southwest Pacific of particular interest to New Zealand and then discuss more specifically some more recent work I have been carrying out with nodules from the Indian/Antarctic region. This latter section involves a consideration of the genetic aspects of manganese nodules from a fairly limited area. A fuller account of these results will be presented elsewhere. (See References--Glasby.)

Figure 1 shows the distribution of manganese deposits in the South Pacific south of the equator. Although there is a fairly scant distribution of sample sites, the nodules are basically concentrated in the region of low sedimentation associated with the Southwestern Pacific Basin. Of particular interest to New Zealand is the distribution of manganese nodules over the Manihiki Plateau. These were first documented by Heezen et al (1966) but it was not until the work of Bezrukov (1971, in press) that their full potential became realized. Basically, these deposits occur in a depth range of 2,000 to 5,000 meters, their surface concentration within the area is strongly related to the bottom topography and they occur in concentrations of up to 50 to 70 kgms/m^2 of sediment surface. At a recent UNESCO Symposium in Wellington, Professor Bezrukov showed a slide in which over one ton of nodules was obtained from a single dredge haul in this particular area and the petrography of these deposits indicates that they represent thick deposits of manganese overlaying small volcanic cores. As David Horn has already mentioned in

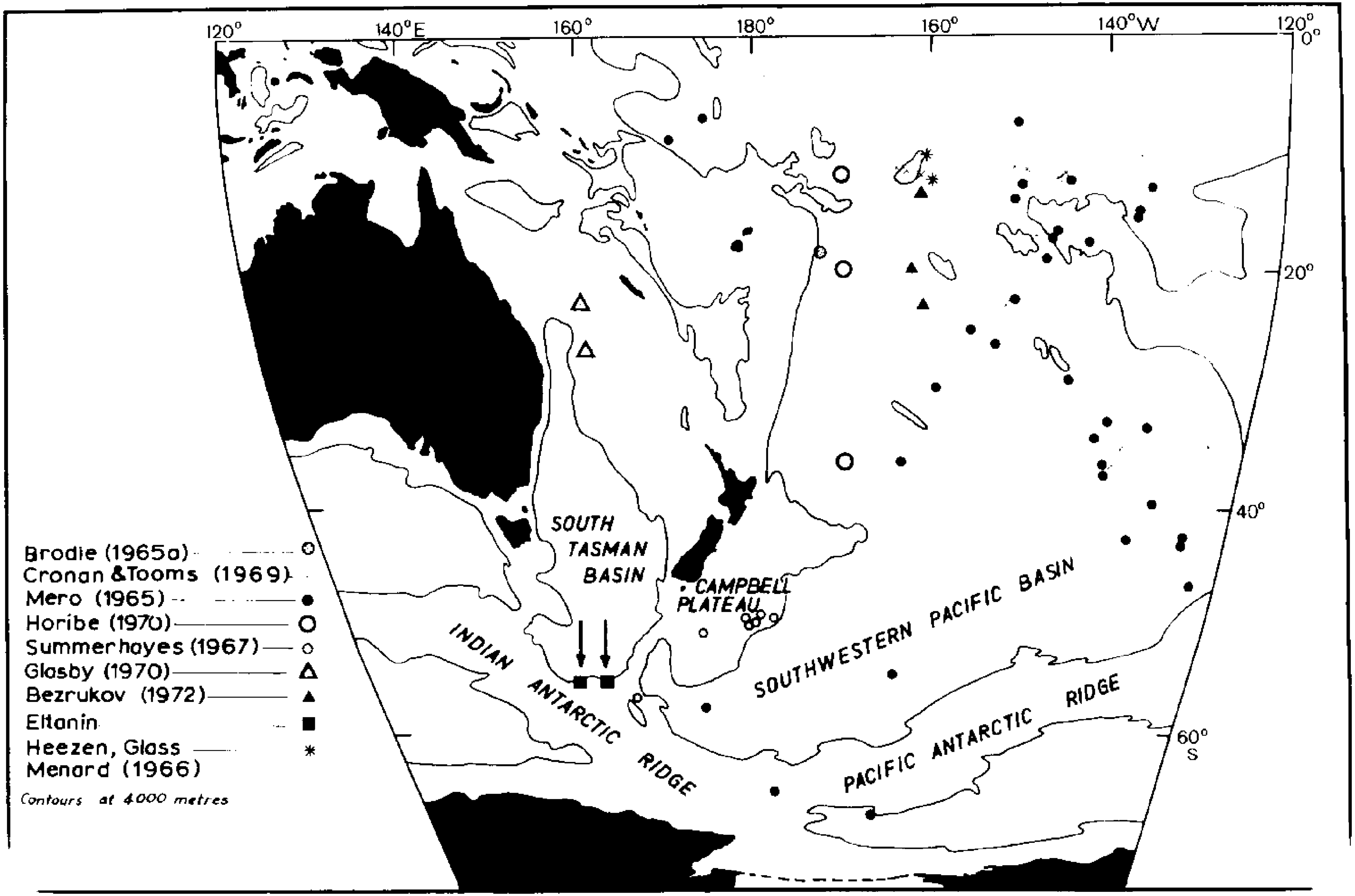


Figure 1. Distribution of Manganese Nodule Deposits in the South Pacific

the previous lecture, nodules from this area are cobalt-rich. These deposits may therefore constitute an economically viable deposit. This is, of course, of interest to New Zealand as they lie off the Cook Islands which are internally self-governing, but which come under the jurisdiction of the 1964 New Zealand Continental Shelf Act.

Within the New Zealand region itself, there are limited resources of manganese deposits. On the Campbell Plateau, Summerhayes (1967) reported thin encrustations of manganese overlying tertiary phosphorite deposits and suggested that their formation is related to the onset of Quaternary volcanism in this region. Since the time of writing, the importance of the volcanicity hypothesis of nodule genesis has largely been refuted. In the vicinity of the Aotea Seamount, it was suggested, on the basis of underwater photographs, that the outcrop on the seamount was submarine volcanic lava flows. However re-examination of material dredged from this region indicates that it is a Miocene phosphorite deposit which has been almost completely replaced by manganese oxides. This phenomenon of manganese associated with submarine volcanic seamounts is quite common in this region and has been observed on the Capricorn Seamount to the east of the Tonga Trench. To the south of New Zealand, very extensive deposits of manganese are associated with two main regions: the Indian/Antarctic Ridge and the Pacific/Antarctic Ridge.

The distribution of manganese deposits in the Pacific has also been studied by Skornyakova and Andryuschchenko (1970). Until very recently, it would seem that the Russians knew far more about nodule distribution in the Pacific than did western scientists. Basically, they delineated two areas of what they considered to be major ore resources of nodules; one off the western coast of the United States and a second in the Southwestern Pacific Basin to the northeast of New Zealand. Both areas are in regions of low sedimentation rate.

The distribution of manganese deposits across the Pacific/Antarctic Ridge has been studied by Goodell et al (1971) and I have taken the liberty of replotting their data so as to include only nodules accreting around volcanic cores and ignoring those accreting around glacial erratics. Goodell et al assumed that the nodules in these regions were formed by manganese being released into sea water as a result of submarine volcanism. This then was swept northward and deposited beneath the Antarctic Circumpolar Convergence. In my opinion, there is an alternative hypothesis to explain the distribution of nodules in this area (i.e., that in situ volcanic fragments are extruded on the axis of the mid-ocean ridge and then migrate to their present position by ocean-floor spreading. As they do so, they accrete manganese. The thickness of the manganese coating therefore increases with distance away from the axis of the mid-ocean ridge. This then is a fundamentally different hypothesis from that presented by Goodell et al. This relatively simple picture of nodule distribution is merely confused by the presence of glacial erratics which act as nodule nuclei within the area. The distribution of nodules across the Indian/Antarctic Ridge System has been studied by Watkins and Kennett (1971, 1972). This is shown to be a region of very abundant nodule deposits, and has been named the Tasman Manganese Pavement. Watkins and Kennett were particularly interested in looking at the stratigraphy of sediment cores from this region and they deduced that there was a stratigraphic break in the upper layers of these cores which they attributed to the onset of a high bottom-current velocity about 3.5 million years ago. This suggested that sediment was being winnowed out of this area over this time period and this created a low sedimentation regime favorable for manganese accretion. This region, however, forms the axis of the mid-ocean region and there are no manganese deposits at the crest of the ridge. It is of interest therefore to test the hypothesis that the distribution of manganese is in fact related to the ocean-floor spreading rather than the onset of high bottom-current velocity.

NODULES IN THE INDIAN/ANTARCTIC REGION

In the following section, the distribution of manganese deposits at two stations, Z2139 and Z2140, taken approximately 500 kilometers north of the Indian/Antarctic Ridge System is described. The samples were collected by the USNS Eltanin and donated to the New

Zealand Oceanographic Institute in Wellington. Basically, Station Z2139 (55°09.5'S, 150°03'E, 3859-3872m) consists of a series of glacial erratics boulders; i.e., granite, diorite, or peridotite coated with manganese. Generally, the manganese encrustation is restricted to the upper surface of the boulder and the underside is free from manganese. This suggests that the boulders were deposited in a region of rocky terrain. The manganese was able to accrete from sea water only on the upper surface of the deposit and not on the underside because diagenetic processes could not operate. The manganese crustal thickness was generally of the order 1 mm. If it is assumed that the rate of accretion of manganese in the deep sea is of the order from 1 to 10mm per 10^6 years, as has been determined by radiometric evidence (Ku and Broecker 1969), it can be calculated that the onset of manganese deposition in this region occurred in the period 100,000 to 10^6 years ago. This corresponds to the last series of glacial advances in the Southern Hemisphere (Margolis and Kennett 1971). These samples were therefore brought to their present position during the last glacial advance when the ice front was much further north than it is at present into a region of very rocky terrain.

Station Z2140 (54°56'S, 154°46'E to 55°00'S, 155°00'E, 4060-4279m) also contains a limited number of glacial erratics. The underside is again devoid of manganese whereas the upper surface and on the back of the upper surface is encrusted with manganese. The predominant morphological type at this station is, however, the botryoidal nodule. These are flattened concretions which consist of a highly weathered volcanic core and are coated with a thin but variable coating of manganese about 1 mm thick. There are also a smaller number of spherical nodules. Again they comprise a volcanic core with a thin coating of manganese.

It is interesting to speculate on the mode of origin of these nodules with volcanic cores. If we make the same calculations as before, assuming that the manganese is about 1 mm thick and assuming the rate of accretion of 1-10 mm/10^6 years, it can be calculated that the manganese has been accreting on these deposits for the last 100,000 to 10^6 years. On the other hand, if it is assumed that the samples that were dredged 500 kilometers north of the Indian/ Antarctic Ridge System and that the ridge has been migrating at the rate of 2 cm per year, it follows that the volcanic cores are on the order of 25 million years old. This then indicates fairly young ages for the manganese and fairly old ages for the volcanic core. This situation can result from one of two causes: either the volcanic cores are much more recent than the calculations would suggest (and this is not altogether improbable because it is a very complex tectonic history of the region), or what is more likely the manganese does in fact post-date the volcanic core by at least an order of magnitude. If this is so, this adds strong evidence to the idea of Watkins and Kennett (1971,1972) that nodule deposition in this region is being controlled by a relatively recent geological event such as the onset of high bottom-current velocity, rather than being related to ocean-floor spreading as appears to be the case in other active mid-ocean ridge systems such as the Indian and Atlantic mid-ocean systems. There are also a number of highly distorted nodules from this region consisting of several nuclei joined together. These result from the very high frequency of occurrence of nodule nuclei on the sea floor. The nuclei accreted manganese during the incipient formation of the nodules, and were so close together on the sea floor that they coalesced to form these highly distorted structures. These distorted nodules therefore reflect the very high frequency of nucleating agents on the sea floor in this region and also the young geological age of the samples. If the nodules were much older than they are, the distortion would have been obscured by a much thicker coating of manganese.

Table 1 shows the composition of the nodules for this locality. To facilitate analysis, the manganese oxide coating was scraped off the deposit, taking great care not to incorporate the nodule nucleus into the sample. The resultant powders were then analyzed by atomic absorption spectrophotometry. Because of the care in sample preparation and the uniform appearance of the

TABLE 1

Chemical analysis of manganese deposits from the Indian Antarctic Ridge. (Analyses in ppm except where otherwise stated.)

Sample No.	$\%Fe_2O_3$	%MnO	Co	Ni	Cu	Zn
Z 2139A*	17.67	20.90	4494	2578	585	196
Z 2139B*	15.57	23.31	2886	1942	385	191
Z 2139C*	19.26	19.94	3172	8404	422	191
Z 2139F*	16.42	18.76	1286	3560	605	90
Z 2140B*	13.73	9.65	1621	2440	2155	190
Z 2140 Botryoidal nodule sample 1**	11.35	22.35	2231	6411	1181	162
Z 2140 Botryoidal nodule sample 2**	11.05	18.72	1190	5123	1487	188
Z 2140 Small rounded nodule**	11.47	19.70	1003	1021	1955	164
Z 2140 Large rounded nodule sample 1**	14.31	17.38	2238	6294	2127	189
Z 2140 Large rounded nodule sample 2**	18.36	12.06	668	3353	1435	184
Z 2140 Large rounded nodule sample 3**	15.56	25.85	1136	5305	2835	183
Z 2140 Large rounded nodule sample 4**	11.91	21.53	1155	2045	2070	183
Z 2140 Large rounded nodule sample 5**	13.00	22.30	1698	8649	2185	183
Z 2140 Pyramidal nodule **	16.23	13.41	1240	3056	1542	183
Mean	14.71	18.99	1858	4299	1498	177
Percent Standard Deviation	18.6	23.9	56.6	56.5	51.6	15.3
Percent Analytical Precision (one standard deviation level)	14.41	4.65	16.02	9.67	10.39	3.90

* Glacial erratic nucleus

** Volcanic nucleus

samples, uniform analytical data were anticipated. This is not in fact the case. Iron varies between 11 and 19 percent as Fe_2O_3, manganese varies between 10 and 26 percent as MnO, cobalt between 670 and 4,500 (parts per million), nickel between 1,000 and 8,600 ppm, copper between 380 and 2,800 ppm, and zinc between 90 and 190 ppm. Manganese and iron show a variation of a factor of 2, and cobalt, nickel and copper of a factor of 7 to 8.5. The most interesting feature of these data is that there is no simple distinction between nodules displaying different types of core, or different morphology. This therefore poses the question as to what is meant by an analysis of a manganese nodule. Basically, there are three possible sources of variability here. First, there is the analytical error, and this will be $\pm$ 25 percent at the 95-percent confidence level (i.e., not large enough to explain the variability observed here). Secondly, there is a factor which has been very much underestimated by geochemists in their interpretation of nodule analysis and that is covariance of trace-element composition of the nodule with the amount of silicate minerals incorporated into the nodule structure. Nodules are very heterogeneous materials comprising of a silicate phase, a manganese oxide phase and an iron oxide phase. I think that this may be an important factor controlling the trace-element variation. The final factor is the intrinsic variation of trace-elements in the authigenic phase of the manganese oxide minerals. In my opinion the variation is so great that there must still be some residual variation in the minor elements from this source. This is difficult to explain since the encrustations come from a very localized area on the sea floor. Further, there is no simple inter-element relationship between Cu-Mn, Ni-Mn, and Co-Fe or any antipathetic relationship between Mn-Fe as might have been anticipated. The main purpose of these data, however, is to emphasize the variability in nodule composition (particularly in the ore metals copper, nickel and cobalt) over a localized area on the sea floor. This observation is particularly relevant if nodules are to be regarded as an ore resource since a detailed knowledge of the statistics of sampling of nodules on the ocean floor will be required in any mining operation. This problem has been largely neglected in the past. To my knowledge, such localized variation in nodule composition have previously been reported for only three localities.

Finally, the nodules from this area are petrographically complex. Polished sections of the nodules show a thin but variable thickness of manganese overlying a highly weathered volcanic core. At higher magnifications, the manganese minerals show well-developed growth cusps separated by silicate minerals. The presence of silicate minerals in the nodule structure emphasizes the heterogeneity of the nodules and may account for some of the observed variation in nodule composition. Localized changes in cusp size and changes from bands to cusps are observed within the nodules. In one case, there was some evidence for *in situ* fracturing of the nodule and subsequent infilling of the fracture by manganese minerals.

In conclusion, the deposition of manganese oxides in this region appears to post-date the formation of the volcanic cores on which the manganese accretes by at least an order of magnitude. This finding supports Watkins and Kennett's hypothesis that the increased bottom-current velocity in this region during the last 3.5 million years is the major factor in the genesis of these nodules. The nodules are highly variable in composition and this is most important in any appraisal of the statistics of sampling of nodules on the ocean floor. Finally, nodules from this area are petrographically very complex and very heterogeneous in composition.

REFERENCES

BEZRUKOV, P.L. 1971: The main scientific results of the 48th voyage of the RV *Vityaz* in the Pacific Ocean (May to September, 1970). *Oceanology 11*: 457-63.

BEZRUKOV, P. L. (in press): On the sedimentation in the northern part of the South Pacific. Proc. *UNESCO Internat. Symp. Oceanogr. Sth Pacif.*, Wellington, Feb. 1972.

GLASBY, G. P. (in press): Manganese deposits in the Southwest Pacific. Hawaii Institute of Geophysics Report.

GOODELL, H.G.; MEYLAN, M.A.; GRANT, B. 1971: Ferromanganese deposits of the South Pacific Ocean, Drake Passage, and Scotia Sea. Pp 27-92 in Reid, J.L. (Ed.) "Antarctic Oceanology I". Antarctic Research Series, American Geophysical Union, Baltimore. 343 pp.

HEEZEN, B.C.; GLASS, B.; MENARD, H.W. 1966: The Manihiki Plateau. Deep-Sea Res. 13 : 445-58.

KU, T-L.: BROECKER, W.S. 1969: Radiochemical studies on manganese nodules of deep-sea origin. Deep-Sea Res. 16 : 625-37.

MARGOLIS, S.V.; KENNETT, J.P. 1971: Cenozoic paleoglacial history of Antarctica recorded in Sub-Antarctic deep-sea cores. Am. J. Sci. 271 : 1-36.

SKORNYAKOVA, N.S.; ANDRYUSHCHENKO, P.F. 1970: Iron-manganese nodules in the Pacific Ocean. Pp 203-68 in Bezrukov, P.L. (Ed.) "Sedimentation in the Pacific Ocean. Part 2".

SUMMERHAYES, C.P. 1967: Manganese nodules from the Southwestern Pacific. N.Z. Jl Geol. Geophys. 10 : 1372-81.

WATKINS, N.D.; KENNETT, J.P. 1971: Antarctic bottom water : major change in bottom current velocity during the Late Cenozoic between Australia and New Zealand. Science, N.Y. 171 : 813-8.

WATKINS, N.D.; KENNETT, J.P. 1972: Regional sedimentary disconformities and Upper Cenozoic changes in bottom water velocities between Australia and Antarctica. Pp 273-93 in Hayes, D.E. (Ed.) "Antarctic Oceanology. II : The Australian - New Zealand Sector". American GEophysical Union, Baltimore. 364 pp.

SCRIPPS INSTITUTION OF OCEANOGRAPHY DATA AND PACIFIC NODULES

By
James Greenslate
Scripps Institution of Oceanography
La Jolla, California

A firm interested in mining deep-sea manganese nodules would like three basic questions answered: (1) Where are the nodules geographically? Especially, where do they exist in the greatest density? (2) What is their net economic value? (3) What are the local physical parameters which are important for recovery operations? Specifically, what are the water depths, the bottom topography, and the general appearance of the sea floor?

The answer to the second question is subject to variation with company and market conditions. Perhaps a useful alternative question would be: What are the composition levels of the most marketable metals in the nodules? This has been answered many times in the presentations today. I shall discuss the questions in the order of the third, the first and finally the second.

We have seen substantial quantities of data during this Conference, but we lack sufficient data on sample site density to truly understand the ocean floor. In an attempt to obtain the greatest possible resolution based on existing data, Jane Frazer at the Scripps Institution of Oceanography has assembled a huge collection of information on deep-sea sediment and ocean-floor material. One of her recent publications is a large-scale map of the North Pacific Ocean showing the surface sediment distribution.

Figure 1 shows eight of the ten portions of the map series. They are positioned together and photographed giving an overview of the general nature of the sediment in the North Pacific area. You have undoubtedly seen other similar representations of the North Pacific floor sediment. There are two major differences between this map series and those previously published: (1) each known data point is shown on the final map, together with that point's sediment type; and (2) there are no generalizations--usually necessary on smaller scale maps.

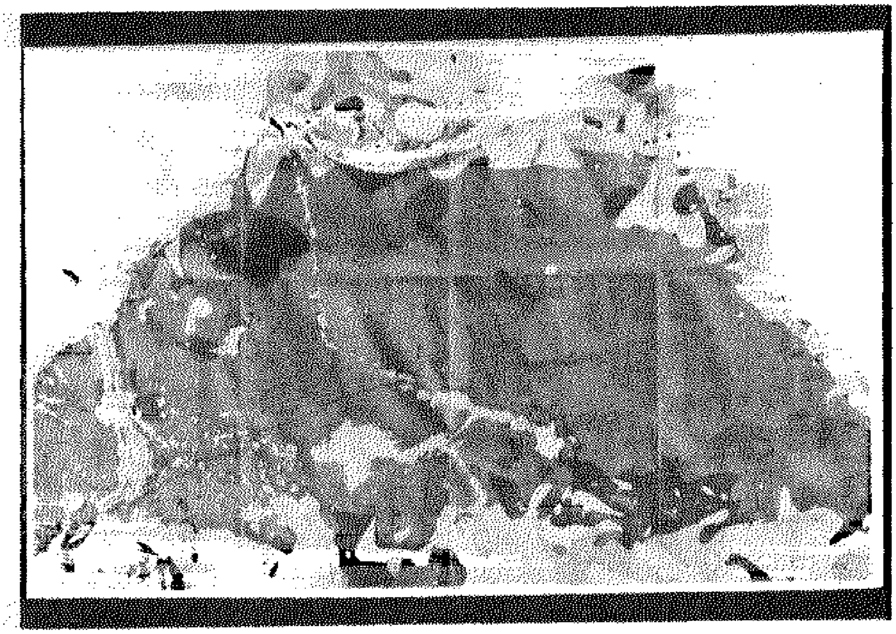


Figure 1. Composite large-scale map of the North Pacific Ocean showing surface sediment distribution (8 of 10 portions of the map).

We could better see these two features if we were to view only one of the map sections. Figure 2 shows the region immediately around Hawaii. Some of the major features of this map represent the Pacific red clay (which is really brown); the carbonate material which is over 30 percent carbonate; the silicious oozes, which means it is less than 30 percent carbonate (but still 30 percent biogenic); and the overlap of the many areas are composites of these various things. This area is a silicious and carbonate-ooze combination. Some of the cross-hatchings indicate various other things: gravel deposits, volcanic debris, etc. These surface materials are interpreted from the top of a core sample; in the case of a grab sample they would be so mixed up you would not know where they were. This does not necessarily give you any indication of what is below the surface layer as the depth increases.

One might ask, just how good is the control arriving at the distribution seen here? Figure 3 shows the individual data points on which the preceding maps were based. It indicates the sample density that occurs at least over the

Figure 2. Surface sediment distribution immediately around the Hawaiian Islands.

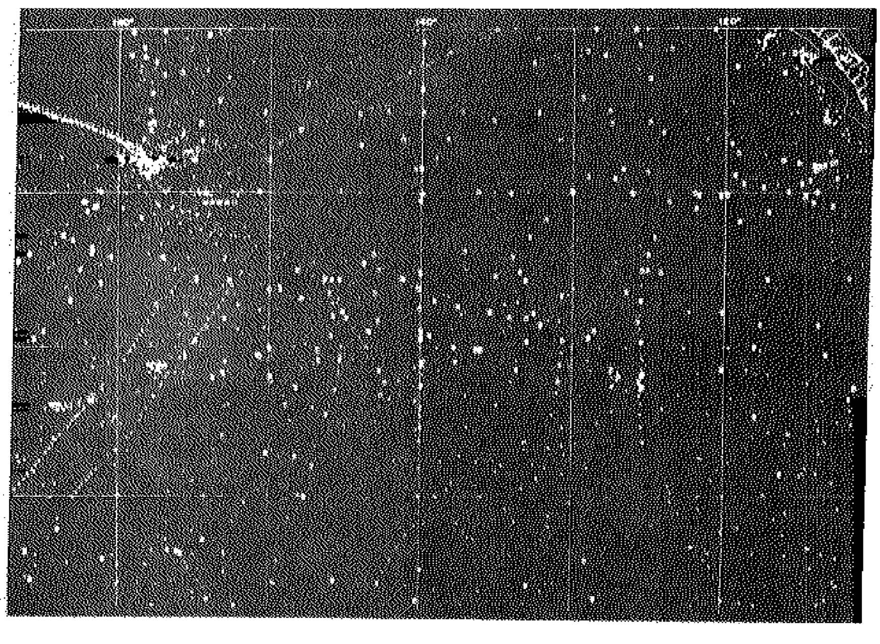


Figure 3. Map showing data points used as a basis for surface sediment distribution maps.

limited area shown. Here a series of numbers and the actual sample station are in the lower left-hand block position of each number. In this particular case these are 5, which represents the carbonate material and 7 which represents the red clay. You will notice on this map that some numbers are circled; these are stations in which manganese of some sort was collected: either manganese nodules, manganese encrustations or, in many cases, micronodules in the sediment. To arrive at the map of Figure 2, literally thousands of data points are involved. To my knowledge this is the largest, most detailed collection of sediment data of the North Pacific region. It includes both published and unpublished material from all of the major oceanographic institutions of the United States, as well as much data from other international organizations.

It provides a reasonably adequate answer to Question 3: What is the sediment type that is found on the ocean floor, particularly in regions where manganese nodules occur? Reference has been made to the International Decade of Ocean Exploration (IDOE) Manganese Nodule Conference which took place in January, 1973, in New York. Most of you are aware of Technical Report Number One, the IDOE Manganese Phase I work that David Horn of Lamont-Doherty Geological Observatory recently completed.

Scripps' participation in Phase I of this Manganese Nodule Evaluation Program has generated Technical Report Number II. The content of Technical Report Number II was gleaned from our existing sediment data files and is organized to provide interested parties access to our data on worldwide manganese nodule distribution, the sediment type for a 60-degree equatorial belt in the Pacific Basin which covers the 30°N to 30°S latitude, and the content of nickel, copper and cobalt in the manganese nodules for this same region. There are 538 manganese deposit sites north of the equator and 240 south of the equator within the belt, and all are included in Technical Report Number II.

The region to which these numbers apply may be redefined. It is a rectangle contained within the latitude 30°N to 30°S and a longitude 80°W to 130°W, or in simple terms, the east central Pacific. Charts have been compiled which show some of the nickel, copper, and cobalt concentrations in the nodules from this general area. Figure 4 is a

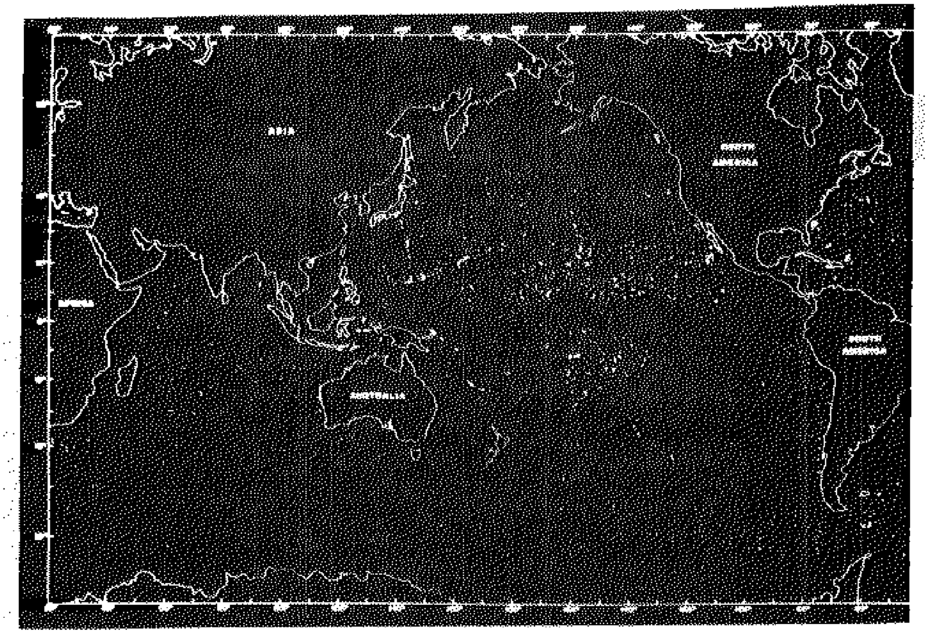


Figure 4. Representation of manganese nodule occurrences in the Pacific.

very generalized representation of the manganese nodules or encrustation occurrences that our data files hold. The same general distribution described in another presentation is also noted here. The Atlantic area was intentionally omitted and has been covered elsewhere. Figure 5 shows the nickel concentration in the nodules from this particular area. The number of analysis sites that are included in Technical Report Number II are 153 north of the equator and 54 south of the equator. In terms of density there is a very good coverage of this particular region. The conclusions one would arrive at from this information are very similar to those of Dr. Horn. Figure 6 shows the copper concentration. As Dr. Horn discussed earlier, the silicious ooze area is in general between 10° and 15° north. Figure 7 shows cobalt with a distribution similar to Dr. Horn's. In general cobalt was associated with bathymetric highs and is inversely related to the copper and nickel concentrations, although there is some variance.

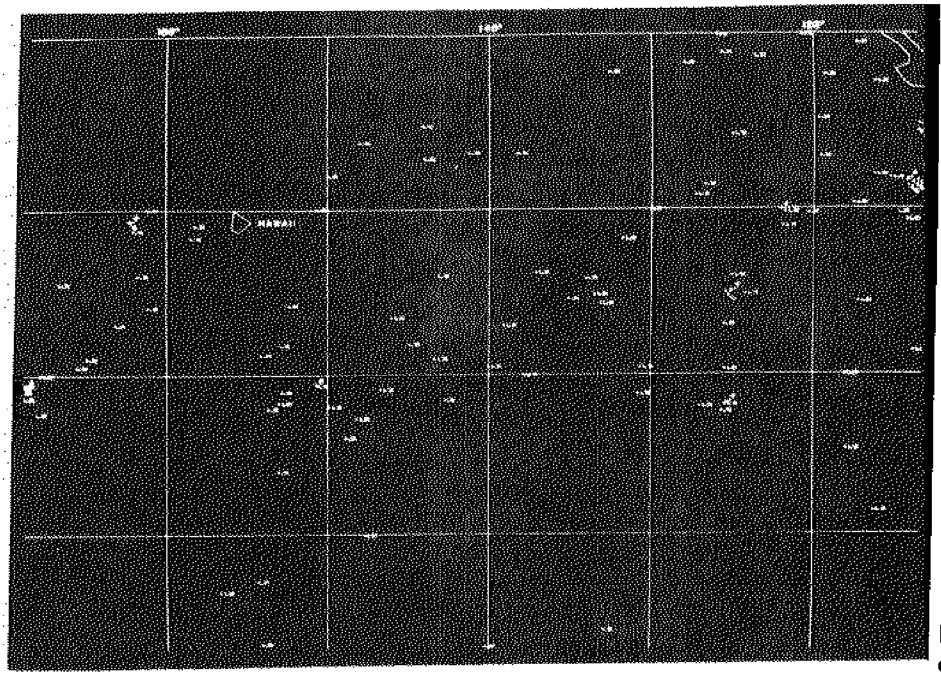


Figure 5. Nickel concentration in nodules of the east central Pacific.

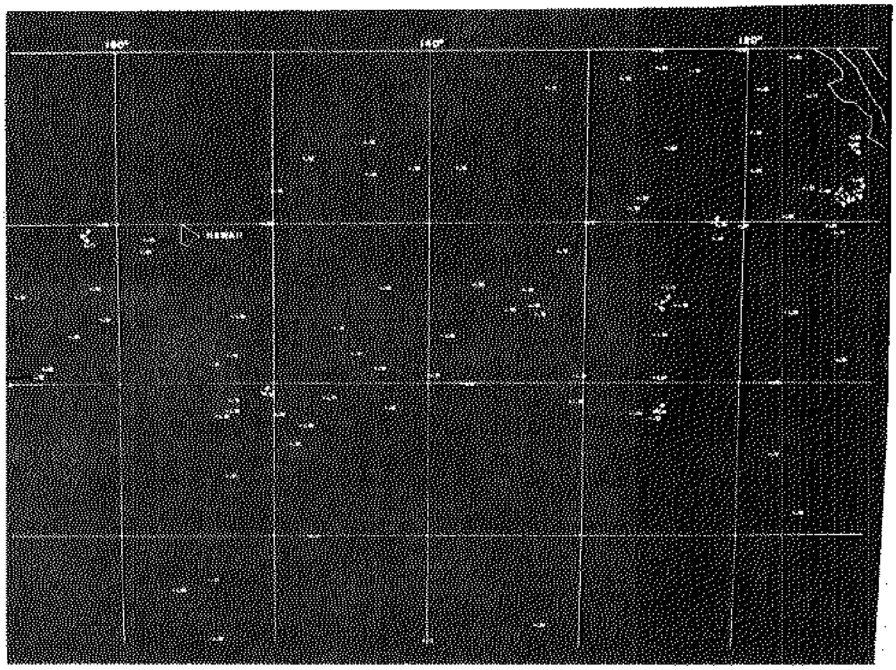


Figure 6. Copper concentration in nodules of the east central Pacific.

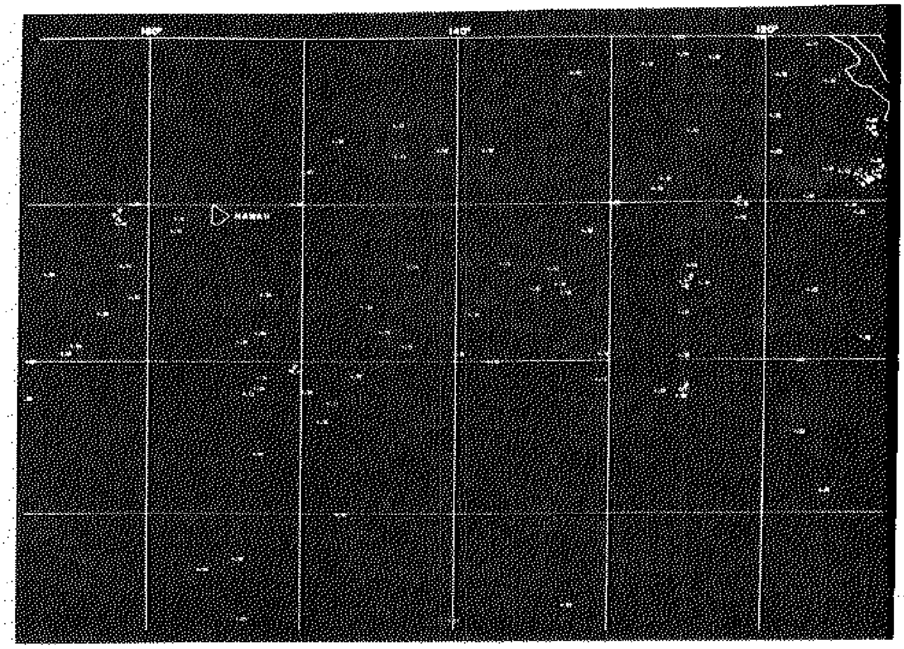


Figure 7. Cobalt concentration in nodules of the east central Pacific.

Even with this sample density, however, there is not sufficient information to draw any specific conclusions on nodule origin or genesis in any limited area. It is my view and the view of my colleagues that one of the difficulties in interpreting our knowledge of manganese nodules is that we have in general tried to apply our limited data to too large a geographic area. If we can take, perhaps, a very limited area, such as Geoffrey Glasby has done with the two regions he discussed, perhaps we could come to some better conclusions. This does not, however, help the person who might be interested in mining the manganese nodules. He must make some sort of a judgment to answer the question: What is the economic value of a given deposit?

In an effort to eliminate some of the variables that Dr. Glasby mentioned, for example, some of those in a chemical analysis, we have calculated a number which is the ratio of the sum, nickle, copper, cobalt over the sum, iron, manganese: $\frac{(Ni+Cu+Co)}{(Fe+Mn)}$ An immediate response to this might be that this ratio represents the depth of the water. Superficially, that is quite true. As can be seen in Figure 8, the ratio becomes quite small in areas where water becomes quite shallow, for instance, in some of the photographic highs the ratio goes to 0.03 and 0.04. Near the coast of

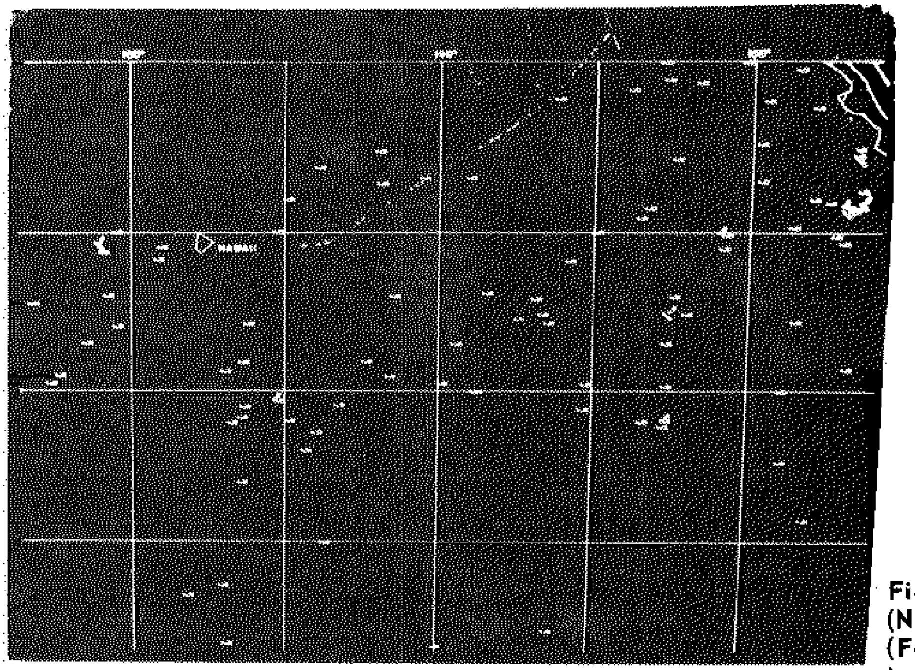


Figure 8. Ratio of (Ni + Cu + Co) to (Fe + Mn) in nodules in the Pacific.

California the ratio goes to 0.01 and sometimes virtually disappears. However, there is still significant variation in this ratio even in the deep water. These data show that in the area of interest for exploiting manganese nodules, this ratio goes quite often to 0.01, which is as high as it generally ever gets. In an area where the water is of similar depth, immediately to the north, this ratio drops by a factor of 2 to 0.05. Perhaps this ratio can be of some value to those who might be interested in exploiting the nodules commercially.

Concerning the geochemical problems associated with manganese nodule appearances which were discussed earlier, my recent studies of sediment chemistry show that at this time the highest concentrations of copper and nickel in the sediment are in general not directly correlated with the highest concentrations of the same elements in the nodules. The occurrence of the most interesting nodules is not in the area where the sediment has the most interesting concentrations.

SESSION IV

Industry

Chairman: **Howard Pennington**

Speakers: **Robert D. Gerard**
John L. Mero
Commander Yoshio Masuda
Raymond Kaufman

NEW POWER GENERATING TECHNIQUES
FOR PROCESSING MARINE MINERALS

Abstract

By

Robert D. Gerard
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York

Projections for increasing energy consumption indicate that about half of the present U.S. reserves of depletable fossil fuels will be consumed by the year 2000, while world reserves of these fuels at economic rates may be exhausted within a few hundred years. Accessible fuel for fission nuclear power has the same reserve life expectancy as fossil fuels. Development of the breeder reactor will extend the nuclear fuel supply to the year 3000, while the yet-to-be developed techniques of controlled nuclear fision could supply virtually unlimited energy.

Other continuous energy sources receiving attention are: direct solar radiation, geothermal power, tidal and wave power. A common problem in most of the electro-power plant developments is the disposal of large amounts of waste heat. Savings in cost, avoidance of environmental damage and improved efficiency can all be achieved using the ocean as a heat sink. Many coastal areas and mid-ocean islands have favorable natural conditions for obtaining cold ocean waters from 1000 meters depth. In tropical areas, the generation of sea thermal power using a modern version of the Claude process is an attractive possibility, particularly since this fuel-free system also produces potable water.

A promising scheme for Hawaii would be a combined electro-power, water-production, and mariculture plant. Hawaii's vast geothermal potential might be used by means of the new hydrofracturing technique to provide super-heated water to a plant using nearby deep-ocean water for cooling. The discharged deep-ocean water would remain a valuable resource

by virtue of its high nutrient content and could be used to support a productive mariculture enterprise. Economics of such a tri-purpose plant would attract other industry. A plant processing ferromanganese nodules would benefit from low-cost, pollution-free electrical power, water, and the availability of a subsurface pipeline to discharge fine tailings back into the deep ocean.

POTENTIAL ECONOMIC VALUE OF OCEAN-FLOOR MANGANESE NODULE DEPOSITS

By
John L. Mero
Ocean Resources, Inc.
La Jolla, California

INTRODUCTION

Although 100 years have elapsed since the discovery that deposits of manganese nodules were widespread in all the oceans of the world, it has only been within the past 15 years that the nodules were recognized as a major potential economic source of industrial metals for the world population. This realization came about through a study conducted in 1957-58 by the Institute of Marine Resources of the University of California after a large haul of nodules, rich in cobalt, was dredged from the Tuamotu Escarpment, just east of Tahiti, by scientists from the Scripps Institution of Oceanography as part of the 1957 International Geophysical Year program. The results of that study were quite favorable as to the technical and economic aspects of mining. Processing the nodules and the published results of that project have sparked the investment of almost $100 million by world natural resource companies in the development of nodules as a source of metals.

It is particularly fitting, in these times of hypertensive environmental awareness, that the manganese nodules of the deep-sea floor should be under such intensive investigation, for not only will there be no measurable environmental damage done in the mining and processing of these nodules, but their full-scale development as a source of industrial metals will allow society to close many of the sulphide mines on land which are presently a substantial source of air and land pollution. Also, because of the unique physical and chemical structure of the nodules, with their large and chemically reactive specific surface areas, there is some indication that the nodules may be quite useful in greatly reducing pollution of the atmosphere from other operations such as power production and from automobile exhaust emissions. What other applications may be found for this gift of the sea remains to be seen until that time when the nodules are brought under intensive investigation of all of their facets.

THE ECONOMICS OF PRODUCING METALS FROM MANGANESE NODULES

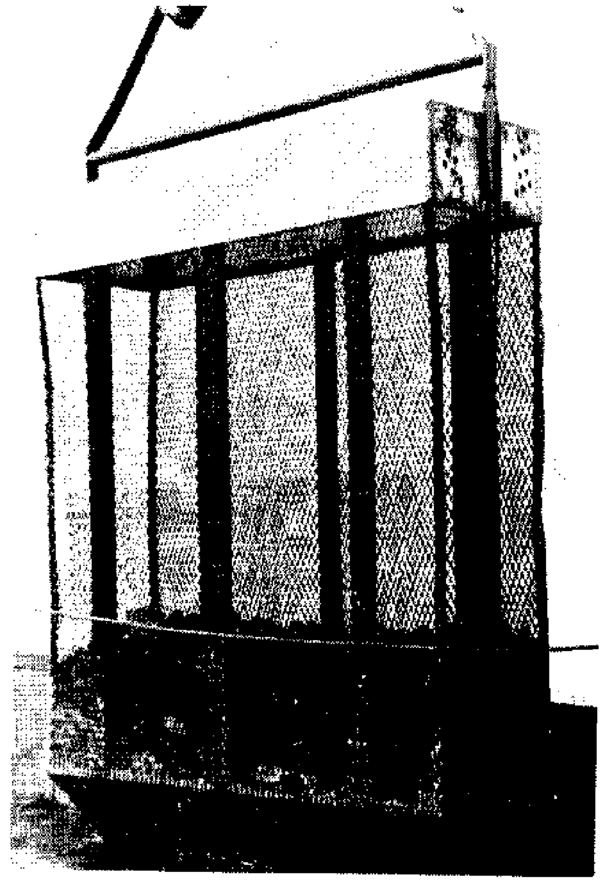


Figure 1. Deep-sea drag bucket of the general design used to secure samples for chemical analysis and tonnage lots of manganese nodules.

There are about 25 or so factors involved in the calculations used to determine the economic value of a deposit of manganese nodules; the more important ones being grade of nodules, concentration of the nodules per unit area of ocean floor, size distribution of the nodules, physical characteristics of the associated sediments, depth of water, distance to port or process facility, topography of the ocean floor in the deposit area, weather in the deposit area, and so on. Of these considerations, the most important factor is the grade of the nodules. Because of this consideration, it is the nodule deposits of the Pacific Ocean which are of greatest interest at the present time. More specifically, it is the nodules in a band between the equator and the north 20^{o} line of latitude and between the North American continent and about the 180^{o} line of longitude which are of greatest interest for it is in this area in which the nodules of highest economic value are found.

Exploration of Sea-Floor Nodule Deposits

Exploration of the nodule deposits in generally accomplished, for economic purposes, by scanning the deposits with a television camera or still camera and periodically sampling with some dredging device, usually a bucket of the general design as shown in Figure 1. Large buckets are also used for tonnage sampling of the deposits for process development work. Some companies use a series of free-fall photographic and grab sampling devices with sample points spaced about one mile apart through a deposit area. The cost of a sophisticated exploration program to find and block out say ten million tons of the nodules, would be about $300,000. The costs of such a program, however, can vary greatly depending on the specifications for sample-point spacing.

Off the south coast of Mexico 100 miles there is quite a high concentration of large nodules--approximately 300,000 tons per square mile at a depth of about 12,000 feet. About 1,000 miles southeast of Hawaii in 15,000 feet of water there are perhaps 15,000 tons of nodules per square mile. About 500 miles northeast of New Zealand, there is an area of what one might call 100-percent concentration--the nodules are practically touching one another. We can sample the deposits or dredge approximately 500-ton lots for process development work; the nodules have been dredged with this type of technique for the past 10 years. A larger system is the 8-ton bucket we were using to depths of 20,000 feet. And some of the techniques we developed 15 years ago were so good that we are still using them.

At the present time, a conservative estimate indicates that there are some several hundred billion tons of mineable nodules in the high-grade areas of the Pacific Ocean. The highest grade of nodules yet discovered and reported is found in a deposit about 1,000 miles north of Samoa. Nodules from this deposit will assay about 1.9 percent nickel, 2.3 percent copper, 0.2 percent cobalt and 36 percent manganese on a dry-weight basis. Deposits of the nodules can be found in other areas of the ocean which assay as high as 2.6 percent cobalt or 55 percent manganese. In general, the chemical composition of the nodules is very uniform over large lateral distances of the Pacific; however, the concentration of the nodules can vary markedly throughout any given deposit. The highest concentration of nodules, excluding the crustal deposits, presently known is about 100 kilograms per square meter of sea floor which would work out to about 300,000 tons per square mile. An average concentration in a deposit considered for mining would probably be in the range of 30,000 to 75,000 tons per square mile of sea floor. In general, the average size of the nodules is about 4 centimeters; however, within a given deposit, this size range may vary from 1 to 20 centimeters.

We have taken pictures of boulders on the ocean floor that must be 10 feet in diameter and look like nodules, but they are probably outcrops of hard rock and have just a crust on them. The largest nodule that I have ever known to have been dredged came up in a tangle of telegraph cable and was about 4 feet in diameter. The upper range of the size of the nodules is very highly biased by the opening of the dredge bucket that we use. The biggest dredge bucket I know of that has been put on the ocean floor is a 20-ton bucket that was used to retrieve nodules as big as a desk. I suppose they get larger, but nothing larger will go into the bucket.

At the present time, potential nodule mining companies are interested only in the monolayer of nodules at the surface of the sea-floor sediments. Although nodule beds can be found at a number of horizons down in the sediment column, it is not thought that it would be economic to mine and process the gangue sediments to secure the nodules buried in the sediments. The fact that the nodule deposits exist only as a thin superficial monolayer measurably complicates the design of an effective mining system as very large areas of the ocean floor must be swept over to allow recovery of the nodules at economic production rates. Although it is possible that the nodules may be piled up in depth in some areas of the ocean floor, generally the devices used to sample the sea-floor nodule deposits would not disclose this fact. If such deposits had been found initially, the mining of the nodules would have been an accomplished fact many years ago. Also, it is not thought possible to mine the crustal manganese deposits of the sea floor due to the difficulties of breaking these crusts free from their solid attachment to seafloor bedrocks. Figures 2 and 3 show typical deposits of the nodules which would be considered economic for mining.

Although deposits of manganese nodules can be found in almost all depths of water in the ocean (they can be found in 6 feet of water in some Scottish Lochs), only those deposits lying below about 3,000 meters are presently being considered as economic to mine. The higher-grade nodules are generally found at depths ranging from 4,000 to 6,000 meters.

On a Pacific Ocean-wide basis, it has been estimated that there are some 1.5 trillion tons of the nodules presently at the surface of the seafloor sediments and that the nodules are forming in this ocean at the rate of about 10 million tons per year. An interesting calculation indicates that many of the industrially useful metals are accumulating in the nodules

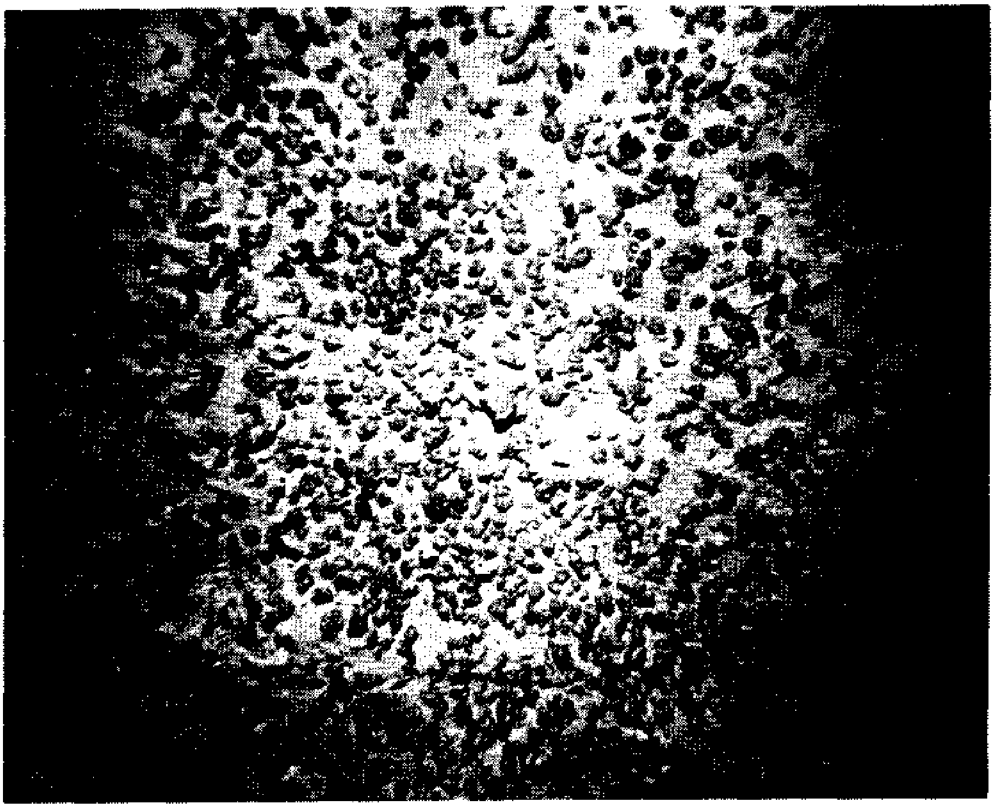


Figure 2. Sea-floor photograph showing a concentration of about 30,000 tons of nodules per square mile of sea floor at N 19° 57', W 126° 06'.

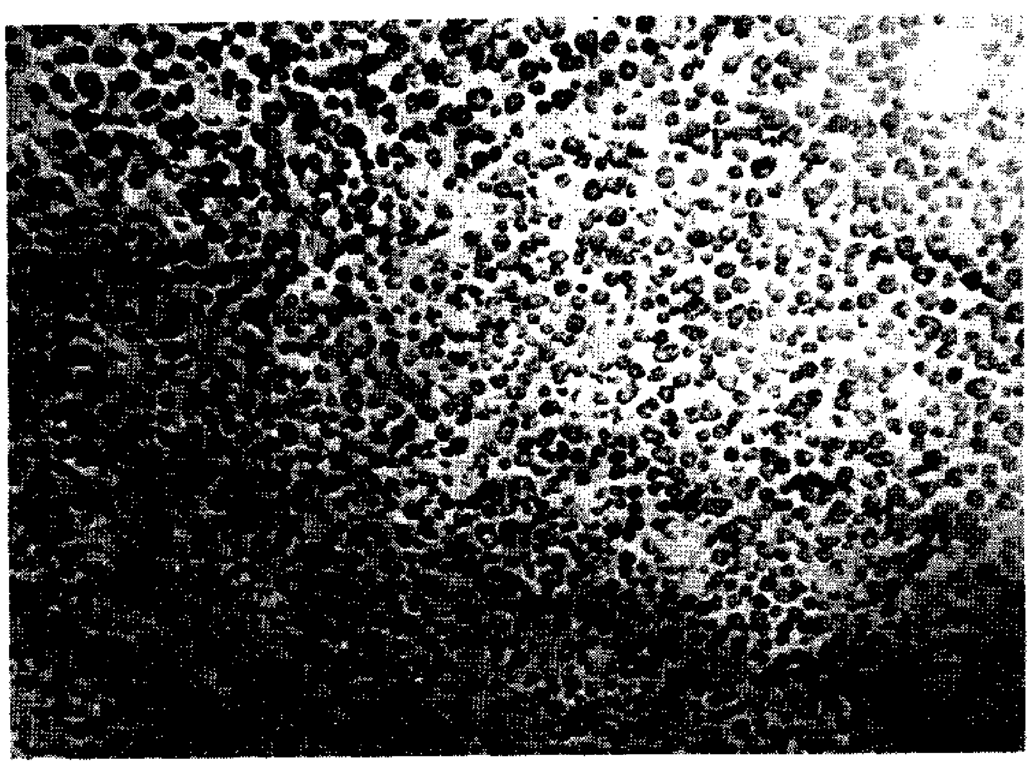


Figure 3. Sea-floor photograph showing a concentration of about 45,000 tons of nodules per square mile of sea floor at 3,695 meters about 250 miles north of Tahiti. It was in this deposit of nodules that the test of the CLB system of deep sea dredging was conducted.

at rates which exceed the present world consumption of these metals, so once the nodules are being mined the mining industry would be faced with the interesting problem of working a deposit which forms at rates greater than it can be mined. Generally, on land, mineral deposits are considered as depleting resources, but in the ocean we find that many of the mineral deposits of economic value, including deposits other than just manganese nodules, are actually forming at the present time at rates which greatly exceed present world consumption of those minerals. This observation, of course, is of academic value only, as the present reserves of metals in the existing deposits would supply the world population for thousands of years even at per-capita consumption levels of those in the highly developed nations of the world. And, of course, one of the major advantages in considering the nodule deposits of the ocean as a source of industrial metals is that they are open to any nation or population of the world that might wish to recover them. Continental mineral deposits, in a number of cases, are closed off to all but a handful of potential consumers.

Deep-Sea Nodule Mining Systems

Although numerous systems have been conceived for the recovery of nodules from the ocean floor, only two appear to have merit from an economic standpoint. The hydraulic system generally consists of a length of pipe which is suspended from a surface float or vessel; a gathering head, designed to collect and winnow the nodules from the surface sediments and feed them to the bottom of the pipeline while rejecting oversized material; and some means of causing the water inside the pipeline to flow upward with sufficient velocity to suck the nodules into the system and transport them to the surface. The two power means for hydraulic dredges presently considered are conventional centrifugal dredge pumps and air-lift pumps. In 1970 one company successfully tested an air-lift dredge in the Blake Plateau nodule deposit in about 2,500 feet of water. At the present time another company has a full-scale air-lift system under construction, which system is expected to be operational sometime in 1973. Generally, the hydraulic systems are quite complicated and, thus, expensive. Capital investments in systems presently being planned or under construction range from about $30 million to about $60 million for systems capable of recovering about one million tons of the nodules per year from depths as great as 18,000 feet of water. The estimated operating costs of these systems range from about $10 to $20

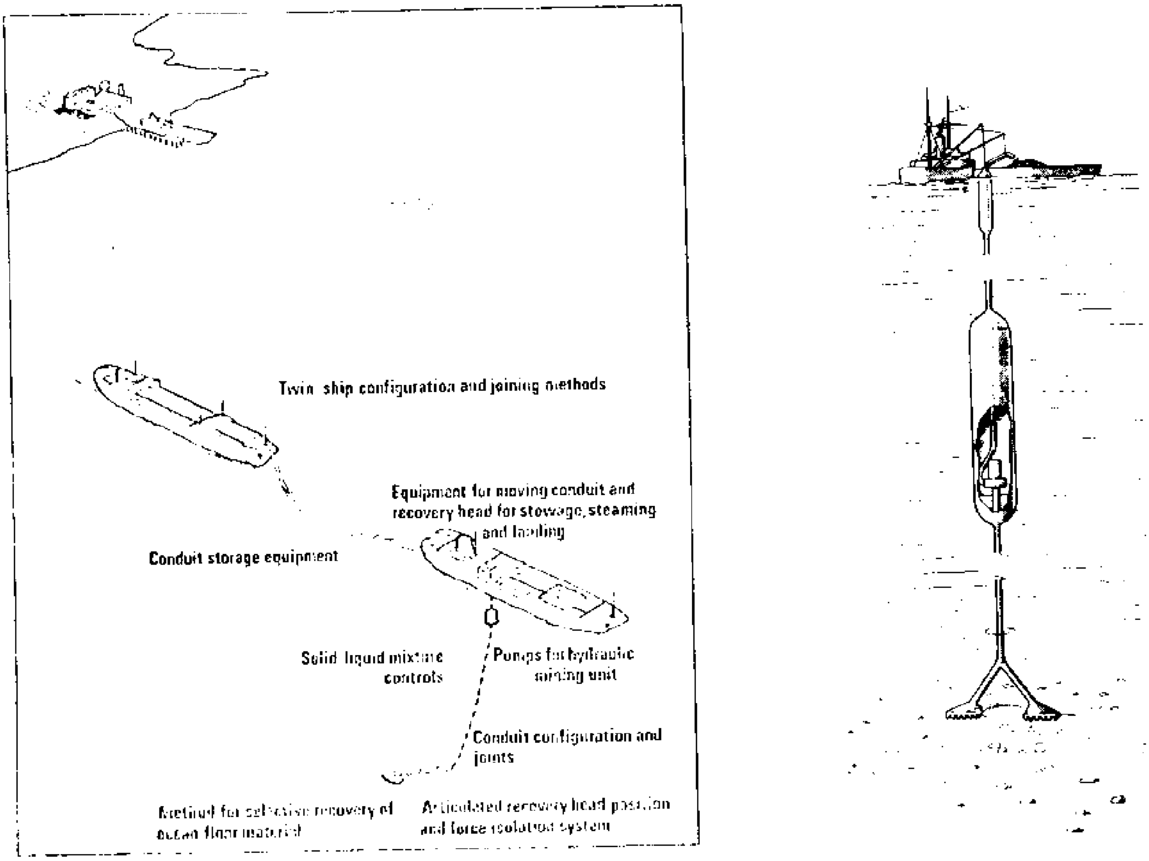


Figure 4. Two of the hydraulic systems proposed for mining the sea-floor nodules. The system on the left is proposed by Deepsea Ventures, Inc., and is powered by an air-lift pump. The system on the right is proposed by the author and is powered by a centrifugal dredge pump submerged to about 15 percent of the depth of dredging.

per ton of nodules produced at the surface of the ocean. Two of these systems are illustrated in Figure 4.

The second type of system presently being planned for full-scale production of the nodules is a mechanical, Cable Line Bucket (CLB) system which consists essentially of a loop of cable to which is attached dredge buckets at 25- to 50-meter intervals and a traction machine on the surface vessel capable of moving the cable such that the buckets descend to the ocean floor along one side of the loop, skim over the bottom filling with nodules along the bottom side of the loop and return to

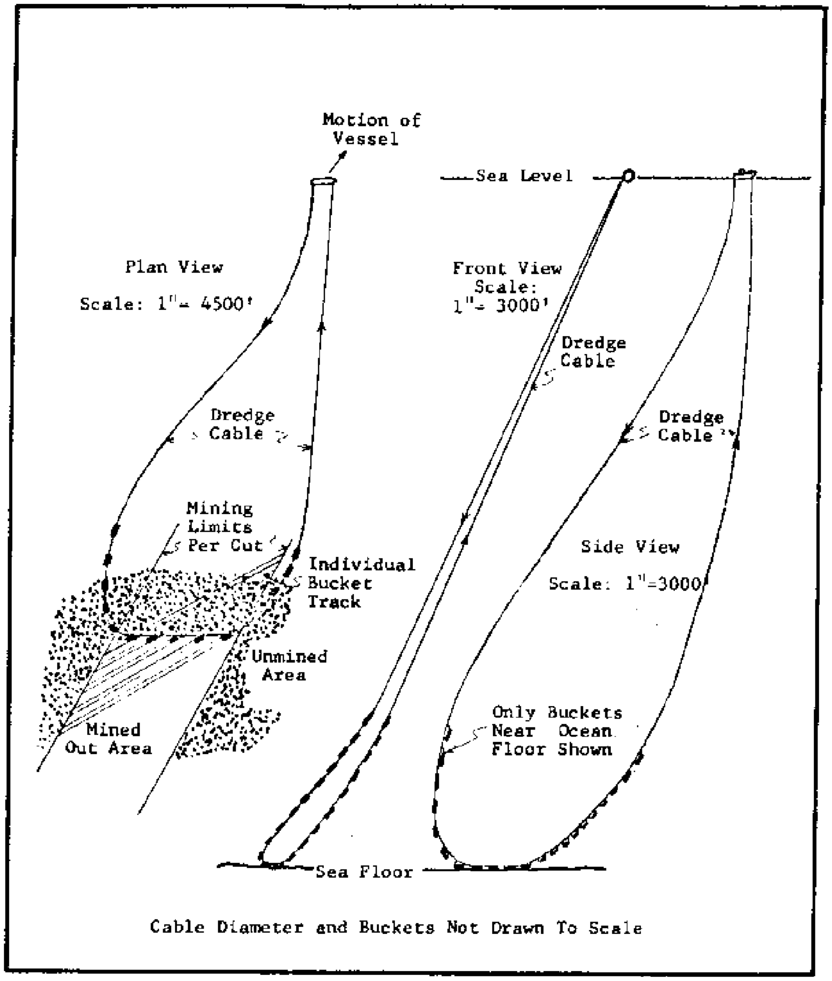


Figure 5. Schematic drawing illustrating the design and operation of the Continuous Line Bucket System for mining deep ocean nodule deposits as proposed by Yoshio Masuda. A successful pilot test of this system was conducted in over 12,000 ft (3,650 m) of water north of Tahiti in the summer of 1970.

the surface on the third side of the loop. This system of dredging is illustrated in Figure 5. Thus far this system of recovering the nodules has been successfully proven in a series of tests which culminated in a test in over 12,000 feet of water a little over a year ago in a deposit of the nodules lying about 250 miles north of Tahiti. At the present time program is underway to test this system on a full-scale production basis during the summer of 1972.

Because of the great simplicity of this system, problems in operating it are relatively minor and the capital costs of the system are relatively low, in the order of $2.5 million for a system, exclusive of the cost of a surface vessel, which can recover about three million tons of the nodules per year from any depth of water. The estimated operating costs of this system, including the cost of chartering a surface vessel, as this system can be mounted on practically any type of vessel capable of transiting the open ocean and of carrying a total load of about 1,000 tons, are about $0.50 per ton of nodules recovered. In addition to being an extremely simple system, the CLB system incorporates a very high degree of flexibility in being able to work in deposits of the nodules of any size range, over relatively great sea floor topographic reliefs and in a range of sediment bearing strengths and characteristics. A given CLB system can be easily modified to operate in any depth of water and all parts of the system are surfaced several times a day for inspection and repair. Also, all complicated components of the system are located aboard the surface vessel for ease of inspection and repair. No measurable pollution of the ocean will be created by the use of this system as it is possible to skim the nodules from the sea floor without disturbing the sediments to any degree.

Processing of the Nodules to Salable Products

The sea-floor nodules can be reduced to salable nickel, cobalt and copper metals or manganese ore by a number of standard industrial techniques. Generally, these techniques involve the dissolution of all valuable metals in the nodules and the differential precipitation or separation of the metals from solution. These processes generally lead to high plant capital costs, in the order of $50 to $100 per annual ton of nodule capacity, and high operating costs, in the order of $20 to $30 per ton of nodules processed. Rather high recovery efficiencies, however, can be achieved with these processes, in the order of 90 to 95 percent of the contained metals in the nodules.

Because of the unique chemical structure of the nodules, with the bulk of the copper, nickel and cobalt metals being contained therein as ions loosely attached to the surfaces of the manganese and iron hydroxide minerals, it has been found possible, not only to leach differentially these metals from the nodules, but to do it in a way which prevents any appreciable amount of the manganese or iron from going into solution. Such a process, which has been discovered and developed at the University of California at Berkeley, and which can be essentially similar to oxide heap leaching processes, leads to very low process plant capital costs and operating costs. With such a process the plant capital costs can be expected to be in the range of about $10 to $20 per annual ton of nodule capacity and the operating costs would be in the range of $5 to $10 per ton of nodules handled. While recovery efficiencies with this differential leaching process are comparatively low, in the order of 60 to 80 percent of the contained metals, it does minimize capital investment and maximize return on investment.

Overall Economics of Mining and Processing Sea Floor Nodules

The use of a hydraulic system to mine the nodules, because it is designed to operate at high capacities, in general indicates a total overall capital investment in the mining system of at least $30 million. Coupled with a differential precipitation process for processing, which would indicate a process plant investment cost of about $75 to $100 million to handle one million tons of the nodules per year, the total capital investment of such a nodule mining and processing system can be expected to be at least $135 million. Such a venture could produce about $67 million worth of products annually operating at an overall recovery efficiency of 90 percent and assuming the manganese-iron by-product left over after the other metals are removed is acceptable as a metallurgical-grade manganese ore. The cost of operating this system is estimated at about $39.3 million per year, yielding a gross operating profit of about $27.7 million per year and allowing a gross rate of return on investment of about 21 percent per year. Such a system would be essentially competitive with land mining operations to produce these metals.

The use of the CLB system of mining, coupled with a differential leaching process, to produce the nodules at a rate of one million tons per year would appear to involve a total capital investment in mining and processing facilities of about $20 million. This operation would produce about $52.1 million per year worth of products operating at an overall recovery efficiency of 70 percent. The operating costs of this system are estimated at about $18.3 million per year yielding a gross operating profit of $33.8 million per year for a 169 percent per year rate of return on investment. Some of the statistics of such operations are shown in Table I. As indicated in Table I, the cost of handling the manganese-iron portion of the nodules would appear to be somewhat greater than the value of the product produced. This indicates that there would be a substantial gain in the profitability of the venture if the copper-nickel-cobalt metals could be taken from the nodules on shipboard at the mining site and the remainder of the nodules returned to the sea floor to seed the mined out areas for formation of nodules for future generations.

The economics of any venture to mine and process the deep-sea nodules, of course, can be measurably improved by increasing the scale of the operation and by producing some of the other metals found in the nodules such as molybdenum, lead, zinc, zirconium, cerium, etc. Eventually, I would imagine that all of these metals and several more will be produced from the nodules. The initiation of production of metals from the nodules, of course, will signal the end of mining land deposits for these metals unless political interference prevents the closing of such mines.

Also, it would appear that initially, the mining of metals from the deep ocean will be a tax-free situation as the mining and processing facility can easily be set up in one of a number of tax-free nations. Companies from high-tax nations, thus, would simply be factored out of ocean mining of the nodules as they would not be competitive if they were forced to continue paying their high tax rates.

As a source of revenues for developing nations of the world, the manganese nodules will never meet expectations for the total revenues generated from such operations. Even if present land-derived metal prices were maintained for ocean products, this would not provide more than a few cents per capita for the people of the less developed nations of the world. Some persons multiply the total tonnage of the nodules presently speculated to be at the surface of the sea floor sediments by the \$50 to \$100 per ton of metals which can be won from the nodules and arrive at a grand figure of several hundred trillions of dollars which they assume is available for the gathering. It is an illusion, of course, and best dispelled as soon as possible. The developing nations will stand to gain infinitely more by the availability to them of markedly less costly basic materials produced by themselves.

Table I. Overall Economics of Two Sea-Floor Nodule Mining Systems. [1]

ITEM	Hydraulic System Capital Costs ($)	Hydraulic System Operation Costs ($/Y)	CLB System Capital Costs ($)	CLB System Operation Costs ($/Y)
1) Preliminary Investigations:	1.0[2]	-	0.1	-
2) Nodule Deposit Exploration:	0.3	0.3	0.3	0.3
3) Mining System:	30.0	10.0	2.0	2.0
4) Process System (Diff. Ppt. Process)	75.0	20.0	-	-
Process System (Diff. Leaching Pro.)	-	-	10.0	10.0
5) Transport of Nodules (Assuming Chartered Vessels and a 4,000 Mile Roundtrip, Deposit to Process Site):	-	4.0	-	4.0
6) Operating Capital and Misc. Costs:	28.7	5.0	7.6	2.0
Total Estimated Capital + Operating Costs:	135.0	39.3	20.0	18.3

		Hydraulic System	CLB System
Value of Products Recovered[3]	($/Y)	67.0	52.1
Gross Net Operating Profit:	($/Y)	27.7	33.8
Gross Rate of Return on Inv.:	(%/Y)	21	169
Cost Per Pound of Co, Ni, and Cu Metals Produced:	($/#)	0.23	0.12
Cost Per Ton of Mn-Fe Ore Produced:[4]	($/T)	84.50	45.80

(1) On a basis of one million dry weight tons of nodules per year assaying 40% Mn+Fe, 0.2% Co, 1.6% Ni and 1.4% Cu.

(2) $ and $/Y figures quoted in millions of dollars.

(3) Assuming process recovery efficiencies of 90% for the differential precipitation process and 70% for the differential leaching process. Mn-Fe in nodules assumed to be produced in the form of a manganese ore valued at about $35/ton. Value of other products assumed at $2/# for cobalt, $1.20/# for nickel, and $0.50/# for copper.

(4) Production costs distributed: Co+Ni+Cu - 30%; Mn+Fe ore - 70%.

The total potential economic value of the nodules in the ocean, of course, can be calculated, but it would be a meaningless value for once full-scale production of metals from the nodules is achieved, the markets and prices for the metals will change markedly with the prices to the consumer falling greatly and the markets expanding greatly. With low-cost nickel, industry would be able to use stainless steels in place of carbon steels for automobiles and structures with a great gain in overall metal utilization efficiency due to the corrosion resistance of this material.

Stated simply, the manganese nodules of the deep sea represent an apparently less expensive source and an essentially inexhaustable source of a host of important industrial metals for all populations of the world. They also represent a new and exciting investment opportunity which will not last more than a few years after initial production of metals from the nodules is achieved. They will, of course, also represent a means of measurably reducing pollution of the atmosphere by permitting the closing down of many pollution-prone land-based sulphide mines and possibly, by use of the nodules for the removal of sulphur dioxide from power-plant stack gases, thereby permitting the power companies to burn cheaper high-sulphur fuels. Because of the very high surface areas of the nodules, in the range of 100 to 300 square meters per gram of nodule material, and because of the highly reactive surfaces, the nodules may also prove important as general catalytic agents in such applications as converting unburned hydrocarbons in automobile exhausts, a prime cause of smog, to harmless carbon dioxide.

In a grander sense, the nodules may be the means for the formation of an effective world government as all the nations of the world may eventually be forced to get together in some kind of an agreement if they wish to secure tax and royalty funds from production of metals from the nodules. But I do not see that happening for many, many years as the nodules, at the present time simply do not represent a substantial enough source of income for the nations to worry about.

But in the final analysis, the deep-sea nodules represent a new challenge for the natural resource producers of the world to provide the world population with less expensive and pollution-free materials through which a higher measure of material life can be achieved. In this process everyone will gain.

JAPANESE PROGRAMS FOR MANGANESE NODULE EXPLOITATION

By
Yoshio Masuda
Oceanographic Unit, Japan Maritime Self-Defense Force
Tokyo, Japan

NEED FOR MANGANESE NODULES IN JAPAN

Japan is an island country, and its limited land resources cannot house its rapidly growing industry. Table 1 compares world copper and nickel consumption in 1960, 1965, and 1969, and Table 2 shows the growth rate by country from 1964 to 1968. The need for copper and nickel has increased in Japan; nickel consumption has grown about 3.9 times in the past nine years.

Table 1 World Consumption of Copper and Nickel: 1960, 1965, 1969

Metal	1960 (tons 10,000)	1965 (tons 10,000)	1969 (tons 10,000)	Growth Rate (1960-1969) (Percent)
Copper	320	433	807	10.8
Nickel	20	28	78	16.3

Most of Japan's copper and copper ore is imported, and all of her nickel and nickel ore is imported. For example, about 2.7 million tons of nickel ore was imported from New Caledonia Island in 1969. While nickel content in ore has decreased, the price has increased.

In examining future nickel, copper, cobalt, and manganese resources, deep-sea nodules have great potential interest to Japan, and Hawaii is nearer to Japan than is New Caledonia. Manganese nodules can absorb a great amount of sulfer dioxide, nitrous oxide, etc.--this was found by an American study. I requested the data, and discovered that they can be very effective in controlling gas pollution. Japanese industry produces severe pollution in Japan, power plants, especially, use oil

Table 2 Copper and Nickel Growth Rates by Country, 1964 to 1968

Country	Copper			Nickel		
	1964 (tons 1000)	1968 (tons 1000)	Growth Rate (percent)	1964 (tons 1000)	1968 (tons 1000)	Growth Rate (percent)
USA	1,825	1,872	9.6	133	145	2.2
Japan	504	785	11.7	31	58	16.9
W. Germany	631	671	1.5	25	35	8.8
England	698	594	----	38	33	----
France	321	323	0.2	21	31	10.2
Italy	223	249	2.8	8	14	15.0
Canada	202	253	5.8	6	9	10.7
USSR	816	948	3.8	100	90	----
TOTAL	6,526	7,041	1.9	389	460	4.3

which is rich in sulfer. It is required to provide anti-pollution machinery, but it is still difficult to find an inexpensive and effective method.

Thus deep sea nodules will be of interest to Japan not only for metal resources, but also as anti-pollution material.

STUDY IN JAPAN

American studies of deep sea nodules have had a great influence on Japan. I heard from a U.S. Navy Lt. Babic about a continuous-line bucket (CLB) system as a recovery system. It is very simple, and has been tested in a watertank, the shallow sea, and the deep sea. After a 1,410-meter test by a Japanese university ship, a study team visited the United States under the guidance of Dr. John Mero of Ocean Resources, Inc., La Jolla, California. This proved very valuable for Japanese companies, and they organized a test near Tahiti using a 1,300-ton ship. The test was successful, and the CLB functioned successfully in 3,765 meters (12,000 feet).

In this test, Michael J. Cruickshank of the Marine Research Laboratory, Madison, Wisconsin, John Mero, and M. Gauthier, CNEXO/France, were aboard with the Japanese study group. These friends supported me and organized the next big test near Hawaii. I cannot describe this because of restrictions, but many nations worked as friends to successfully complete a deep-sea test. I believe this is very significant. Many Japanese companies want to develop the CLB in coordination and cooperation with other nations having a strong interest in deep-sea resources.

In Japan, merchant marine, nickel, iron, fishing, shipyards, and motor and rope companies are the main companies having an interest in this study. Of course, the Japanese government has an interest, but it has not been very active. Some study funds were supplied for the Tahiti test, but the CLB test itself was supported by many companies. The Japanese government is building a fine survey ship for nodule deposit surveys.

FUTURE STUDIES

It is my opinion that manganese nodules will be successfully mined in two to three years. Other scientists have estimated ten years; but new techniques may develop before the scientists' estimate; this is a common occurrence in science. Of course, hard study, work, and friendly support are prerequisites. I expect Hawaii to play a large role because it is the center of the Pacific, and the greatest benefit and interest will be given to Hawaii.

The deep-sea floor is flat and wide, and nodule resources are on the seafloor rather than under it. The 5000-meter depth is not as far as the moon: it is just 4 hours for a man walking. A CLB is one kind of conveyor. We used this conveyor between the sea surface and the seafloor, and it was easy to carry nodules to the sea surface after some improvements were made.

Dr. Mero estimated that it would cost only $5 per ton for the CLB to dredge nodules. I do not know the details of his calculation but my estimation is that it will be more expensive. If we were to dredge from 500-1000 tons of nodules per day from 5,000 meters using a 20,000-ton Japanese ship, daily costs would be:

Ship charter	$ 5,000.
CLB ($1 million; 3 year depreciation)	1,000.
Other fees	2,000.
TOTAL	$ 8,000. per day

If it takes two days to collect 1,000 tons including transportation and contingency days, it will be $16 per ton; thus our current cost estimate is $15 to $30 per ton. Of course, it will be much less expensive when deposits are near port facilities and are shallower, such as those near the island of Kauai, and the cost of the CLB will decrease with increased production. But my opinion is that 1,000 tons per day will be acceptable for Japanese industry, because ore prices are higher in Japan than in the United States due to the shortage of resources. From 2,000 to 3,000 tons per day may be possible in the future.

At the present time values of nickel, cobalt, copper, etc., will be higher than $20 to $30 per ton in the Japanese harbor, and nodule processing is much easier than processing of other ores. Also, the anti-pollution effort has the value of $30 per ton in addition to the metal resources. (This is based on 50-tons-a-day nodule consumption per 5 million kilowatt hours (per day) and 0.1 yen per kilowatt hour of anti-pollution fees from the electric company. It is also based on data from an American study.)

Nodule dredging as a future business will be attractive and will be beneficial to developers.

I would expecially like to emphasize one need in the nodule-supply business. One line dredging was the only way to get samples from the deep sea until recently, so the nodule supply was limited in amount, and we could not test nodules in large quantities. (The price is high: $20,000 per ton.) In Japan, several companies want to do some scale tests on the processing of nodules, but the nodule supply is limited. On the other hand, the CLB must undergo long-term tests and improvements. Many new patents, experience, and knowledge will be owned by developers.

Hawaii is the center of the Pacific, and test ships will visit it often. Some companies may begin their nodule supply businesses with a great pioneering spirit. Please support the pioneer spirit for the future of Pacific Ocean Development.

JAPANESE PROGRAMS IN MANGANESE NODULE EXPLOITATION

Survey Objectives

Build a new survey ship by 1973.
Conduct a nodule survey by that ship beginning in 1974.

CLB Machine

Reconstruct the CLB and test it in cooperation with other interested countries: 1972-1974.

Processing Test

Test processing in some scale - 1972-1975.
Test anti-pollution in some scale - no proposed schedule.

In order to accomplish this program, the Japanese will do their best to coordinate and cooperate with other countries.

LAND-BASE REQUIREMENTS FOR DEEP-OCEAN MANGANESE NODULE MINING

By
Raymond Kaufman
Deepsea Ventures, Inc.
Gloucester Point, Virginia

It is a pleasure to be here in Hawaii to discuss land-base requirements for deep-ocean manganese nodule mining. Land-base needs are very closely related to site selection; that is, determining the most economical location of the nodule processing plant support activities. Key considerations of site selection today are the availability of energy and the need to provide for effective environmental protection. These two items are the principal driving forces associated with the location of all large chemical plants in these times. This will include the plant needed to extract the metals contained in manganese nodules since it will probably be a large chemical processing facility.

In order to provide a proper frame of reference, the principal elements of the entire ocean mining operation, shown in Figure 1 will be briefly reviewed.

<u>ELEMENTS OF AN OCEAN MINING OPERATION</u>

- MINE SITE AND ORE BODY
- MINING MACHINE(S) AND VESSEL(S)
- OCEAN TRANSPORT - ORE; PRODUCT
- LAND TRANSPORT - ORE; PRODUCT
- PROCESS PLANT - SEA; LAND
- LOGISTICS SUPPORT
- ADMINISTRATIVE SUPPORT - MARKETING
- RESEARCH & EXPLORATION

FIGURE 1

The principal elements of an ocean mining operation include first a mine site and an ore body. We have heard, in other presentations, about the distribution of the nodules in the Pacific Ocean and the allusion to the large quantities of nodules found therein. But, just because the nodules are there does not mean that they represent an ore body. From the miners' viewpoint, a great deal of effort and information is required before a deposit or occurrence can be considered an ore body. At this early stage in the development of the resource, we believe that according to data published by the scientific community there are not as many mine sites or ore bodies available as has been assumed. The next element is the mining system. The mining machine gathers and collects the nodules and brings them to the sea surface from the sea floor. The ocean transport elements carry the ore to shore from the mine site. Also because of the large quantities of products which are extracted, and which will undoubtedly be marketed worldwide, ocean transportation of the product will be required. Land transport is another major element. If the plant is located in the continental United States, large quantities of ore may be transported by land from a marine terminal to the plant site. In addition, portions of the products will have to be distributed to markets by land transport modes.

The process plant is needed to beneficiate and refine the ore. There are many approaches to nodule ore processing including location of the plant at sea on a ship or floating platform. The natural location for the initial plant at least is on land, and we believe that the first nodule plants will be located on shore.

Logistics support is another major item. A large marine-chemical plant operation will require a major back-up support complex including the logistics support for the ocean mining operation and the process plant. This must be complimented by administrative support functions and product marketing. Finally research and exploration must constantly be in progress--research in process development and exploration to find better mining sites.

The principal land elements are shown on Figure 2 and include a marine terminal, the mining operation supply system, the process plant, and associated administrative support. Each one of these elements will be discussed in further detail.

LAND ELEMENTS
• MARINE TERMINAL
• MINING OPERATION SUPPLY
• PROCESS PLANT
• ADMINISTRATIVE SUPPORT

FIGURE 2

The marine terminal will be examined first by referring to Figure 3.

MARINE TERMINAL
• DEEP WATER
• LAND
• ORE UNLOADING & STACKING
• MINING SHIP FUEL/WATER
• PRODUCT TRANSPORTATION
• REAGENT DELIVERY

FIGURE 3

For a large-scale operation which contemplates mining at least a million tons of nodules a year (as if nodules are to be brought to shore for processing, the size ships that are required to do this economically, will range between 35,000 to 60,000 tons deadweight. These ships require draughts of from 35 to 40 feet full load, and perhaps will be between 600 and 700 feet in length. Therefore, a deep-water port will be required. This is not the same type of deep-water port that is needed by the new super tankers (LCC) to transport petroleum. Ports with water depths of up to 40 feet are available in many areas throughout the United States. There are not, however, enough of them on the mainland or in Hawaii to provide maximum flexibility needed in site selection. The decision of where to locate the marine terminal is of major importance and each candidate must provide the complete facilities needed to handle the large ships contemplated. To permit an understanding of what the traffic might be for such a deep-water port for one processing plant, and assuming the terminal is in the State of Hawaii, the following example is provided. The round trip to the mine site might be 3,000 miles. We can say that a one-million-ton-a-year operation will require 20 round trips a year per 50,000-ton ship. Assuming 12 days per round trip, this means that one ship can handle the operation and it would be coming to port about once every two weeks to unload the unprocessed nodules for a one-million-ton-per-year operation. For two-, three-, and four-million-ton-per-year operations, the traffic would increase proportionately. The marine terminal requires a fairly large waterfront and pier facility and also land facilities for stacking and storing the nodules as they are unloaded from the ore carrier. Included at the facility will be some type of large, high-capacity unloading equipment for handling the ore. The ocean mining company may elect to build its own private marine terminal, depending upon the quantity of material handled. If there is enough nodule ore to keep the terminal occupied on a dedicated basis, then the ocean mining company might include the construction and operation of the terminal in its system. On the other hand, if it is just a one-ship operation, a municipal or public bulk unloading terminal may be sufficient. The process plant is best located adjacent to the marine terminal to reduce land transportation distances and costs. Indications are that for the size plant which will be needed, the land requirement will range between 100 and 300 acres. The required unloading capacities at the terminal will be in the 2,000 to 3,000 ton-per-hour range, which is within the state of the art for unloading bulk commodities.

The mining ship will be operating at sea, undoubtedly all year around, and will have to be refueled at sea. The refueling can be accomplished from the ore transport ship by carrying fuel out to the mining ship. As the transfer of nodules or ore takes place, the mining ship is simultaneously replenished with fuel. Refueling needs for the mining ship may require the installation of appropriate oil-storage capacity at the marine terminal. This might be on the order of perhaps 40,000 to 100,000 tons per year of fuel oil and will require a small fuel oil tank farm. Also if some type of washing or separation of nodules is accomplished on the mining ship, fresh water may have to be taken out to the mining ship. The evaporating capacity of the mining ship may not be large enough to provide the needed fresh water.

A study of product transportation needs indicate that a large percentage of the metals produced, particularly if produced in the Hawaiian Islands will be transported to market by sea. For a plant processing one million tons of dry nodules per year, for example, we can have approximately 250,000 tons of manganese, 12,000 tons of nickel, 10,000 tons of copper, and 2,300 tons of cobalt produced. The marine terminal, if adjacent to the plant, can provide convenient dockage for the product transport ships.

Associated with the plant and with the marine terminal is the delivery of required reagents. These will be needed to operate the chemical process plant. There are many basic processing approaches for the extraction of the metals contained in the ore: hydrometallurgical, pyrometallurgical, etc. Each in turn will require several types of special reagents. The availability of reagents locally is of major importance in site selection. In the State of Hawaii, unfortunately, most of the needed reagents are not readily available.

The next segment of the land operation, as shown in Figure 4, is the supply base.

SUPPLY BASE - MINING OPERATIONS

- PIER AND DOCKS
- OFFICE--PORT CAPTAIN AND STAFF
- WAREHOUSE--SPARES, SUPPLIES, ETC.
- SUPPLY SHIP/CREW BOAT
- SURVEY SHIP

FIGURE 4

Once the mining operation is underway at sea, a base for support of the marine operation will undoubtedly be required. This base need not be located at the marine terminal or at the plant site. The principal elements include piers and docks for a supply ship. The supply ship will transport personnel to and from the mining ship for changeover of operation personnel, and also will transport the required stores and spares. In addition, space ashore will be needed for the Port Captain and his staff and for large warehouse facilities for repair parts and supplies for the mining ship. A fairly high-speed crew boat will probably be needed to transport the personnel. Possibly accompanying the mining ship will be a survey ship, needed to delineate the mine site incrementally as the mining will take place over many years.

The essential elements of the process plant are shown in Figure 5.

PROCESS PLANT

- LAND - STOCKPILE, PLANT, STORAGE
- PLANT CONSTRUCTION - MATERIALS, COST
- ENERGY - ELECTRICITY, GAS, OIL
- WATER
- REAGENTS
- LABOR
- WASTE DISPOSAL

FIGURE 5

As discussed previously a large tract of land will be required. It is hoped that this may be available in the State of Hawaii. In response to an earlier inquiry, it was indicated that land associated with the deep-water port may be available on the Island of Hawaii. An important question of course is how much and at what price? The land requirements depend upon the size of the plant; i.e., the quantity of nodules to be processed and land needs can be between 100 to 300 acres or more.

Major factors that must be evaluated in site location analysis include the local cost of plant construction and materials. This information will be needed by an ocean mining company in conducting its site selection study. The availability of this information from State representatives would be very helpful in evaluating siting a plant in the State of Hawaii. Electrical energy capacity for a nodule processing plant can be on the order of from 50 to 200 megawatts, depending upon size and type of plant; i.e. the tons of nodules to be processed and the type of process selected. The possible availability of geothermal energy on the Island of Hawaii sounds very exciting and may be a way whereby Hawaii could provide clean energy at prices comparable to fossil-fuel produced electrical energy now available on the mainland. Other energy or reagent requirements may include gas and oil or coal. The process plant will also require water. Large quantities of water will be needed for process and cooling uses. Process water probably can be recirculated. Depending upon the process used, cooling water requirements can be anywhere from 300,000 to 600,000 tons per day. Depending on the process used, reagents can include acids, caustics, chemicals and salt (brine). The brine requirement may be satisfied in conjunction with a geothermal plant. Brine, a potential waste of a geothermal plant, could be useful as a reagent for the process plant. Labor requirements will include construction labor and operational labor. For a plant located in Hawaii, it is expected that the major skills are available to build a complex chemical plant. However, labor costs are known to be high. This type of information will also have to be provided for evaluation of a potential site located in Hawaii.

Another very important item is waste disposal. From an environmental point of view the use of a chemical process for extracting the metal values in the nodules will be very beneficial because it can be designed to recycle reagents. Anticipated discharges into the atmosphere--water vapor and carbon dioxide--are not considered to be pollutants. If liquid waste is produced, it will be sufficiently clean to permit harmless discharge into the ocean. However, the question of solid-waste disposal is going to be critical. For instance, 100 pounds of dry nodules which are to be processed only for copper and nickel, will contain approximately one pound of gas and water vapor, about 3 pounds of product and about 96 pounds of solid waste. This means that in a million tons of nodules we can have 960,000 tons of solid waste in need of disposal. To provide a physical feel for this, the amount of material might cover 10 acres 3 to 4 feet high. The solid wastes are oxides and silt, and are very fine--probably 100 to 300 mesh, and may cause a major waste problem. Solid-waste disposal will have to be given very careful thought in planning for the nodule plant. The natural thing of course would be to return the waste to the sea: it came from the sea, and perhaps it can be returned to the sea via the transport ship returning to the mining site. Another approach is to not bring the wastes to the land at all: try, if possible, to leave them in the sea at the mine site by processing at sea. This approach also has many major problems.

On the other hand, a plant that processes the nodules for the manganese as well, is in a slightly better position because once the oxides are removed (in particular the manganese oxide) the resulting residue is primarily clean silt and has water-holding capacity. It probably can be spread out over the lava fields on the Island of Hawaii and in a very short time could be used to cultivate agriculture products. It also could be used in clean land fills. These certainly are viable solutions.

A final item of importance is general and administrative support, as shown in Figure 6. The State and local tax situation must be evaluated. In addition, what sort of helping hand, if any, will the local government give to businesses looking to the siting of plants or bases in the area under its jurisdiction? Other factors include: insurance; labor relations history; wages, (relative wages compared with other areas); cost of living; schools; food; climate; local communications and world-wide communications; and the general attitude of local and State government towards the establishment of an industrial complex in the area.

It is hoped that this brief paper will provide sufficient background for the representatives of the

GENERAL - ADMINISTRATIVE SUPPORT
• TAXES - LOCAL, STATE
• INSURANCE
• LABOR RELATIONS
• WAGE RATES
• COMMUNITY CONSIDERATIONS - COST OF LIVING, SCHOOLS
• CLIMATE
• COMMUNICATIONS
• GOVERNMENT - LOCAL, STATE

FIGURE 6

Hawaii State Department of Economic Planning and Development to understand the onshore needs of a nodule ocean mining company. The location of the operational support base and the process plant in Hawaii are distinct possibilities. I hope that the Department looks at this favorably and as an opportunity and will encourage a complete, or partial ocean mining operation to be established in Hawaii. Transportation costs are a large percentage of the overall operation costs, and the nodules are close by. The future development of marine resources, not only nodules, will eventually stem from this general area of the Pacific.

DINNER SPEECH

Robert Jenkins

ASPECTS OF MINING FROM A HAWAII BASE

By

Robert W. Jenkins
Dillingham Mining Company
Dillingham Corporation
Honolulu, Hawaii

INTRODUCTION

My presentation will cover a subjective review of how ocean mining as previewed for us today appears to a mining engineer who has spent his career in operations. Since most of you are in highly specialized fields (law of the sea, oceanographic engineering, marine biology and other fields) my experience should be of interest to you.

The legal aspects were discussed first today and it might be worth noting that throughout history, laws have generally followed mining rather than by the procedure now being proposed. In fact, mining people (prospectors, miners and other entrepeneurs) have in the past, ignored established governments and local laws. The '49ers invaded California, ignored Spanish laws and set up their own laws, which finally resulted in the U.S. Mining Law of 1872--now being maligned.

It is not likely that free-world enterprises large enough to entertain visions of ocean mining will act like the old '49ers, but on the other hand, our legal friends may find their elbows being jostled when government or private corporations, foreign or domestic, decide there are over-riding economic advantages in ocean mining.

Mr. Kaufman outlined the site requirements for a shore base for ocean mining. It is quite obvious that the site should have sophisticated facilities as well as a reasonable home base for personnel. Harbor facilities for handling large ore-bearing vessels on a quick turn-around schedule are elaborate. Plant facilities would probably resemble a good-sized refinery with stockpiles replacing storage tanks.

A support base and plant such as this for an economically self-supporting operation would be highly visible in Hawaii. We can anticipate that Island ecologists will question the use of Hawaii as an industrial base, particularly if the State must contribute in any way to the project--regardless of the mutual economic advantages.

WHAT IS UNUSUAL ABOUT OCEAN MINING?

The ocean environment is radically different even from existing offshore dredging operations. Depths of 16,000 feet open a new field in control and operating problems. The novelty of the mining problems may be visualized by comparing the ore bodies to be mined with land operations of the same magnitude. The largest open-pit base-metal ore bodies today cover a few hundred acres and are hundreds of feet deep. The ocean deposits are inches thick and tens of thousands of acres in area. It is much easier to stake a claim on land than to define boundaries offshore. Likewise verification of reserves after they have been located and proposed as the basis of a project may also be difficult--not only from the standpoint of repeated location, but also because of a lack of accepted standards for sampling thin deposits.

Because of the remoteness of the mining site, few people will ever know the impact mining has had on the ocean floor. This lack of knowledge will certainly contribute to wildly differing opinions concerning the effects of ocean mining. In the case of Dillingham's mining operations at Ocean Cay in the Bahamas, removal of the mantle of barren aragonite from the coral bottom and release of organic matter from the surface of the oolites by suction dredging has enhanced the growth of the fish population rather than causing the calamaties predicted in published statements. Statements in Scientific American about airlift recirculation of organic materials from the deep ocean floor to make them available to ocean life makes me speculate whether mining fleets may have a problem of interference by fishermen flocking to ocean-mining sites.

Many new opportunities for novel-type metallurgy using solutions, heat, pressure, ion exchange and electrolysis in new combinations will be developed for processing the mined ore. Some interesting developments are sure to follow. Which of these processes will be carried out on board ship and which will be shore-based operationswill have to be determined by each operator. Mining is a syngenetic business; and ocean mining will undoubtedly employ existing techniques and develop new ones.

One interesting aspect of ocean mining is the tendency of each mining company to develop its own equipment, processes, exploration techniques and evaluation criteria. Most major mining ventures activated today have very little novel technical deviations. Larger shovels and trucks, automated processes, and computerized evaluation techniques make good public relations copy, but they represent minor advances. In ocean mining, we have major challenges in every aspect of the ventures--locale, mining theater, extraction and processing equipment. These represent a tremendous technical and financial burden on mining organizations entering this new field.

WHAT IS NOT NEW ABOUT OCEAN MINING?

Risk is the most prominent aspect of mining. Ocean mining has all the operational risks; extraction, concentration, and processing. In addition there are marine risks. It will be interesting to see how these risks are viewed by the financial community as resolved in percent-equity and return-on-investment criteria for future investment.

Mining is a capital-intensive industry, a view of the statistics on industries in the first 500 and second 500 lists, indicate that mining tops the list in relation of capital to revenue with a ratio of $1 in capital to $0.87 in revenue. The figures generally quoted by ocean mining advocates do not satisfy this criteria at this time. This problem can only be resolved by finding higher-grade deposits or by coming up with more net values from the ore processed, by higher recoveries, by more by-products or by more efficient processes.

Mining is an interdisciplinary industry. Ocean mining obviously fits this pattern. In fact, it is difficult to define a mining engineer's scope of work. It is just as difficult to define what mining in the ocean will entail. Base-metal mining generally extracts small quantities from large volumes of ore. The material-handling and waste-disposal quantities are astronomical for an economic size operation. The problems in an ocean environment combined with undefined environmental impact will be of major concern to the industry.

Ocean mining like all modern, large-scale mining, involves large infrastructure expense. Camps, roads, harbors, water supply, and waste disposal, all combine to make their share of the miner's capital equal to or more than the cost of his mining and processing tools.

This is where we Hawaiians come in. Do we want to become involved and help this industry, to really welcome it to our shores, to reduce the infrastructure problems? It will not be done without work and dissension. But considering the long-term potential of the reserves off our shores, we should be able to intelligently work with the key elements of this new branch of mining and build a long-term industry--a sophisticated and essential industry--which will help to diversify our economy. We face the greatest challenge.

SESSION V

Evaluations

Chairman: **Robert D. Gerard**

Speakers: **Oswald Roels**

Burton B. Barnes

Don Overly

ENVIRONMENTAL IMPACT OF TWO MANGANESE NODULE MINING TESTS

By

O. A. Roels#, A. F. Amos*, C. Garside#, K. C. Haines*, T. C. Malone#, A.Z. Paul+, and G. E. Rice*

INTRODUCTION

The proposed mining of manganese nodules from the deep-sea floor has triggered a perhaps unique collaboration among industry, the government and academic institutions to determine the environmental impact of the proposed mining operations before their start. In this way it will be possible to greatly reduce or completely eliminate potential environmental hazards due to the mining operations. This collaboration may lead to the development of mining techniques having such beneficial environmental effects as artificial upwelling.

It is, therefore, of the utmost importance that a very careful study of the environmental impact of projected mining techniques be made, and that adequate baseline information on the physical, chemical and biological environment of potential mining areas be gathered. Our Laboratory has initiated such a study.

This paper discusses (1) a general approach to the study of the environmental impact of deep-sea mining; (2) our observations made during a suction-dredge mining test held in the North Atlantic Ocean (Blake Plateau) in the

---

#Lamont-Doherty Geological Observatory of Columbia University, Palisades, N.Y. 10964 and University Institute of Oceanography, City University of New York, N.Y. 10031.

*Lamont-Doherty Geological Observatory of Columbia University, Palisades, N.Y. 10964.

+Florida State University, Department of Oceanography, Tallahassee, Florida 32306

summer of 1970; and (3) our study of the environmental impact of a continuous line bucket (CLB) dredge mining test held in the Pacific in August-September, 1972.

GENERAL APPROACH TO THE STUDY OF THE ENVIRONMENTAL IMPACT OF DEEP-SEA MINING

The proposed mining of ferromanganese deposits from the deep sea will have a measurable effect on benthic and pelagic environments within the mining areas. As now envisioned, deep-sea mining operations will result in the removal and redistribution of sediments and benthic organisms and, where suction dredging is employed, in the discharge of nutrient-rich, sediment-laden bottom water into the surface layer or at other depths in the water column.

Our research program consists of (1) the establishment of physical, chemical and biological baseline environmental conditions in potential mining areas; (2) the documentation of changes induced in benthic and pelagic ecosystems by deep-sea mining; (3) the elucidation of their underlying mechanisms and implications in relation to current and potential marine resources; (4) the formulation of guidelines for future mining operations which will minimize harmful environmental effects while enhancing the development of potentially beneficial by-products; and (5) the determination of the properties which should be monitored during deep-sea mining to provide the information needed to evaluate the environmental impact of specific mining methods and to devise mitigating measures, if necessary.

The pattern of near-bottom circulation and mixing, and the behavior of "new" water masses formed when bottom water is discharged into overlying water masses will affect local concentrations of organic and inorganic compounds in the water column as well as the distribution and abundance of benthic and pelagic organisms. It will be necessary to determine what changes occur, as well as the time required for the perturbed systems to return to their original state. A time-series study will be undertaken of the following parameters in the mining area:

(1) The character, origin and circulation of the bottom water which is in contact with the manganese pavements.

(2) The volume and dimensions of the transient water masses created by the admixture of bottom water and surface water, and the rate at which these patches lose their identity due to advection and turbulent mixing.

(3) The concentrations of inorganic nutrients, oxygen, trace metals and particulate organic material in the effluent, the alkalinity and the pH of the effluent and receiving waters, their distribution in the discharge area, and the rates at which these parameters are changed in the water mass as a consequence of phytoplankton growth and other biological and physical processes.

(4) The residence time of fine sediments in the surface layer and its effect on light penetration and the concentration of dissolved inorganic nutrients and trace metals, and the residence time of disturbed sediments in the near-bottom layer.

(5) Changes in the taxonomic composition, distribution and abundance of benthic and pelagic organisms; the underlying mechanisms of these changes; and the degree to which they are reversible.

ENVIRONMENTAL IMPACT ON THE WATER COLUMN OF A SUCTION-DREDGE MINING TEST HELD IN THE ATLANTIC IN THE SUMMER OF 1970

Suction-dredge deep-sea mining will (1) stir up sedimentary material as the dredge-head sweeps the ocean floor; (2) destroy the benthic organisms and their habitat in the path of the dredge-head; and (3) introduce sedimentary material, associated organisms and bottom water into the surface water.

We estimated the environmental effect on the water column of surface-discharged sediment-laden bottom water during a pilot suction-dredge mining test on the Blake Plateau in the summer of 1970.

The temperature and salinity of the water discharged at the surface, or at an intermediary level in the water column, and the rate of mixing of the discharged water with the in situ water at the point of discharge, will determine the salinity and temperature of the resulting mixture and hence its density and stratification in the water column. Under the experimental conditions employed during the Blake Plateau test, the bottom water was discharged at the surface and remained in the euphotic zone, mainly due to some warming in the airlift pumping process and to the lower salinity of the bottom water.

Figure 1 illustrates this phenomenon: it shows the mining vessel with its port-side discharge of sediment-laden bottom water. This photograph was taken three minutes after the injection of rhodamine dye solution into the discharge. The dye patch can be seen clearly in the surface layer, and three hours later the dye patch, marking the discharged bottom water, was still in the upper ten meters of the water column.

In manganese-nodule areas in the Pacific, temperature and salinity conditions of the bottom water will vary. A computer program is now being developed in our laboratory to predict the density of mixtures resulting from the discharge of bottom water at the surface, or at intermediate depths, at different rates on a worldwide basis. Obviously, modifications of the discharge technique could greatly influence the behavior of the discharged bottom water--it might, for example, be sprayed over the sea surface to ensure rapid mixing and warming.

The effect of the discharge of nutrient-rich, sediment-laden bottom water on oxygen concentration in the surface water was demonstrated to be negligible in our Blake Plateau experiment. Figure 2 shows the oxygen concentration of samples of sediment-laden bottom water collected from the overboard discharge during the mining test, which were incubated in glass carboys in the laboratory under an oxygen-free nitrogen atmosphere

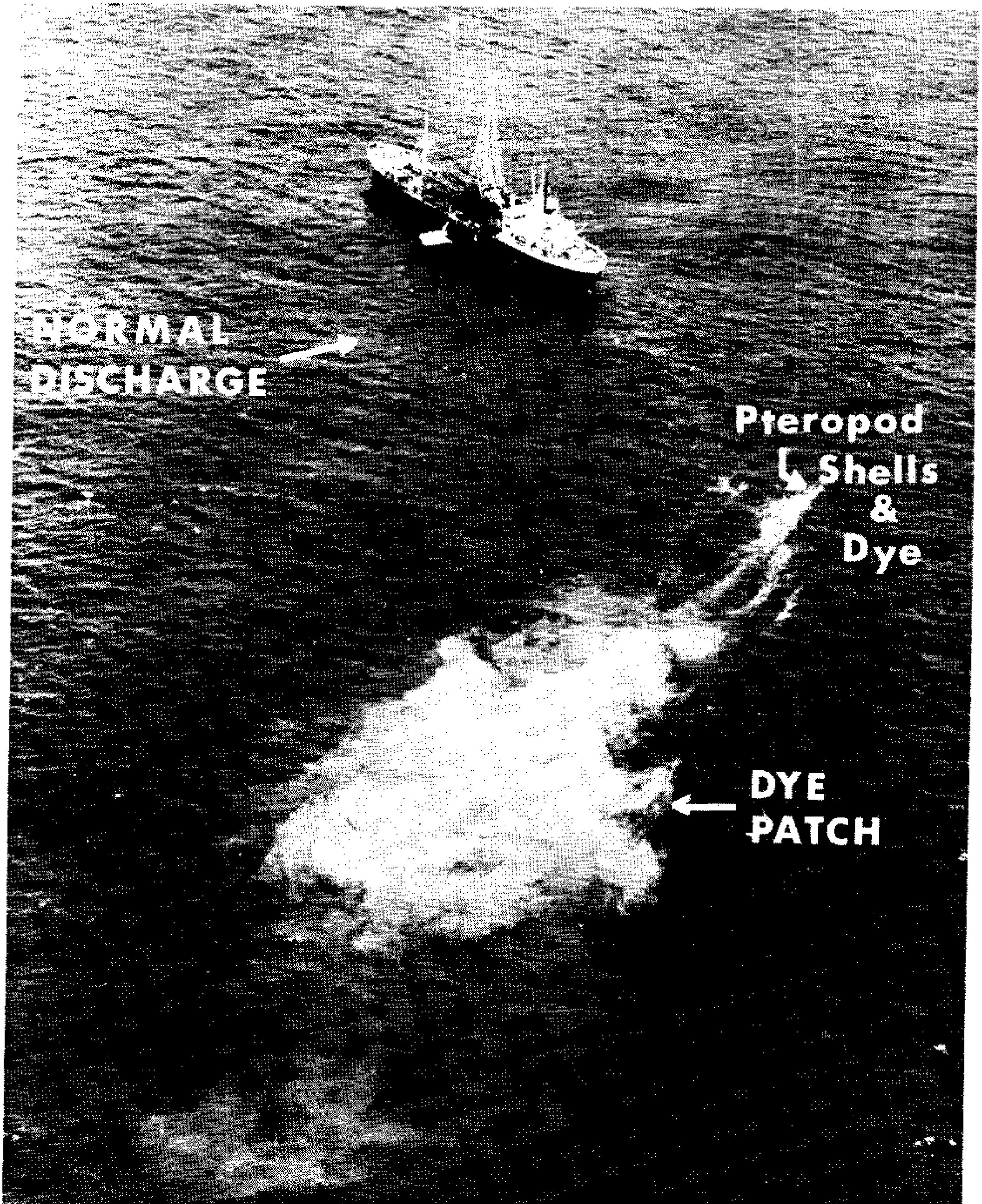


Figure 1. Aerial photograph of dye injected into the mining effluent 8 minutes after its discharge from *Deep Sea Miner*. The normal outboard discharge can be seen amidships on the port side.

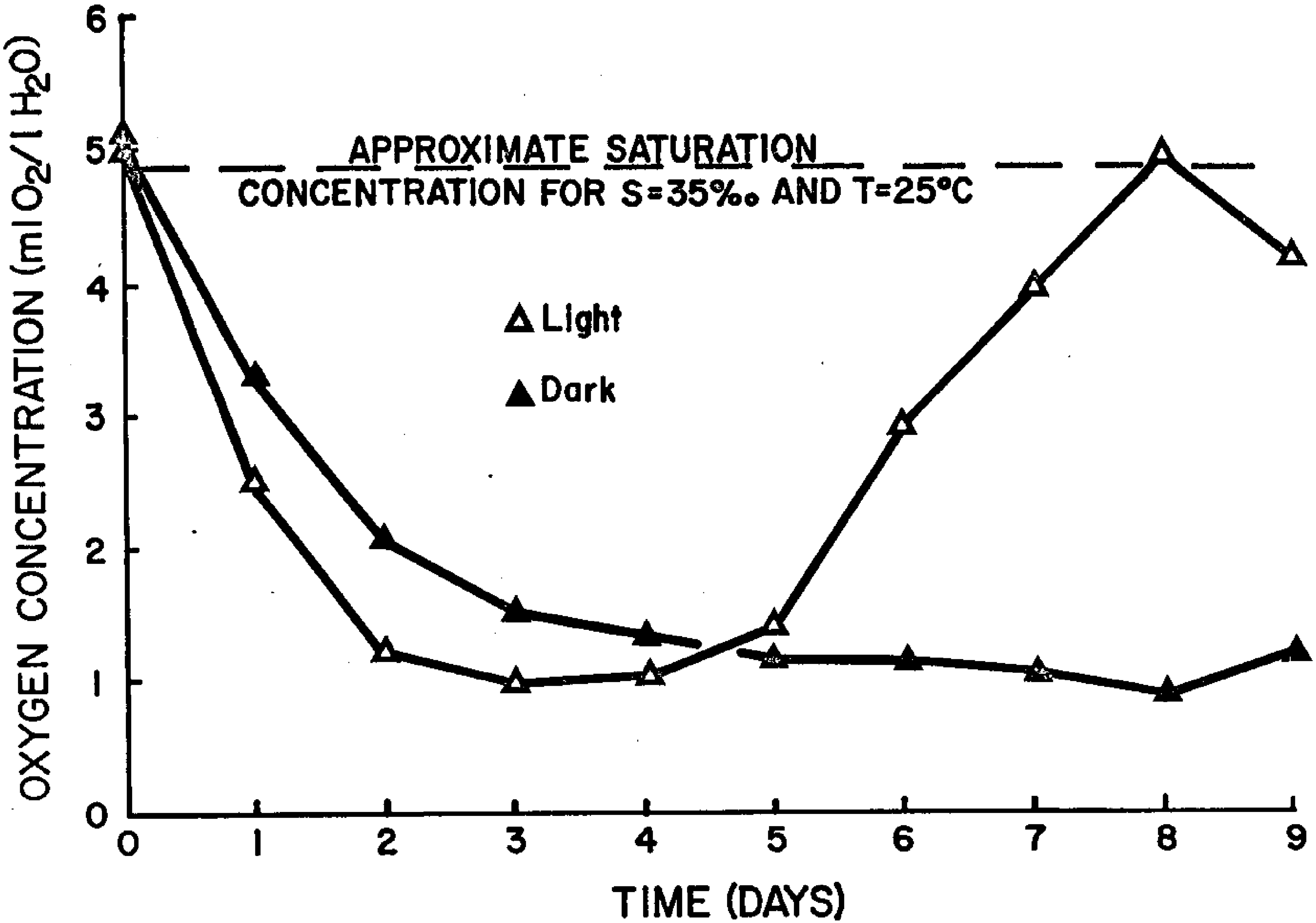


Figure 2. Oxygen concentration in dark and illuminated bottles containing deep water and sediment, as a function of time.

either in the light or in the dark for a period of nine days. The graph shows clearly that in the light bottle, oxygen was depleted rapidly from 100 percent to approximately 20 percent of saturation after two days' incubation; in contrast, the oxygen concentration in the light bottle started to rise again from the fifth day and it had reached saturation again by the eighth day after the start of the experiment. This was due to the photosynthetic production of oxygen by a bloom of a green coccoid alga, dormant cells of which were probably present in the sediment brought up with the bottom water. The photosynthetic process restored the oxygen of the sediment-laden deep water exposed to light. In contrast, the dark bottle reached a fairly low oxygen concentration on the third day of the experiment, and this oxygen concentration did not vary much for the next six days.

Our results indicated that the development of anoxic conditions was very unlikely under conditions like those observed on the Blake Plateau because the discharged water remained at the surface where it can support the growth of oxygen-producing phytoplankton; moreover, low levels of oxygen are not likely to be reached in the open sea because mixing and free exchange of oxygen from the atmosphere would preclude the formation of an anoxic layer.

Figure 3 shows the nutrient concentration measured on the ninth day of the oxygen experiment referred to in Figure 2. As is clear from the table, the nitrate and phosphate of the water in the light bottle were depleted on the ninth day, whereas that in the dark bottle remained quite unchanged from the concentration prevailing at the beginning of the experiment.

The spontaneous development of a green coccoid alga on the sixth day of the experiment in the light bottle contributed to the regeneration of oxygen levels. This may have been the only phytoplankton to survive since the sample was kept in frozen storage before it was used in these experiments. Some recent findings made on R/V CONRAD Cruise 15-10 in July, 1972, in a manganese nodule area (Bermuda Rise, North Atlantic)

		LIGHT	DARK
OXYGEN	% SATURATION.	101.4	18.6
NITRATE	μG AT N/L	0.95	20.73
NITRITE	μG AT N/L	0.13	0.17
AMMONIA	μG AT N/L	0.16	0.94
PHOSPHATE	μG AT P/L	0.46	2.72

Figure 3. Nutrient concentrations of oxygen saturation experiment on day 8.

have indicated that several species of small pennate diatoms exist on the sea floor (at depths in excess of 6,000 meters) which are viable and grow when exposed to light. If this is a general phenomenon, the discharge of bottom sediments in the photic zone will seed these waters with algal species not usually found in oceanic phytoplankton communities. This could affect the species composition of phytoplankton in mining areas as well as the food-chains which these organisms initiate.

Experiments were run during the Blake Plateau test to determine the effects of discharged bottom water on phytoplankton growth. Bottom water enrichments in excess of 10 percent were required to stimulate growth. Since the actual concentration of bottom water in the surface layer which resulted from this mining experiment was less than 0.3 percent, we concluded that the discharge of bottom water into the photic zone would probably not have a significant affect on phytoplankton growth.

Recent and more detailed experiments (preliminary results only) lead us to believe, however, that any enrichment, regardless of initial dilution, will enhance phytoplankton productivity. The degree of enhancement will be a function of (1) the nutrient concentration of the discharge; (2) the volume and rate of discharge; (3) the rate at which the effluent is diluted by mixing with surface water, and (4) the species composition and standing crop of phytoplankton in the receiving water and in the discharge.

The overall conclusions from the Blake Plateau experiment were that, under the experimental conditions (1) the discharged bottom water remained in the euphotic zone; (2) it was most unlikely to produce anoxic conditions; and (3) it would significantly increase phytoplankton growth only if the concentration of deep water, after mixing with surface water, was considerably higher than 0.3 percent in the resulting mixture (0.3 percent was the maximum concentration of discharged bottom water at the surface during the mining test we observed).

Because no research vessel was available to work closely with the mining vessel, the results of this study were incomplete since (1) no benthic study was undertaken, (2) no study of near-bottom currents and turbidity was conducted, and (3) no trace-metal study was conducted.

Therefore, we undertook quantitative measurements of the benthic biomass in a manganese nodule province on the Bermuda Rise in July, 1972, aboard the R/V CONRAD. Our conclusion, based on an admittedly very small number of samples, is that the benthic fauna in this area is extremely sparse: average biomass determined in the quantitative samples from this cruise was 9 mg/m^2 of bottom area. This is illustrated in Figure 4.

The mining would, therefore, affect a small quantity of animals in absolute terms, although its relative impact may be important.

ENVIRONMENTAL IMPACT OF A CONTINUOUS LINE BUCKET (CLB) DREDGE MINING TEST HELD IN THE PACIFIC IN AUGUST-SEPTEMBER 1972

The major environmental effects of a CLB mining system would be: (1) stirring up sedimentary material

RANGE	0.000 - 0.037 G/M^2
AVERAGE	0.009 G/M^2
GENUS	- SPONGES
	- TANAIDS
	- ISOPODS

Figure 4. Benthic biomass in a manganese nodule province of the North Atlantic.

as the buckets dredge nodules from the ocean floor, (2) destruction of benthic organisms and their habitat, and (3) introduction of sedimentary material into the entire water column as the buckets are hauled to the surface.

In August and September, 1972, we had an opportunity to observe the environmental impact of a (CLB) mining test in a siliceous ooze province in the North Pacific. As guests aboard the University of Hawaii's R/V KANA KEOKI, our plan was to measure the physical, chemical and biological conditions of the overlying water column and to observe the benthic fauna at the test site before, during, and after the mining operation.

To do this, we used the following equipment: a continuously recording salinity/temperature/depth (STD) sensor (Plessey Model 9030 internally recording), 12-liter Niskin bottles equipped with reversing thermometers and attached to the hydrographic cable used to lower the STD, a bottom camera, a bottom grab sampler, and a 210-milimeter diameter coring device. (See Figure 5)

The STD provides a continuous profile of temperature and salinity for the entire water column but does not have

STD

CONTINUOUS SURFACE-TO-BOTTOM PROFILES OF TEMPERATURE AND SALINITY

BOTTOM GRAB SAMPLE

STERILE MANGANESE NODULES FOR BIOLOGICAL STUDIES

12L NISKIN BOTTLES

- SALINITY
- TEMPERATURE
- DISSOLVED OXYGEN
- NITRATES
- NITRITES
- AMMONIA
- PHOSPHATES
- SILICATES
- PARTICULATE MATERIAL
- ORGANIC CARBON AND NITROGEN
- NEPHELOMETRY
- TRACE METALS

BOTTOM CAMERA

- BOTTOM FAUNA
- MANGANESE NODULE DISTRIBUTION
- BOTTOM CURRENTS
- EVIDENCE OF MINING OPERATIONS

CORING

- UNDISTURBED SURFACE
- BENTHIC ORGANISMS
- TRACE METALS
- PHYTOPLANKTON GROWTH EXPERIMENTS
- EVIDENCE OF MINING OPERATIONS

Figure 5. Sampling program aboard the R/V *Kana Keoki* in the North Pacific.

the precision to reveal any changes in the bottom water structure caused by a mining operation. To observe any such possible changes the twelve 12-liter Niskin bottles were placed at internals above the ocean floor and samples were collected for salinity, temperature (reversing thermometers), dissolved oxygen and nutrients, dry-weight particlate material, organic carbon and nitrogen, trace metals and light-scattering (nephelometry) determinations. The bottom camera was used to observe the benthic faunal distribution, manganese nodule distribution, evidence of bottom currents and evidence of the mining operation. The bottom grab samples were used to collect manganese nodules for manganese nodules for microbiological studies and the coring device was used in an attempt to collect undisturbed surface sediment for quantitative analysis of benthic faunal distribution, trace element analysis of the sediment, a phytoplankton growth experiment and evidence of the mining operation. Figure 6 is a schematic showing how the STD/Niskin bottle casts were taken. A pinger was used to allow us to come close to the ocean floor without making contact (contact with the bottom would stir up sediment that might contaminate the bottom Niskin bottle sample). We were able to collect our deepest sample within 5 to 10 meters of the bottom for all of our casts. The complete analyses of the data collected are still being made, but a preliminary statement can be made.

No evidence of any disturbance in the water column was detected. The dry weight of the particulate material in the water overlying the mining test site varied between 10 and 250 mg/m^3 both before and during mining. Similarly, particulate organic carbon and nitrogen concentrations ranged from 8.3 to 49.8 mg/m^3 and 1.0 to 3.6 mg/m^3, respectively. On one station where the STD accidentally hit the ocean floor the particulate material in the bottom bottles was 167,000 mg/m^3, so it is obvious that when a much larger bucket is dragged along the ocean floor, the turbidity of the surrounding water must be increased by several orders of magnitude over the baseline condition. How long this material remains in suspension and what effect it has on the benthic community must be determined by more sophisticated measuring procedures.

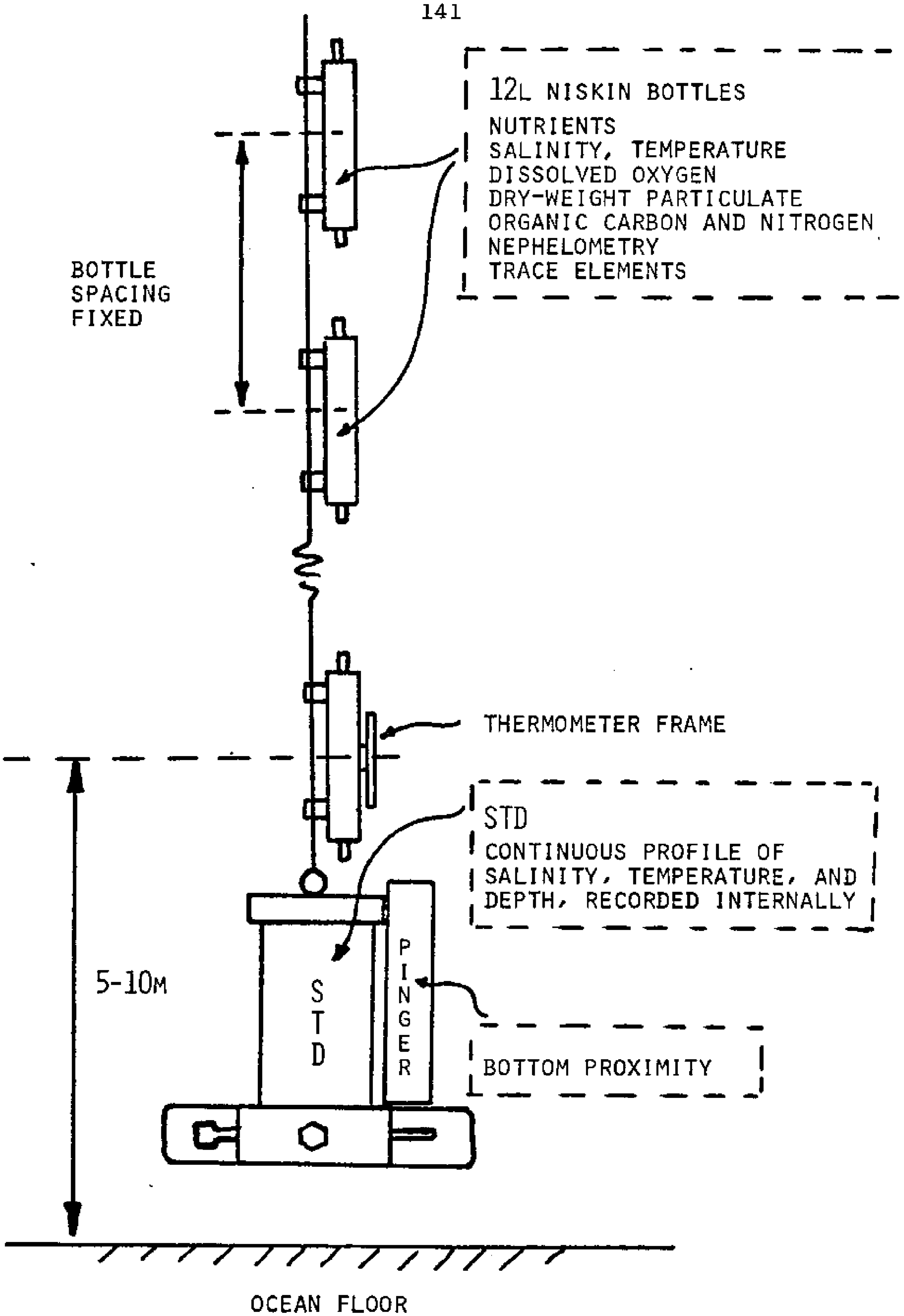


Figure 6. Schematic showing arrangement of STD/Niskin bottle package.

The bottom photographs revealed a considerable diversity in benthic fauna (Figures 7 and 8). The terrain, as determined from bottom photographs taken at 11-second intervals with the camera 2 to 6 meters off the ocean floor, varied from 0 to 100 percent manganese nodule coverage to manganese pavement to rocky outcroppings. The great majority of the picture showed evidence of benthic faunal activity, in particular, mounds, burrows and fecal coils, knots and spirals. In some cases, there was evidence of weak to moderate bottom currents as shown by erosion of fecal material and orientation of stalked organisms such as sponges and tunicates. Organisms photographed were sponges, gorganians, actinarians, bryozoians, crinoids, asteroids, ophiuroids, echinoids, several species of holothurians (the dominant class photographed), mollusks, cephalopods (squid), pycnogonids, decapods (shrimp), tunicates and rat-tailed fish. Some of the burrowing and mound-building organisms appeared to be present in large colonies (Figure 9). These would obviously be disturbed by a bucket-dredge operation. If the mining was done in strip form--leaving some areas undisturbed--then this would allow the mined areas to be repopulated eventually by these organisms.

We know from bottom photographs that trigger weights and other equipment that contact the ocean floor do make scars and troughs in the sediment (e.g., Heezen and Hollister, 1971, p. 159) and certainly a large bucket chain would have a greater impact.

Of the 450 photographs examined to date, only one showed evidence of a possible man-made disturbance on the ocean floor, other than obvious hits with the camera itself. This one photograph (Figure 7) shows a long scratch or trough that could have been made by the dredge line. Mounds and fecal material were also evident and it is possible that this is an animal track. However, out of all the photographs examined, only a handful show animal tracks. In the next frame to Figure 7, a large elasipod holothurian seems to be in motion, but no evidence of its plow mark can be seen. It is possible that the composition of the bottom sediment is such that mobile species do not leave

Figure 7. Bottom photograph of dredge bucket scratch.

Figure 8. Bottom photograph of manganese nodules in the North Pacific.

Figure 9. Bottom photograph of manganese pavement fragments in the North Pacific.

visible tracks in this area.

The design of the buckets is such that they collect primarily nodules with a minimum amount of sediment. Many of the buckets came to the surface with sediment clinging to the outside, but no sediment was observed in the surface waters as the buckets were hauled up.

Future efforts at monitoring mining tests must include equipment that allows us to know exactly where we are in relationship to the mining vessel and the bucket line (e.g., underwater television).

We did not observe nor measure any environmental effect of the CLB dredge mining test we monitored in the North Pacific in September 1972 with the methods described here, except for the possible track of the dredge line observed in one of the 630 bottom photographs made. One problem with these measurements was not knowing whether our equipment at the end of more than 5,000 meters of sea cable was actually over the mined area.

REFERENCES

Amos, A.F., C. Garside, K.C. Haines and O.A. Roels, 1972. Effects of surface-discharged deep-sea mining effluent. Mar. Tech. Soc. J. 6 (4) : 4-45.

Heezen, Bruce C., and Charles D. Hollister, 1971. The Face of the Deep. Oxford Univ. Press, New York, London and Toronto, p. 159

ACKNOWLEDGMENTS

This work was supported by RF-05058, a grant from the National Oceanic and Atmospheric Administration; Lamont-Doherty Geological Observatory Contribution No. 0000; and University Institute of Oceanography, City University of New York, Contribution No. 00.

ROLE OF NOAA'S MARINE MINERALS TECHNOLOGY CENTER IN DEEP-SEA MINING

By
Burton B. Barnes
United States Department of Commerce
National Oceanic and Atmospheric Administration
Marine Minerals Technology Center
Tiburon, California

It gives me great pleasure to speak to you regarding the role of the Marine Minerals Technology Center in deep-sea marine mining. Before describing our immediate plans and future aspirations for deep-sea involvement, I would like to discuss our current programs, and review for you the background for project development at Tiburon. A few of our ongoing projects will be undergoing a transition to deep sea; many will be phased out in preparation for our priority involvement in the deep sea.

Since its inception in 1963, the Tiburon, California research center has confined its activity to the Continental Shelf, looking for potential development of natural resources within the boundaries of the continental margin. Today, nine years later, a clearer picture of that potential is apparent, as well as the potential of the natural resources found in the deep sea. Our role as an agency of the Federal Government is also better defined. The mission of the Tiburon facility in the past has been strongly oriented to mining technology--developing tools and methodologies to apply to Continental Shelf mineral deposit assessment. Our major projects have included characterization of deposits with advanced geophysical instrumentation, design and development of engineering technology for sampling equipment, and engineering experiments associated with vertical lift of multiphase materials. In the past year we have embarked into research dealing with environmental prediction. A pilot study underway in Massachusetts Bay involves a cooperative Federal, State, academic and industry consortium which is studying the impact of offshore mining of sand and gravel on the ecology. A major effort, co-funded by the Advanced Research Projects Agency and the National Oceanic & Atmospheric Administration (NOAA) has been underway for two years to evaluate the application of geophysical tools and techniques for solving geotechnical problems. Acoustical and electrical tools have been developed to measure both in situ and continuous-track physical properties of the Contental Shelf sediments.

We are now making the transition from Continental Shelf problems to deep-sea problems, and in order to make maximum use of our resources we are changing to more contract and less in-house research and development.

Our perspective for both deep-sea and important Continental Shelf work is focusing on industry needs as well as national needs. Our Center's programs are being established to meet these needs. Government and industry have cooperated to this end, and industry has established special panels for marine mining. The National Security Industrial Association/Ocean Science and Technology Advisory Committee (NSIA/OSTAC) Panel is one example. Government liaison committees from the American Mining Congress and the American Petroleum Institute are others. State and local governments involved with regulation of offshore mining are also involved.

At a recent meeting of the NSIA/OSTAC Panel and the Center we outlined several technical services the government should provide, which would not be in conflict with free enterprise. These include:

- Mapping and surveying
- Environmental monitoring and prediction
- Deep-ocean test facilities
- Environmental prediction research
- Advisory services and technical interface between Government and industry
- Sponsoring fundamental technology and equipment development, when pertinent

The last three items represent the primary roles of the Marine Minerals Technology Center program.

Mr. Marne Dubs, of Kennecott Copper Company, in a speech before a recent meeting of the American Mining Congress, summarized the potentials of offshore mining when he said that two ocean resources offer the best immediate promise for exploitation: These are:

1. Continental sand and gravel
2. Deep-sea ferro-manganese deposits

Hard-rock mining, placer deposits and phosphorite offer relatively poor potential. For the deep-sea ferro-manganese deposits, primary interest lies in copper and nickel components. The nodules contain as much as 1.2 percent copper, and because of the present demand and projected requirements for this high unit-value commodity, the search in the deep sea looks profitable. Exploration is now narrowing in on deposits yielding a high concentration of copper and nickel. The zone of importance has been isolated to a belt running from 5° South latitude to 20° North latitude between 115° West longitude and 160° West longitude; this is nearly 3 million square miles of the ocean's 100 million square miles. Approximately a half-million square miles is considered high potential. Mr. Dubs forecasted serious production of deep-sea manganese by 1980, indicating production would not replace land supplies, but would supplement them.

The immediate problems in deep-sea mining are mainly legal, but industry is concerned about environmental impacts. It has specified that it should become an immediate and major program for government involvement at the Marine Minerals Technology Center.

Three other areas follow this in priority, basically they are:

1. Serve as an interface between government research and the mining industry.

One of the key roles of the Marine Minerals Technology Center is liaison--as an interface--to keep government informed of needs and progress of industry, and to be a Center where industry can find out what is happening in government that might affect or aid its plans and activities--with particular reference to technological implications.

2. Develop equipment and determine sediment engineering properties.

I have already indicated our past involvement. In the future we expect to provide the stimulus for new technology by providing concepts and ideas to industry, and then provide funding for certain research and development and engineering to be carried out by the private sector.

For example, in the area of sediment properties it is important to obtain data for transporting ore collecting devices and to know how these devices interact with the seafloor. Tools must be developed for in situ measurement of shear strengths and bearing capacity. Such instruments are currently not available.

3. Deep ocean bathymetry.

Of major concern is the state of the art for obtaining high-resolution bathymetry. Industry needs better definition of micro-topography to assure that dredge-heads will be capable of negotiating rocks, boulders, outcrops, and other obstructions without damage. Details of topography measuring from 1 to 2 feet high and 8 to 10 feet wide need resolving--rapid and accurate instruments are required. This will require deep-towed self-powered self-contained survey systems.

Macro-scale bathymetry for fast reconnaissance measured as conventially done from the sea surface should be improved to delineate topographic features having resolutions of from 50 to 100 feet and having less than 10-degree slopes. Present technology cannot obtain this.

In order to begin immediately, projects at the Marine Minerals Technology Center are being redirected for the remainder of Fiscal Year 1973. Our first look at industry's priorities began in August 1972 by way of a pilot experiment to measure the environmental impact of deep-sea mining. The experiment was funded by NOAA's Environmental Research Laboratory, parent organization of the Tiburon Center. Dr. Oswald Roels of Lamont-Doherty Geological Observatory, Palisades, New York, and members of his staff, along with the University of Hawaii, participated in an international industry consortium to conduct a manganese nodule mining experiment in the North Pacific. The results of these tests are presently being analyzed.

Because the major portion of this fiscal year's Marine Minerals Technology Center's budget is dedicated to environmental studies of Continental Shelf sand and gravel dredging, most of the deep-sea involvement will center on defining the problem areas and assessing the research needed. Specific actions are:

1. Acquire information on ferro-manganese provinces.
2. Define specifications for a deep-sea test-bed site.

3. Determine the state of the art in trafficability, and assess the potential for remote-sensing applications using geophysical systems.
4. Develop soils-property testing methodology, and standards for measuring engineering properties of saturated sediments.
5. Determine the state of the art in macro/micro bathymetry and determine the status of deep-tow survey systems.
6. Coordinate NOAA's main line components whose capabilities may be identified with other industry requirements (i.e., National Data Buoy Center and National Ocean Survey).
7. Continue mineralogical studies into ferro-manganese formation history and genesis.

I have sketched briefly our present role and what we intend in the future. In concept, this deep-sea program has NOAA's blessing and the U.S. industry's endorsement.

Tiburon Center's goal is to assure that the development of mineral resources off the coasts of the United States and the deep-sea regime will proceed in an orderly manner without conflict with the other benefits provided by the ocean environment. To accomplish this goal, our research efforts are directed towards two objectives: (1) Develop and maintain a capability to predict probable environmental effects from potential marine mining operations, and (2) Develop fundamental marine mining technology and special environmental disturbance-control techniques to pave the way for industrial development of extractive systems compatible with other marine resources and the marine environment.

Again, our program is based on the premise that an offshore mining industry is desirable and is a needed objective of the United States. We expect the program to follow an orderly development with the cooperation of government and industry.

ASSESSING THE CONSEQUENCES OF ALTERNATIVE RESOURCE ALLOCATION PLANS FOR OCEAN MINING

By
Don H. Overly
International Research & Technology Corporation
Washington, D.C.

OPENING REMARKS

The available literature on ocean mining is clearly oriented toward the physical sciences and some of the abstract problems of international law. Professor Woollard somewhat reduced my concern however, when he indicated that we must now view ocean mining beyond the narrow physical science point of view; we must account for in very explicit terms the social, economic, political, and perhaps even cultural impacts associated with the development of an ocean mining industry. Other speakers identified the international implications of ocean mining with the possibility of new institutions emerging from what are now symbolic quests. We have also heard about the technological risks and institutional uncertainties. All this stated concern leads to the general theme of assessment to which the rest of the day is devoted. So I will define quickly what assessment means, or what it perhaps should mean. Second, I will outline a methodology for conducting large-scale assessments. Finally, I would like to identify some of the problems and implications associated with assessment.

THE MEANING OF ASSESSMENT

Assessment is an analysis of who benefits and who is hurt with respect to any alternative resource allocation plan. This is not equivalent to the analysis of single budgets. In principle, assessment would require an examination of how international organizations, national governments, state and local governments, private business, special interest groups, and even individuals, are affected by a given policy. The "resource allocation plan" or policy subject to assessment can include broad strategies for international agreements, lobbying efforts, corporate R&D budgets, and government tax incentive plans. The question assessment deals with is: Are programs detrimental or beneficial? This is not a valueless question, as it is often treated, as we must deal explicitly with priorities, distribution of power, ethics, and morality.

Although recognition of values certainly increases the complexity of any assessment, it does help to move the analysis from a seminar or boardroom blackboard to the real world.

Various points of view must be considered in alternative resource allocation plans. For example, a specific R&D program which leads to jobs might have some labor unions for it and others against it. The R&D program may be opposed by environmentalists. If it appears that corporate profits may accrue from it, competitors will certainly oppose it. In a tax incentive program which lead to industrial growth, some Congressmen will be for it and some Congressmen will be against it. The same is true with international agreements and investments. The thrust of any assessment methodology, really, is to identify how the "actors" in the system will react.

In any assessment, the system must be defined: we must first identify the program, issue, industry, or policy being considered, and the characteristics of its immediate and future operating environment. For industry, this requires identification of competitors, suppliers, customers, and those who are providing constraints. Particularly the strong interactions between the resource allocation plan and other interests in society must be identified.

Once the overall system is specified, the actors within the system and predictions of how they are going to act must be identified. Are "they" going to buy what you want to sell? Are "they" going to set up restrictive legislation? Are "they" going to declare war? Are "they" going to burn down your corporate headquarters? Are "they" going to refuse to work? Ignoring some actors in favor of others could have disastrous consequences. Predicting what "they" might do in response to alternative resource allocation plans is based largely on the projected perceptions and resources these actors have. Some will be neutral, some will benefit, and some will be hurt. In order to understand the overall impact of any resource allocation plan, these impacts must be understood in social, economic, political, technological, and legal terms.

AN ASSESSMENT METHODOLOGY APPLICABLE TO OCEAN MINING

The assessment methodology outlined here, is not designed only to satisfy the curiosity of a narrow range of interests--whether a physical scientist, social scientist, or lawyer. This methodology deals with the policy and managerial issues which, in principle, must be resolved before resources can rationally be allocated.

The methodology must be able to account for proprietary strategies; you must be able to examine the utility of your secrets privately until you want outside participation. The second requirement is that you should be able to speculate systematically about the strategies of others, particularly with respect to customers, suppliers, and competitors. Meeting these two requirements makes it possible, in principle, to account for the reaction of any interest in society to any resource allocation plan.

The first step in any assessment process is the definition of goals. A partial goal structure which might apply to ocean mining is illustrated in Exhibit 1. As shown, the first level of service goals might be to obtain specified market

EXHIBIT 1: GOAL STRUCTURE

<u>1.0 SERVICE</u>

1.1 Obtain Market Shares
1.1.1 Fluids and Solubles
1.1.2 Consolidated Subsurface Deposits
1.1.3 Unconsolidated Surface Deposits

<u>2.0 FISCAL</u>

2.1 Costs
2.1.1 Manpower
2.1.2 Investment
2.1.3 Debt
2.2 Revenues

<u>3.0 PRESTIGE</u>

<u>4.0 OTHER</u>

shares. A further service goal might be adding knowledge to the industry or world. Objectives dealing with fiscal operations, prestige, and so on can be articulated and elaborated upon. Assessment of a large corporate plan or government policy probably would require a goal structure dealing with ten to fifteen levels of abstraction before goals are adequately defined.

After goals are expressed, performance indicators which measure progress toward these goals must be defined. Broad functional areas might include those shown in Exhibit 2. A seventh area called "Other" could define lobbying and public relations activities. This hierarchy, too, needs to be elaborated upon so as to identify the specific indicators that measure the progress toward the goals.

EXHIBIT 2: INDICATOR STRUCTURE

1.0 Prospect
2.0 Explore
3.0 Exploit
4.0 Process
5.0 Transport
6.0 Distribute/Sell

Next, the societal indicators must be specified. This is, again, a partial hierarchy and is partially illustrated by Exhibit 3. The specification of indicator types is very critical because it is here that a structure is established which permits accounting for, in principle, all impacts associated with a strategy. Profits and losses, environmental emissions, employment, legislation, and technology, for example, can all be accounted for with this structure.

EXHIBIT 3: SOCIETAL INDICATORS

1.0 Economic
1.1 Resource Inputs
1.2 Inventories
1.3 Outputs
2.0 Social
2.1 Conflict Generating
2.2 Stability Generating
3.0 Legal/Regulatory
4.0 Political
5.0 Technological

Measures must be specified for the indicator types so as to determine values or units. Examples are illustrated in Exhibit 4. Hierarchies of these types can be used to characterize any industry, program, process, or strategy. When applied to ocean mining there is the objective structure, which has time-dependent statements; the indicator structure, which measures progress toward goals; the indicator types, which make it possible to account for all impacts; and the indicator measures, which assign values and units to indicators.

EXHIBIT 4: INDICATOR MEASURES

1.0 Quality
2.0 Quantity
3.0 Location/Source
4.0 Other

The above hierarchies define an industry or strategy. It is necessary to conduct a similar exercise for its operating environment, beginning with those societal units which potentially will be affected by the resource allocation plan being assessed. Exhibit 5 illustrates five categories of interests which are assumed to represent the operating environment. In the corporate environment, private organizations might be of greatest interest, as it includes competitors, suppliers, and customers; labor unions; and lobbying groups. After all societal units are specified, goals, indicators, indicator types, and indicator measures must be defined. So far we have characterized the industry and its operating environment. We can say that we are complete--we have left nothing out, and that in principle could account for any perturbation that takes place. The next step in the analysis is to construct alternative strategies.

EXHIBIT 5: SOCIETAL UNITS

1.0 Living Units
2.0 Voluntary Social Organizations
3.0 Private Organizations
4.0 Public Domestic Organizations
5.0 International Organizations

Categorization of Indicators

After all the indicators to be used for the analysis have been identified, they are grouped into five categories:

1. I_ℓ = independent industry internal indicators
2. E_ℓ = independent indicators of the operating environment
3. L_ℓ = dependent industry indicators derived, using explicit relationships (formulas) containing independent indicators of the industry and its operating environment
4. e_ℓ = derived (dependent) indicators obtained from explicit relationships (formulas) containing independent indicators of the operating environment
5. G_j = indicators, in terms of which a goal is stated

The indices ℓ, and j are symbolic labels referred to as the ℓth or jth indicator. Values of I_ℓ and E_ℓ therefore represent input data to the assessment process and L_ℓ, e_ℓ, and G_j represent intermediate output data, since they are derived from the independent (input) indicators by means of explicit relationships. Although the assessment of each strategy is made in terms of the objective and goal indicators (G_j), the values of the other derived (dependent) indicators (L_ℓ and e_ℓ) are recorded because it is often helpful to examine the values in the subsequent assessment process.

Formulation of Alternative Strategies (Resource Allocation Plans)

The starting point for formulating alternative strategies for future change is to extrapolate the values of each of the independent indicators that describe industry operations and their operating environment, using recent trends as a guide and not including the incorporation of any new systems that are not already in operation and implemented on a large scale. The purpose of constructing this "control strategy" is to learn what would happen if recent trends continue and no major efforts are made to resolve the problems that exist or that may develop in the future. Construction of the control strategy makes it possible to answer the question: "What is likely to happen if current trends continue?"

Using the control strategy as a base, other strategies based upon different assumptions can be developed. As a result, indicators will have different values and will relate differently to goals.

Referring to the characteristics of the control world and present industry plans, plus likely future changes in its operating environment, a "surprise-free" strategy is constructed. The description of this world is basically the description of a set of plausible assumptions concerning projected values of all important independent indicators and a consistent derivation of the implied values of all important dependent indicators, along with a prose description of major components of the strategy for bringing about the major changes between the surprise-free and control worlds. Once constructed, this surprise-free strategy is used as the point of departure for describing other possible strategies.

As a guide in constructing alternative strategies so that they exhibit a full range of assumptions concerning possible major differences between the surprise-free strategy and the strategy that may actually represent the industry in the future, it is useful to think of a two-dimensional "map" on which two basic and largely independent overall attributes of each world can be displayed. These attributes are:

1. The degree to which, as a result either of internal policy decisions or changes within its operating environment, the general character of the industry is oriented toward social services as opposed to maximizing revenues; and

2. The extent to which the industry is aggressive and expansive as opposed to defensive or passive, either in response to internal changes in policy or to changes in policy or to changes in the external operating environment.

Each strategy should have explicit assumptions concerning both the industry and the environment. Broad policy changes that will take place by government, private industry, or by individuals must be considered. Other assumptions might account for the overall support the industry receives. There might be an increase in international tension. The technology for conventional processing of ores might advance. Demand for mineral ores may stabilize. The possibility that these events may occur cannot be dismissed.

Different assumptions regarding the industry must be considered. Competition may increase. New technologies will become available. Government subsidies may be provided. No formal recipes for the construction of alternative strategies have been devised. The formulation of each strategy is simply an attempt by one or more individuals to construct an alternative way to make progress toward industry objectives while at the same time maintaining self-consistency and plausibility in the process. In some cases, a particular strategy will eventually fall short of achieving some of the objectives, at least by specified times in the future, and these deficiencies may be evident before any formal assessment of the strategy is carried out. Such deficiencies may result from limited creativity on the part of the people formulating the strategy from characteristics that are basically inherent in the major components of the strategy. Thus, the process of constructing each overall strategy is inherently an iterative one in which the strategic planners are simply applying their best efforts to devise an attractive strategy.

Weighting of Goals

Once the list of specific goals has been prepared, it is subjected to a two-step analysis. The first step is to specify the degree to which the attainment of each goal is likely to reinforce or detract from the other with respect to each strategy; the second is to specify relative priorities for the achievement of the goals, taking into account the results of the first step.

The first step is carried out by using a technique called "cross support analysis." A formal procedure is used to poll a panel (typically about a dozen people), representing different industrial interests, for their opinions concerning the extent to which each goal supports or negates each of the other objectives. These opinions are stated in the following way. Each panelist is given a form in which all of the objectives are listed, both vertically and horizontally, along two sides of a square array, as illustrated in Exhibit 6. Each square in the array corresponds to the intersection between one goal and another. With respect to each such intersection between two different goals, each panelist is asked to answer the following question: "To what extent will the achievement of one goal automatically tend to support or negate the achievement of the other goal, independently of the particular way in which the first goal is achieved?" The panelists are asked to answer the question by indicating whether the support is high (H), medium (M), low (L), or zero (Z), and whether it is positive or negative support. A positive H, for example, indicates that the first goal, if accomplished, will automatically strongly support the achievement of the second goal. Z indicates that there is no significant evident connection between the two. A negative H (-H) indicates that achievement of the first goal automatically will make it very difficult to achieve the second goal. Following discussions and iterations of the ratings by the panel, the final version of each panelist's form is collected by the moderator for subsequent analysis, as follows:

First, each of the letter indicators of judgment is converted to a numerical scale as follows: H=8, M=4, L=2, Z=0. Using these numerical values, the arithmetic averages of the expressions of opinion of all panel members are constructed for each square in the matrix to form an overall consensus for a cross-support matrix. All of the numbers in the squares of the cross-support matrix corresponding to a particular row (i.e., goal) are then summed to provide a semi-quantitative measure of the degree to which achievement of each objective tends to support the other objectives as a whole. Referring to Exhibit 6, these cross-support values for each goal are computed as follows:

Relative cross-support value of j<u>th</u> goal =

$$c_j = \sum_{\ell} \alpha_{j\ell}$$

The second step in the relative weighting of industry goals is to reassemble members of the panel and ask them to rank-order all the objectives in decreasing order of priority and, having done so, to set a priority for each goal on a scale from 1 to 100. Single weights for each goal are then specified by taking the arithmetic average of the number of

GOALS

GOALS	1	2	3	4	...	ℓ	...	N
1	α_{11} -	α_{12} =8 H	α_{13} =0 Z	α_{14} =4 M				
2	α_{21} =2 L	α_{22} -	α_{23} =0 Z	α_{24} =0 Z				
3	α_{31} =4 -M	α_{32} =0 Z	α_{33} -	α_{34} =0 Z				
4	α_{41} =8 H	α_{42} =0 Z	α_{43} =2 L	α_{44} -				
⋮								
i						$\alpha_{i\ell}$		
N								α_{NN}

$$c_1 = \alpha_{11} + \alpha_{12} + \ldots \alpha_{iN} = \sum_{\ell=1}^{N} \alpha_{1\ell} = 12 + \ldots$$

$$c_2 = 2 + \ldots$$

$$c_3 = -4 + \ldots$$

$$c_4 = 10 + \ldots$$

$$c_i = \sum_{\ell=1}^{N} \alpha_{i\ell}$$

EXHIBIT 6. GOAL CROSS-SUPPORT MATRIX

points allocated to each objective by each member of the panel. The results are then presented to the panel and divergent views are explored in a discussion period. Following the discussion, each panel member is given an opportunity to change the weights he wishes to associate with any goal, and the results are again averaged.

The results of the two steps are then combined by adding (or subtracting) increments to the weights assigned to each objective in proportion to the measure of the extent to which each goal supports (or detracts from) all the others. This is accomplished by first renormalizing the values of c_j in such a way that the maximum value of c_j is λ times the maximum value associated with the priority for achievement of any of the goals, where λ is a parameter that can be specified by a panel. The use of this renormalization procedure is obviously a matter of judgment and is done in a spirit of giving some additional, but not overriding, importance to the cross-support values in arriving at a final overall set of relative priorities for the attainment of the objectives. A typical value of λ might be 0.25. Whatever value is chosen, the sensitivity of the final results to its value should be determined by treating it as a variable parameter.

A final step is to reconvene the panel, display the relative priorities for the goals, with cross support between them taken into account, and call for votes by the panel members for any final changes in the results. If a majority of the panel vote to change the priority of a particular goal, the panel is asked to specify a value for the priority and a group average is taken. This procedure could be used to fix λ.

As an alternative, the formal cross-support analysis, which can become exceedingly tedious as the number of goals becomes large, can simply be omitted. The number of components in the cross-support matrix, if the number of objectives is 100, for example, is 10,000 in which case the panel may require as much as five or six days to complete the process. If the explicit cross-support process is omitted, the panel should be asked to consider, at least to some extent, some allowance for the impact of goals on each other when they specify, directly, the priority ratings for each goal.

Whether or not the results of the cross-support analysis are explicitly used in setting relative priorities for the goals, the cross-support matrix can be of considerable assistance in a subsequent step in the analysis, namely the selection of independent indicators from which, through explicit formulas, the values of the indicators in terms of which the goals are derived.

Alternative Methods for the Assessment of Alternative Strategies

Given detailed descriptions of each of the alternative strategies or resource allocation plans, the assessment of the impact of each of them on industry objectives and its operation environment can be performed at any of a variety of different levels of detail, depending on the time and resources available to the decision-maker, the extent to which he is prepared to use his own integrated judgment in assessing the alternatives, and the degree of complexity of the description of each alternative. The methods available for carrying out the assessment described here represent an effort to strike a balance between logical consistency and practicality. They combine the exercise of judgment by the analyst with the use of quantitative techniques in such a way that steps that depend heavily on judgment are clearly distinguished from steps that can be performed by arithmetical manipulations.

Five methods below are summarized, and they proceed from the simplest to the most complex.

The starting point for application of each of these assessment methods begins with a careful review of the summaries of each of the strategies and associated assumptions. After this review, any of the following methods can be used for relative ratings of the alternative strategies at progressively greater degrees of disaggregation. In all cases the rating process is one that is carried out by an exercise of overall judgment on the part of a panel of experts.

Method I

The assessment method consists simply of studying each of the summary descriptions of the strategies, industry objectives, and its operating environment, and then rank-ordering the different strategies according to the decision-maker's overall judgment of their relative attractiveness.

Having rank-ordered the strategies, each strategy is given a figure of merit (a number between 0 and 100, for example) to specify the degree of relative attractiveness of each strategy. The purpose in ascribing numerical figures of merit to each strategy is primarily to exhibit strategies that, in the judgment of the analyst, are relatively close to each other in overall attractiveness.

Although this method for assessment may appear rather trivial to people who are thoroughly familiar with the more sophisticated modern methods for planning and assessment, it should be pointed out that this is basically an explicit version of the way that most corporate decison-makers choose between alternative planning options that are presented to them by their staffs. In most cases, of course, even the numerical rating of different alternatives is not formally undertaken.

A possible format for presenting the results of this kind of assessment is shown in Exhibit 7.

1978		1984		1990	
S_i	F_i	S_i	F_i	S_i	F_i
1	F_i	1	F_1	1	F_1
2	F_2	2	F_2	2	F_2
3	F_3	3	F_3	3	F_3
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

EXHIBIT 7. METHOD I

S_i = Strategies

F_i = Figures of Merit

Method II

The process is the same as in Method I except that the major components (for example, the introduction of a new technology) that are incorporated into each strategy are separately identified, rank-ordered, and weighted with respect to their relative contributions to the overall attractiveness of each strategy. This disaggregation, typically into half a dozen or less major components, helps to focus attention on the primary sources of major advantages or disadvantages in each strategy. Having identified the more attractive components of each strategy in this way, the decision-maker may then wish to modify some of the strategies by including some of the more attractive components of other strategies and ask for a reformulation of new strategies that include such changes. This process can then be repeated until the decision-maker is satisfied that, in some overall sense, a "best" strategy has been constructed.

The use of such an assessment method is illustrated schematically in Exhibit 8.

Example for particular time frame:

Strategies & Strategy Components	F_i	
1	F_1	$F_1=F_{11}+F_{12}+F_{13}$ ...
1.1	F_{11}	
1.2	F_{12}	
1.3	F_{13}	
.	.	
.	.	
.	.	
2	F_2	$F_2=F_{21}+F_{22}+F_{23}$ ...
2.1	F_{21}	
2.2	F_{22}	
2.3	F_{23}	
.	.	
.	.	
.	.	

EXHIBIT 8. METHOD II

Method III

In this method, explicit use is made of weighted industry and societal goals. A rectangular array (matrix) is constructed that vertically lists all the different strategies and horizontally lists all the goals, along with each of their associated relative weights (measures of relative priority). The assessment then proceeds by using an individual or a panel that exercises individual or collective judgment in rating each strategy with respect to its relative effectiveness in attaining each of the goals. These relative ratings can be indicated by the use of suitable adjectives, such as negligible (Z), low (L), medium (M), or high (H), and minus signs can be used to indicate when a strategy is judged to detract from the attainment of a particular objective. Each of the adjectives can then be associated with the number in such a way as to exhibit a rather wide range of possible measures of effectiveness (i.e., a geometric scale, such as 0,1,2,4, and 8, rather than an arithmetic scale).

Once this matrix has been filled out, a figure of merit for each strategy can be constructed by multiplying the rating under each goal by its weight and then summing all the products for each strategy. The resulting number is a measure of the relative attractiveness of each strategy with respect to the achievement of industry goals with respect to the operating environment. After the assessment has been completed, the sensitivity of the results to changes in the relative weights given to different objectives can very easily be determined. Whether or not the decision-maker wishes to use the relative values of the overall figures of merit in determining which strategy he should use, use of this method will more directly exhibit important differences between the strategies in a convenient format. A summary of this method is given in Exhibit 9.

Strategy (S_i)	Industry Goals				Operating Environment				Figures of Merit		
	Number				Number						
	1	2	3	...	1	2	3	...			
	Relative Weights				Relative Weights						
	w_1	w_2	w_3	...	v_1	v_2	v_3	...	F_{pi}	F_{ni}	F_i
1	a_{11}	a_{12}	a_{13}	...	b_{11}	b_{12}	b_{13}	...	F_{p1}	F_{n1}	F_1
2	a_{21}	a_{22}	a_{23}	...	b_{21}	b_{22}	b_{23}	...	F_{p2}	F_{n2}	F_2
3	a_{31}	a_{32}	a_{33}	...	b_{31}	b_{32}	b_{33}	...	F_{p3}	F_{n3}	F_3
⋮	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮

a_{ij} = measure of progress of *ith* strategy toward *jth* Industry Goal.

b_{ij} = measure of progress of *ith* strategy toward *jth* National Goal.

F_{pi} = figure of merit of *ith* strategy with respect to attainment of Industry Goals as a whole.

$= \sum_j a_{ij} w_j$ [e.g. $F_{p1} = a_{11}w_1 + a_{12}w_2 + a_{13}w_3 + \ldots$]

F_{ni} = figure of merit of *ith* strategy with respect to attainment of National Goals as a whole

$= \sum_j b_{ih} v_j$

$F_i = W F_{pi} + V F_{ni}$ = over-all figure of merit *ith* strategy

W = over-all weight given to Industry Goals

V = over-all weight given to National Goals

EXHIBIT 9. METHOD III

Method IV

This method is similar to III except that each strategy, as in Method II, is disaggregated into its major components. Each component of each strategy is then rated with respect to each goal, and the same is done for each overall strategy. This procedure leads to a systematic display, then, not only of the overall figures of merit for each strategy, but also, within each strategy, the relative value of each major component in the overall achievement of goals. Examination of the results may suggest, as in Method II, that new mixes of components of strategies should be formulated and reassessed. Analyses of the sensitivity of results to changes in objectives or in the weights given to individual objectives, as well as in assumptions regarding the effectiveness of individual components of each strategy, are relatively easy to carry out in this method. Use of the method is illustrated in Exhibit 10.

CONCLUSIONS

Each of the above methods works; they have been tested and the complex ones computerized. Their existence and utility, however, are meaningless unless policy makers and managers consider the implications of assessment.

A well-run assessment often will tell you things you don't wish to know. Often a credible assessment will be insufficient to overcome pre-set biases or a commitment to a program. For this reason, the results of an assessment should not be considered to be more than a valuable input into the decision-making process.

Strategies (S_i) & Strategy Components (S_{ik})	Industry Goals				National Goals			Figures of Merit		
	Number				Number					
	1	2	3	...	1	2	3			
	Relative Weights				Weights			F_{pi}	F_{ni}	F_i
	w_1	w_2	w_3	...	v_1	v_2	v_3	F_{pik}	F_{nik}	F_{ik}
1	a_{11}	a_{12}	a_{13}	...	b_{11}	.	. .	F_{p1}	F_{n1}	F_1
1.1	a_{111}	a_{121}	a_{131}	...	b_{111}	.	. .	F_{p11}	F_{n11}	F_{11}
1.2	a_{112}	a_{122}	a_{132}	...	b_{112}	.	. .	F_{p12}	F_{n12}	F_{12}
1.3	a_{113}	a_{123}	a_{133}	...	b_{113}	.	. .	F_{p13}	F_{n13}	F_{13}
⋮	⋮	⋮	⋮							
2	a_{21}	a_{22}			etc.			F_{p2}	F_{n2}	F_2
2.1	a_{211}							F_{p21}		
2.2	a_{212}	etc.	$\left\{ a_{ij} \; a_{ijk} \right\}$		$\left\{ b_{ij} \; b_{ijk} \right\}$			F_{p22}	etc.	etc.
2.3	a_{213}							F_{p23}		

Notation the same as for Method *III*, plus:

a_{ijk} = measure of progress of *kth* component of *ith* strategy toward *jth* Industry Goal.

b_{ijk} = measure of progress of *kth* component of *ith* strategy toward *jth* National Goal.

$\sum_k a_{ijk} = a_{ij}$ [e.g. $a_{111}+a_{112}+a_{113}+ \ldots = a_{11}$]

$\sum_k b_{ijk} = b_{ij}$

$F_{pik} = \sum_j a_{ijk} w_j$ = Figure of merit of *kth* component of *ith* strategy with respect to Industry Goals.

$F_{nik} = \sum_j b_{ijk} v_j$ = Figure of merit of *kth* component of *ith* strategy with respect to National Goals.

$F_{ik} = W\,F_{pik} + V\,F_{nik}$ = Figure of merit of *kth* component of *ith* strategy with respect to over-all weighted Industry Goals and National Goals.

EXHIBIT 10. METHOD IV

SESSION VI

Assessment Workshop

Chairman: **Eugene M. Grabbe**

Leader: **David C. Povey**

Reporters:

Legal and Political Policies – **Francis M. Auburn**

Exploration and Mining – **John L. Mero**

Industry/Processing – **Raymond Kaufman**

Economics – **Agatin T. Abbott**

Environment – **Oswald Roels**

Technology and R & D – **Robert D. Gerard**

Hawaii's Role – **J. Thomas Stuart**

ASSESSMENT WORKSHOP ON MANGANESE NODULE DEPOSITS IN THE PACIFIC

By
Eugene M. Grabbe
Center for Science Policy and Technology Assessment
State Department of Planning and Economic Development
Honolulu, Hawaii

INTRODUCTION

An Assessment Workshop was held on the second afternoon of the Conference from 1:30 to 5:00 p.m. Workshop participants were experts in the field or were aware of the present status of the manganese nodule field from attending the day-and-a-half of technical sessions. Of the 90 individuals attending the Symposium, 44 took part in the Workshop. Members of State and Federal agencies, the Hawaii State Legislature, universities, industry and consultants participated.

The following sections of this paper cover: (1) objectives and general approach, (2) Report by members of each team giving the top three ranking actions or policies formulated in order of priority with their comments, (3) a short description of the Workshop methodology, (4) a complete listing of all ideas generated by each team with number of votes given each item, and (5) a list of Workshop participants.

OBJECTIVES AND GENERAL APPROACH

The objectives of the Workshop were to identify possible solutions and resources needed to meet problems arising in the exploration, recovery, and utilization of manganese nodules.

Assessments were made by having teams consider specific questions developed from the Conference participants' responses to pre-Workshop questionnaires. The form requested responses to the following question: "What do you see as the present needs and future developments in the exploration and utilization of manganese nodules in the Pacific?" It also asked for a priority rating (high, medium or low) of the item and an indication of the interest area (international, national or Hawaiian). About 50 questionnaires were returned, giving 118 items for consideration, from which seven key assessment areas were selected. For each assessment area a "how-" type question was posed. These questions are given in the Workshop Team Reports section.

WORKSHOP METHODOLOGY

The Assessment Workshop used the "Nominal Group Process" developed by Dr. André Delbecq of the University of Wisconsin for problem definition and policy formulation (References 1 to 4.) Participants were assigned to teams and each team considered one question. The process has the following steps: a silent period for idea generation, listing on a chart of all proposals by a recorder, discussion of listed items for clarification, and ballot voting to assign priorities to the top six proposals.

Two teams decided that they could not respond to their "how" questions without first setting priorities for related "what" questions, so they repeated the process several times.

A reporter from each team presented the three top-priority proposals for his subject area to the Workshop group and then questions and comments were entertained from the Workshop as a whole.

The Workshop leader was David Povey, Pacific Urban Studies Planning Program, University of Hawaii. He was assisted in running the Workshop by a staff of seven.

WORKSHOP TEAM REPORTS

TEAM 1: LEGAL AND POLITICAL POLICIES

Reporter: Francis M. Auburn
University of Auckland, New Zealand

<u>Question</u>: How can a suitable approach be taken to granting and controlling rights to manganese nodule deposits in the Pacific? (Continental Shelves, archipelago problem, North Sea approach, patrimonial seas, etc.)

Recommendations: (1) Distinguish between national and international jurisdiction by deriving a United Nations Convention on a generally acceptable definition of "territorial sea," "exclusive jurisdiction for resource exploitation," etc. The team felt that this provision would be a condition precedent, either to a global ocean administration or to an intermediate approach. This first recommendation would promote uniformity and thereby certainty and stability for mining. Other team members felt that such a recommendation should be dealt with simultaniously with global ocean administration, and that the two are interdependent. This recommendation in itself requires much patience and time, which industry may not have. On the other hand it was felt that industry could wait for a relatively short time if it were indeed assured that a successful end would be found.

(2) A global ocean administration, possibly specifically for ocean mining in international waters, should be established. A possible example would be the United States State Department draft common heritage concept. The group felt that this matter may well be time consuming, perhaps because it is closely sensitive to the settlement of the first recommendation and because it is a new and complex law. Common heritage is not a clear concept: in one view the concept has to do with the distribution of benefits; in another view it has to do with developing nations who do not trust developed nations to adhere to an equitable solution. Therefore control is a major issue.

(3) Exercise what we termed an "intermediate approach," which would cover patrimonial sea, exclusive resource zone, trusteeship, and special circumstances for archepelagos and islands. The group felt that there is a wide range of intermediate approaches, and that this matter is sensitive to the first two recommendations. This is an interim approach and it is unlikely that existing understanding of these concepts will cover the known attractive manganese deposits. It is possible that this approach might be complicated by nations' abilities to defend their claims militarily. Others in the group felt that the natural resources in the Pacific (with the

exception of the Continental Shelf, etc.) should be the joint property of the Pan-Pacific Countries, thus granting and controlling rights to manganese nodules belonging to them and shared by them. In this view, adjustment of their respective shares would be settled by considering factors such as the coast length, population, etc., of each specific country. Another view suggested that a regional ocean development community on evaluation of customary law based on state practice could be established.

TEAM 2: EXPLORATION AND MINING
Reporter: John L. Mero, Ocean Resources Inc.
La Jolla, California

Question: How can the greatest needs for exploration of manganese nodule deposits be met? (Test areas, methods, equipment, etc.)

Recommendations: We did not really know what the needs were, so we first had to determine the highest priority needs and then vote on techniques to satisfy the greatest need. It was the general concensus of the team that not enough data exist, which are available to the general public, to justify investments by mining companies who have not done their own exploration. So we identified the following highest priority needs of the 19 ideas submitted:

(1) Techniques for continuous data collection and remote sensing.

(2) Financial and government support.

(3a) Determination properties characterize an economically attractive deposit.

(3b) Knowledge of bottom properties related to engineering and technology.

Then we proposed ten ways to satisfy the greatest need, which is how to develop techniques for data collection. The ideas which received the greatest votes were:

(a) Identify parameters of nodules for remote sensing techniques (scintilometer, geophysical methods, etc.)

(b) Identify properties to be measured and the needed level of accuracy (extent of metals, weight per area of seafloor, etc.), coupled with investigation of remote sensing or, probably the most cost-effective way of gathering this information.

(c) Encourage the combined cooperation of industry, the academic community and government agencies (funds).

TEAM 3: INDUSTRY/PROCESSING

Reporter: Raymond Kaufman, Deepsea Ventures, Inc.
Gloucester Point, Virginia

Question: How can industry meet its most pressing needs in the processing of manganese nodules? (Large, stable, floating platforms; beneficiation; shorebased operations; power/water chemical requirements; Hawaii's Foreign Trade Zone, etc.)

Recommendations: If we agree that there is some benefit to mining manganese nodules and that this natural resource is truly going to be needed to fulfill the requirements as the demand for the metals in nodules grows with the increased population, then we must look at it in a realistic way to encourage rather than discourage its exploitation in a meaningful way.

If we approach it from that point of view and look at industry and processes required as elements of the question our team addressed, the first thing we decided was that we should not talk about the selection of the processes themselves. That in itself is a very very complicated and detailed technical matter: there are many many approaches to processing, and we felt that certainly we neither had the time nor the expertise to fully develop that. So first we directed ourselves to the most pressing needs associated with industry processing. Voting on nine proposed needs gave the following priorities:

(1) Suitable sites for industry

(2) Environmental acceptance

(3) Inexpensive power to meet processing requirements

(4) Reduced transportation costs.

(1) Site Selection: Assuming that there will be a processing plant, where should it be located? We looked at the major elements of site selection and also considered other ideas of general concensus. It was agreed that the first plant, sometimes referred to as the first generation of plants, will probably be located on a shore site facility, near a deep-water port facility, rather than at sea someplace on a floating platform, or artificial island, or ship.

(2) Environmental Acceptance: We felt that it was extremely important early in the development of the processing plant to obtain acceptance of the plant and its location, and to communicate to the citizens what is required. We felt that the process plant developer needs a fixed set of environmental standards to work toward. The people who decide what the quality of the environment associated with the plant will be, should establish a fixed set of standards, so that the developer can meet those standards which should remain fixed at least throughout the economic life of the plant. Associated with this is early presentation to environmental groups: What is involved? How it will change the environment? How can the plant be designed so that it will have an acceptable environmental impact?

(3) Power: Yesterday we saw presentations of what power requirements are going to be associated with population growth and industry growth throughout the world, and we saw that availability of power at reasonable rates is a very important factor in site selection. Associated with this we identified a subject that we called joint industry-governed facilities. What we meant here is that the government should encourage the development of power plants or energy producing activities in various ways, we did not imply that the government should go into the power-generation business, but the State government or national government

should encourage private industry to expand their power plants to meet future needs by various taxation methods (exemptions, price lists, revenue bonds, etc.). Associated with this was the development of low-cost energy sources. Here we directed our attention primarily to the State of Hawaii. What would encourage a process plant to be set up in the State? One of the principal factors in site selection is the cost of energy, and it is much higher in Hawaii than it is in other industrial locations. That is just one factor, but an important factor, and therefore we felt that the development of low-cost energy by reducing the cost of fossil fuel, fuel oil in the Islands, or the development of geothermal energy could be a way to accomplish this.

(4) Transportation costs: Transportation is a large element in the overall ocean mining operation. It is part of site selection and has similar requirements: proximity to mine sites and markets, special and dedicated marine terminals (deep-water ports) and optimal number, size, and speed of ships.

TEAM 4: ECONOMICS

Reporter: Agatin Abbott, Geology and Geophysics, University of Hawaii, Honolulu

Question: How can we plan for the economic impacts of the exploration and utilization of manganese nodule resources in the Pacific?

Recommendations: The economics team agree that the deciding factor of the entire manganese project is economics. If mining nodules is uneconomic it will obviously either not begin, or it will fail midway. The other factors being considered hinge on mineral economics in one way or another, and the subject is really broad. Our top-priority considerations were:

(1) Request an appropriate University agency to initiate an economic analysis of the industry--its past performance, current status, and future prospects--as these relate to the Pacific operations. We had Hawaii in mind, rather than just the general Pacific area. I presume, although we didn't name it, that we had the University of

Hawaii in mind rather than some mainland University. This is a pretty big assignment for a University. It would not, certainly, be restricted to the Economics Department. The State of Hawaii has had no association concerned with mineral economics. We have had no economic mineral industry here at all, so that we are not geared to this kind of thing at the present time. The analysis would involve a Task Force having subsections that would be established at the University. It would include people from economics, geophysics, geology, engineering, and other areas within this University. We might also call on people from other Universities having special talents. The problem of assigning a task such as this to a University suggested the problem of who was going to fund it. Should it be the Federal Government, the State Government, or private enterprise? We were unable to answer this.

(2) Develop the ability to assess the cost of production of deep-sea metals by various methods of mining and processing. This delves deeply into what Raymond Kaufman discussed yesterday, and the various mining and processing methods--the costs, tonnages, etc.--all are involved. Again we believe that a University agency, supported by both information and personnel from Federal agencies such as the Bureau of Mines; the U.S. Geological Survey, Economic Geology Branch; etc.; might work out an economic figure on the types of mining and processing. It is a very large job.

(3) Carefully study metal market trends--past, present and particularly future. This concerns the trends of metals that would be expected to be extracted from manganese nodules (of which there are quite a number)--and new ones seem to be popping up from time to time. The whole field of mineral economics is involved here, and again the Department of Commerce and the Bureau of Mines can supply information. The Bureau of Mines publication Minerals: Facts and Problems was mentioned as a good source of economic market trends in various metals.

TEAM 5: ENVIRONMENT

Reporter: Oswald Roels, Lamont-Doherty Geological Observatory
Columbia University, Palisades, New York

Question: How can we study and anticipate environmental effects of large-scale mining and processing on the marine environment?

Recommendations: The panel originally came up with 22 answers to this question which could essentially be divided into two categories. Some involved expressions of principals regarding how to go about it; others involved detailed approaches to specific small parts of the problem. The three recommendations which finally gained the highest priorities by vote are basically generalizations, and I think this is important in panel sessions of this type to recognize the nature of the results. I have been involved myself in trying to answer this question and have estimated that it would take something like five man-years to develop a detailed program to supply the answer; so only broad generalizations could really find almost unanimous concensus. It was then of some interest to know that the top two recommendations were broad in nature and received votes from nearly everybody on the team. The third recommendation (more specific in nature) received less than half as many votes and was closely followed by three other specific proposals.

(1) Establish an interdisciplinary program to assess the environmental impact on deep-sea mining and all processing, by forming an expert group to study base-line conditions and to measure environmental changes caused by deep-sea mining and all processing.

(2) Direct the interdisciplinary group established above to ask for cooperation from any industrial and scientific groups active in deep-sea mining, in assessing the environmental impact of deep-sea mining and all processing on a world-wide basis.

(3) Develop a monitoring system and establish and control safe environmental limits (this is what you people have in mind) for deep-sea mining and ore processing. I was very pleased to hear that the Industry and Processing team's top recommendations on the environment were similar to our third recommendation: the establishment of environmental standards for deep-sea mining and all processing.

TEAM 6: TECHNOLOGY AND R&D

Reporter: Robert D. Gerard, Lamont-Doherty Geological Observatory, Columbia University
Palisades, New York

Question: How can the major problems in technology best be attacked? (Faster surveys; on-line, in situ analysis; metallurgy, etc.)

Recommendations: We find that two of our proposed items are very similar to those that were given by the Exploration and Mining team.

(1) Conduct detailed fine-scale surveys in a variety of sea-floor provinces where ferro-manganese nodules are known to exist. This involves a complex series of survey requirements and represents a kind of condensation of several of the originally discussed topics. A variety of sampling techniques, sensors, etc., were suggested. They included remote sensing devices characterized by the deep-tow-type packages and other sampling techniques which would include large-volume box corers for samples that can be studied in detail in the laboratory.

(2) Conduct long-term (1-year) ocean flow observations in typical ferro-manganese nodule areas using simple, recoverable recording devices. These devices would include stop-motion photography (one frame per hour), perhaps over a year's time with photographs at short intervals--minutes or hours; current meters; tide gauges; and, if feasible, isotopic nodule growth-rate measurements.

(3) Insure fuller academic/industry exchange of data and information. This was an item that involved considerable discussion and there were very few, if any, detailed expressions of how this could take place. It certainly looms high as a desirable goal and could perhaps be accomplished through the influence of a key Government agency.

TEAM 7: HAWAII'S ROLE

Reporter: J. Thomas Stuart
Office of the Marine Affairs Coordinator
State of Hawaii

Question: How can Hawaii contribute to the exploration, recovery and processing of manganese nodules in the Pacific? (Research center, processing, shipping center, etc.).

Recommendations: Our panel came up with certain recommendations that were really "in-house" recommendations. Our team members were all either from Hawaii State government or from local industry.

In Hawaii at present, we have three major industries: tourism, the military and agriculture. Agriculture is declining; the military is slowly declining; and tourism, some people feel, is going to "eat itself up" one day. The State, I am sure, will support a policy to develop a more stable base for our economy. If manganese nodule mining is feasible for Hawaii, the State should encourage it. Our team decided the recommendations could be classified as functions and resources. The top-priority items are listed for each of these classifications.

A. Functions

(1a) Leadership in Exploration of the Pacific. The Hawaii Institute of Geophysics has been a leader in many areas in geophysics exploration in the Pacific, and we feel that it is an ideal organization to continue its role of leadership in research in manganese nodules in the Pacific, through original studies, support studies, or joint studies from groups on the mainland.

(1b) A Processing Center. The basic question has been touched on: Is it economical to establish a processing center? What are the world economics? and can we do it in Hawaii? Ray Kaufman discussed the problems that we face and where we might provide for a plant site. The State and/or a combination of the State and private industry should initiate action for thorough analysis of all potential plant sites in Hawaii; and if they are available, what should the Hawaiian position be in regard to establishing a processing site? Obviously, we are close to the source of the ore. You can reduce transportation costs but once it is here the waste product does not go any farther.

(2) Spin-Off Industries. One of the main points our team considered was that if we could establish spin-off industries here, instead of worrying about letting the "big guys" on the mainland take care of all the copper we produce, we could have the plants right here, and use the raw material on whichever island we selected for our processing. We would then have no major transportation costs of raw material to the manufacturing concerns. Transportation would involve carrying the finished product from Hawaii to the mainland. This brings up the problems of deep-water ports, transportation, and transhipments, etc., which we did not have time to discuss.

B. Resources

(1) Study of Hawaii's Role. Some of the needed studies are discussed under other items mentioned in both the Functions and Resources sections.

(2a) A Processing Center. The primary concern about establishing a processing center would be determining the market potential in general and the potential for Hawaii. We would need to study the same things we study for spin-off industries. If the processing industry is established on a full-time basis, it would probably be one of the biggest industries in Hawaii. Since we are all from Hawaii, our team made "in-house" recommendations. It is one of the things that Don Overly said you have to look out for: if 200 people say the world is flat, what does the world really look like?

(2b) Resource Bed Proximity. We are close (600-900 miles away) to the area that has the highest manganese, cobalt, and nickel contents. We can provide a base of operations for various survey ships coming through. Although our team did not discuss it, the State does have plans now for acquiring its own area of the harbor. When an oceanographic vessel comes into port, it will be provided with power, water and other facilities. Such a harbor area would service and support the University's research ships, and any other ships that are in port. It is the kind of thing that we would like to get into to build an academic industry in the State.

(3) Existing Research Facilities. The role of the University of Hawaii's Institute of Geophysics has been mentioned above. It operates several research vessels. There are other resource research groups at the University such as the Departments of Ocean Engineering and Chemistry, the J.K.K. Look Laboratory, and the Computer Center. Other Government agencies and private organizations are located in Hawaii. Examples are the State of Hawaii Marine Affairs Coordinator, Makai Range, Inc., the Naval Undersea Center, and the National Marine Fisheries Service.

COMPLETE WORKSHOP TEAM RECOMMENDATIONS

In the voting process each team member voted for what he considered to be the top six proposals, giving the top item 6 points and the lowest ranking item 1 point. Each team member therefore cast 21 votes. Since the teams had different numbers of members, the votes given in the next section have been normalized to 100. Thus, if all team members gave an item top priority it would have 43 percent of the vote (6/21=0.43). Several team members did not vote for six proposals but used some procedure that resulted in low vote totals. Normalizing to 100 removes these anomalies.

Results were transcribed from the charts used at the Workshop. Items marked "deleted" were omitted because of duplication, or were combined with other similar proposals.

SUMMARY

The results of the Assessment Workshop should prove valuable to Federal and State agencies and decision makers, to Universities and to private industry in highlighting the areas in which R&D, analysis and other actions are needed. The Center has received favorable comments on the Workshop, which held the interest of the participants--all of whom stayed for the full 3½-hour Friday afternoon session.

Team 1: LEGAL AND POLITICAL POLICIES

Question: HOW CAN A SUITABLE APPROACH BE TAKEN TO GRANTING AND CONTROLLING RIGHTS TO MANGANESE NODULE DEPOSITS IN THE PACIFIC? (Continental shelves, archipelago problem, North Sea approach, patrimonial seas, etc.)

	No. of Votes	Rank
1. Distinguish national from international jurisdiction by deriving at a United Nations convention, a generally acceptable definition of territorial sea, exclusive jurisdiction for resource exploitation, etc.	23	1
2. A global ocean administration, possibly specifically for ocean mining in international waters; e.g., U.S. State Department draft common heritage concept.	18	2
3. Deleted.	-	-
4. More planning and study of local conditions.	8	6
5. Deleted.	-	-
6. Excepting continental shelves, etc., whole natural resources in Pacific should be joint property of Pan-Pacific countries; granting and controlling rights belonging to them and shared by them. Adjustment of the respective share is settled by considering factors like coast length, population, etc., of each Pacific country.	8	7
7. Deleted	-	-
8. Plan actions in Hawaii to facilitate global ocean administration.	10	5

Team 1: LEGAL AND POLITICAL POLICIES	No. of Votes	Rank
9. Deleted.	-	-
10. Deleted.	-	-
11. Evolution of customary law based on State practice; e.g., gentlemen's agreement, unilateral claims, regulatory arrangements; e.g., S-2801; e.g., international cartel; e.g., enforcement limitations.	11	4
12. Deleted.	-	-
13. Deleted.	-	-
14. Intermediate approach - patrimonial sea, exclusive resource zone, trusteeship, "special circumstances" to cover archipelago.	15	3
15. Extension of Continental Shelf; e.g., alter Continental Shelf Lands Act, U.S.	1	-
16. Regional ocean development community.	6	-
	100	

Team 2: EXPLORATION AND MINING

Question: HOW CAN THE GREATEST NEEDS FOR EXPLORATION OF MANGANESE NODULE DEPOSITS BE MET? (Test areas, methods, equipment, etc.)

WHAT ARE THE NEEDS?

		No. of Votes	Rank
1.	Is there enough data?	3	-
2.	Is enough known about deposits?	1	-
3/14.	Techniques for data collection and remote-sensing devices.	22	1
4.	Size and range of manganese nodule deposits.	3	-
5.	Evaluate concept of ocean mining and need for ocean mining as opposed to land mining.	3	-
6.	Nodule genesis.	5	-
7.	What properties characterize a rich deposit?	9	3
8.	Center for nodule study with a strong leader.	1	-
9.	Geological principle/tool regarding manganese formation.	8	-
10.	Financial and government support.	13	2
11.	Data from other sources	4	-
12.	Knowledge of bottom properties related to engineering and technology.	9	3
13.	Delineation of deposits.	5	-

Team 2: EXPLORATION AND MINING	No. of Votes	Rank
14. See 3/14.	–	–
15. Technology.	3	–
16. Fundamental scientific and statistical studies.	5	–
17. Standardization of data measurements.	3	–
18. Collection, analysis, and distribution of existing data.	3	–
19. Evaluation of mining, processing and transportation.		–
	100	

Team 2: EXPLORATION AND MINING

Question: HOW CAN TECHNIQUES FOR DATA COLLECTION BE DEVELOPED? (First-ranked need, Item 3/14)

		No. of Votes	Rank
1.	Parameters of nodules for remote-sensing techniques (scintilometer, geophysical methods).	18	1
2.	Methods of correlation and handling of data.	10	3
3.	Method for accurate geographic positioning of deposit.	8	-
4.	Combined cooperation of industry, universities, and government (funds).	15	2
5.	Identification of properties to be measured and needed accuracy of measurements (extent of metals, weight/area of seafloor).	18	1
6.	Applications of existing techniques (samplers, side-scan sonar, high-frequency acoustic, reflection profiles).	6	-
7.	Economic evaluation of existing techniques (cost per data point), more detection and data-gathering equipment needed.	6	-
8.	On-going evaluation of total component system.	10	3
9.	Funding of technique development (level of funding to be considered).	8	-
10.	Choice of developer.	1	-
		100	

Team 3: INDUSTRY/PROCESSING

Question: HOW CAN INDUSTRY MEET ITS MOST PRESSING NEEDS IN THE PROCESSING OF MANGANESE NODULES? (Large, stable floating platforms; beneficiation; shore-based operations, power/water chemical requirements, Hawaii's Foreign Trade Zone, etc.)

WHAT ARE THE NEEDS?

	No. of Votes	Rank
1. Suitable sites.	35	1
2. Reduce transportation costs.	12	4
3. Cheap power requirements.	15	3
4. What is beneficiation process?	-	-
5. Amount of government support required.	6	-
6. Environmental acceptance.	23	2
7. Long-term leases of land.	-	-
8. Tax incentives.	9	-
9. Analysis of site selection.	-	-
	100	

HOW CAN THE NEEDS BE MET?
TRANSPORTATION AND SITES
(Items 1 and 2 from NEEDS)

1. Rate application to conferences.	-	-
2. Pre-concentration of mining sites.	8	-
3. Ore transport in foreign-flag vessels.	8	-

Team 3: INDUSTRY/PROCESSING	No. of Votes	Rank
4. Plant located adjacent to marine terminal.	15	-
5. Location of shore bases near mine sites.	15	-
6. Specialized and dedicated marine facilities.	-	-
7. Optimal number, size and speed of ships.	15	-
8. Deep-water port facility	39	1
9. Location of refinery with respect to markets and mine sites.	-	-
10. Submarine barges.	-	-
	100	
ENVIRONMENTAL (Item 6 from NEEDS)		
1. Industry/government education program.	20	-
2. Environmental standards.		
3. Early presentation to environmental groups.	26	2
4. Industry/State monitoring program.	7	-
5. International participation.	-	-
6. Fixed environmental standards.	47	1
	100	
POWER (Item 3 from NEEDS)		
1. Joint industry/government facilities.	33	1
2. Process modification to suit availability of power sources.	-	-

Team 3: INDUSTRY/PROCESSING	No. of Votes	Rank
3. Industry/State/Federal nuclear plant.	-	-
4. Geothermal plant--early development for Hawaii.	25	2
5. Long-range planning to meet power requirements for growth.	17	-
6. Low-cost fuel oil.	25	2
4/6. Develop lowest cost energy source. Combines 4 and 6; this item was proposed after the vote was taken.)	(50)	-
	100	

Team 4: ECONOMICS

Question: HOW CAN WE PLAN FOR THE ECONOMIC IMPACT OF THE EXPLORATION AND UTILIZATION OF MANGANESE NODULE RESOURCES IN THE PACIFIC?

	No. of Votes	Rank
1. Develop the ability to assess the cost of production of deep-sea metals by the various methods of mining and processing. Information collection, University agency, Bureau of Mines, and U.S. Geological Survey.	10	2
2. Survey, sample and assay manganese areas, map known reserves for various metals (University agency).	7	4
3. Request appropriate University agency to initiate economic analysis of industry--past performance, current status, and future prospects--as these relate to Pacific operations.	11	1
4. Study trends in supply and demand of nickel, copper and cobalt in the U.S. (Bureau of Mines, Commerce).	8	-
5. Planning for impact must be on a regional basis. Using improved demand and technological forecasting studies (Hawaii State Department of Planning and Economic Development, Bureau of Mines, other Federal agency).	3	-
6. Catalog and locate potential production sites, considering known processes and their pre-requisite (Department of Planning and Economic Development).	6	6
7. Estimate cost of setting up mining procedures and cost of ore beneficiation--land or sea? (University agency, industry).	6	6

Team 4: ECONOMICS

	No. of Votes	Rank
8. Request appropriate State agency to contact existing and potential firms to determine degree of interest and commitment to manganese operations in the Pacific.	3	-
9. Determine cost trends in the exploration and development of land nickel and copper mines (Federal agency, mining schools).	3	-
10. As marine metal from nodules enter market, estimate international market effects (Treasury Department, Interior Department).	1	-
11. Request State of Hawaii to indicate degree of State support committed to ocean mining (land, facilities, and tax concessions).	7	4
12. Plan land-based support such as administration, docks, scientific laboratories, housing, etc. (State agencies).	5	-
13. Integrate planning for manganese development with the State's comprehensive planning and land use control process (Department of Planning and Economic Development).	9	3
14. Estimate capital availability based on growth estimates of land and marine-based mining (Federal agencies, business schools).	6	5
15. Establish information clearinghouse for processes and methods to facilitate advanced planning of physical facilities (University, Federal government).	5	-

Team 4: ECONOMICS	No. of Votes	Rank
16. Determine taxes--local and national policies (State, Federal).	6	6
17. Determine impacts on land-based mining once production is established (Federal agency).	4	-
18. Determine the relevant level of planning--industry, State, and national.	-	-
	100	

Team 5: ENVIRONMENT

Question: HOW CAN WE STUDY AND ANTICIPATE ENVIRONMENTAL EFFECTS OF LARGE-SCALE MINING AND PROCESSING ON THE MARINE ENVIRONMENT?

		No. of Votes	Rank
1/6/11.	Establish very close collaboration between industry, the public, and the U.S. Government in environmental impact assessment of deep-sea mining and processing (e.g., IDOE, NOAA, American Mining Congress, government, universities, and interested groups).	21	2
2/15.	Establish interdisciplinary program to assess environmental impact of deep-sea mining and processing by forming expert groups (see 15).	22	1
3.	Provide research-vessel and mining-vessel space and time to conduct a complete monitoring of the oceanic environment before, during, and after mining tests.	5	-
4.	Establish small areas for detailed studies of environmental base-line conditions in a prospective mine area, including adjacent control areas.	9	4
5.	Deleted.	-	-
6.	Approach all industries from any nation to collaborate on environmental impact assessment. (Voted as 1/6/11)	-	-
7.	Collect all existing information in equatorial Pacific relevant to the base line in the marine environment and compile in an Atlas.	9	4

Team 5: ENVIRONMENT

		No. of Votes	Rank
8/17/20.	Develop suitable equipment and techniques to monitor both short-and long-term effects of mining operations in the ocean.	6	–
9.	Develop <u>in situ</u> equipment (visual and mechanical) to monitor normal sea-floor processes (biological, geological, etc.)	3	–
10.	Develop floor-chart path to link final environmental assessment programs together.	1	–
11.	Request deep-sea mining industries to solicit public and government participation in their own nations in environmental impact assessment. (Voted as 1/6/11)	–	–
12.	Obtain cooperation from industry to make publicly available all environmental impact information.	–	–
13.	Deleted.	–	–
14.	Determine effect of mining on benthic organisms compared to organisms living right off the ocean bottom.	–	–
15.	Form expert groups to assess all baseline conditions and manganese nodule areas to measure changes in these conditions during and after mining. (Voted as 2/15.)	–	–
16.	Evaluate the effects on the environment of present and proposed processes for converting nodules to metal (waste disposal, etc.).	5	–

Team 5: ENVIRONMENT

		No. of Votes	Rank
17.	Develop monitoring equipment to interface with various types of mining equipment. (Voted as 8/17/20.)	-	-
18.	Trace movement of sediments following mining and determine settling times.	-	-
19/21.	Assess harmful and potentially beneficial environmental effects of deep-sea mining to guide development of improvements in mining and processing techniques.	9	4
20.	Develop sensitive analytical techniques to measure subtle long-term changes in concentration of organic and inorganic species in sea water. (Voted as 8/17/20.)	-	-
21.	Explore possible beneficial efforts of mining organizations (reduced number of land-based mines, useful by-products, mariculture, etc.). (Voted as 19/21.)	-	-
22.	Establish monitoring (environmental system for deep-sea mining and processing).	10	3
		100	

Team 6: TECHNOLOGY AND R&D

Question: HOW CAN THE MAJOR PROBLEMS IN TECHNOLOGY BEST BE ATTACKED? (Faster surveys; on-line, in situ analysis; metallurgy, etc.)

	No. of Votes	Rank
1/7/9. Pre-mining surveys:	16	1
a. Remote sensors for information processing, in situ-neutron activation tools.		
b. Deep-tow instruments, side-scan sonar.		
c. Improve box cores (large).		
d. In situ physical property instruments; e.g., penetrometer.		
2. In situ analysis--small area surveying of economically interesting manganese deposits.	6	-
a. Element analysis--remote sensor especially Pingle-sled.		
b. Sediment/H_2O interface analysis--chemical/manganese/sediment-type potential and vector between two.		
c. Nodule density--morphological analysis.		
3. Fundamental understanding of nuclide-absorption/nucleation reactive colloid chemistry and how to apply to real world.	8	-
4/5. Systems analysis:	12	5
a. Large pool of motivated scientists and engineers.		

Team 6: TECHNOLOGY AND R&D

	No. of Votes	Rank
b. Development of sea kindly hull forms--low water plane (LWP) area multi-hull.		
c. Mathematical simulation of dredging and cable systems.		
5. Deleted.	-	-
6. High-resolution macro/micro bathymetry deep-sea sediment behavior in response to mining conditions. Establish test site for ground truth studies.	13	4
7. Very careful site seldction by academicians and industry. Add academic personnel on mining ships under government support to conduct experimental programs of monitoring effluent.	-	-
8. Insure academic interaction with all mining activity.	14	3
9. Detail surveys of limited areas where nodules might be expected to have different characteristics. (Voted as 1/7/9.)	-	-
10. Metallurgical research.	-	-
11. Past mining survey.	4	-
12. Better standards of analytical techniques and analysis.	6	-
13. Identify problem areas.	-	-

Team 6: TECHNOLOGY AND R&D

	No. of Votes	Rank
a. Advanced navigation on surface and bottom.		
b. How to proceed in rough water in very bad storms without losing rig.		
c. Stable platforms for life environment.		
14. Develop advanced deep-sea T.V. systems.	2	-
15. Long-term bottom measurements. Stop-motion photos--1 year duration, bottom profiles current and diffusion; growth rate nuclear tracer experiments	15	2
16. Recovery and processing:	3	-
a. Platforms--multi-hull spherical.		
b. Shore-based technology.		
(1) Disposal of tailings.		
(2) Production of power and water.		
	100	

Team 7: HAWAII'S ROLE

Question: HOW CAN HAWAII CONTRIBUTE TO THE EXPLORATION, RECOVERY AND PROCESSING OF MANGANESE NODULES IN THE PACIFIC? (Research Center processing, shipping center, etc.)

		No. of Vote	Rank
1.	Existing research facilities.	5	3
2.	Government, joint private/public industry development.	4	-
3.	Good location for product distribution.	4	-
4.	Foreign Trade Zone.	3	-
5.	Develop geothermal power.	3	-
6.	Study of constraints to local processing--land, power, harbor, construction and operating labor, water, etc.	5	-
7.	Resource bed proximity--immediate offshore, Keana Point, etc., 600-900 nautical miles distant.	6	2
8.	Availability of plant site.	-	-
9.	Support-base function for shipboard operation.	9	(3)
10.	Availability of manpower.	-	-
11.	Promotion of Hawaii area as a resource base.	3	-
12.	Leadership in exploration in Pacific.	14	(1)
13.	Deleted.	-	-
14.	Processing Center.	14	(1)

Team 7: HAWAII'S ROLE

		No. of Vote	Rank
15.	Study of transshipment.	-	-
16.	Floating platform experimentation.	1	-
17.	Favorable State attitude toward industry.	4	-
18.	Spin-off industries (using products extracted from manganese nodules).	10	(2)
19.	Economic feasibility of the industry.	6	[2]
20.	Study of Hawaii's Role.	9	[1]
		100	

Rank: Functions ◯

Resources □

WORKSHOP PARTICIPANTS

Agatin Abbott, University of Hawaii, Department of Geology and Geophysics
Helen Altonn, Honolulu Star-Bulletin
Anthony Amos, Lamont-Doherty Geological Observatory, Columbia University
James Andrews, University of Hawaii, Department of Oceanography
Francis M. Auburn, University of Auckland, New Zealand
Burton Barnes, Marine Minerals Technology Center, NOAA, Tiburon, California
Jesse Burks, Naval Undersea Center, Kailua, Hawaii
David Cole, University of Hawaii, Sea Grant Office
Robert Cooke, International Nickel Co., Bellevue, Washington
Edward M. Davin, IDOE, National Science Foundation, Washington, D.C.
Jane Frazer, Scripps Institution of Oceanography, La Jolla, California
Robert Gerard, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York
Geoffrey Glasby, New Zealand Oceanographic Institute, Wellington, New Zealand
James Greenslate, Scripps Institution of Oceanography, La Jolla, California
Sheldon Hall, Kennecott Copper Co., San Diego, California
Barbara Horn, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York
David R. Horn, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York
Bill Huijnen, Occidental Mineral Corporation, Wheat Ridge, Colorado
Robert Iversen, National Marine Fisheries Service, Honolulu
David L. Jones, HAWTIC, Hawaii State Department of Planning and Economic Development
Raymond Kaufman, Deepsea Ventures, Inc., Gloucester Point, Virginia
George Kent, University of Hawaii, Department of Political Science
Isoa Kikuchi, Mitsui & Company, New York
Roy Leffingwell, Hawaii Association of Industries, Honolulu
Shelley M. Mark, Director, Hawaii State Department of Planning and Economic Development
Commander Yoshio Masuda, Japan Maritime Safety Force, Tokyo

John Mero, Ocean Resources, Inc., La Jolla, California
Maury Meylan, University of Hawaii, Dept. of Oceanography
J. Robert Moore, University of Wisconsin, Marine Research Laboratory
Charles Morgan, University of Wisconsin, Marine Research Laboratory
Maury Morgenstein, University of Hawaii, Dept. of Oceanography
Senator Donald Nishimura, Chairman, Hawaii State Senate Committee on Economic Development
Myron Nordquist, U.S. Department of State, Office of Legal Advisory, Washington, D.C.
Kyran O'Dwyre, Dillingham Corporation, Honolulu
Howard Pennington, State of Hawaii, Marine Affairs Coordinator's Office
Louis Rancitelli, Battelle Northwest, Richland, Washington
Anthony Raspolic, U.S. Department of Interior, Ocean Resources
Oswald Roels, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York
Craig Rovzar, State of Hawaii, Department of Planning and Economic Development, Foreign Trade Zone
Ludwig Seidl, University of Hawaii, Ocean Engineering
George Sheets, University of Hawaii, Center for Engineering Research
J. Thomas Stuart, State of Hawaii, Marine Affairs Coordinator's Office
Clarence Walker, Mermaid Beach, Queensland, Australia
Conrad Welling, Lockheed Missiles & Space Company, Sunnyvale, California

WORKSHOP STAFF

Eugene M. Grabbe, Hawaii State Center for Science Policy and Technology Assessment, DPED, Workshop Chairman
David C. Povey, Pacific Urban Studies and Planning Program, University of Hawaii, Workshop Leader
Ginger Plasch, Hawaii State Center for Science Policy and Technology Assessment, DPED
Wilkes Covey, University of Hawaii, Department of Oceanography
Jerry Foreman, University of Hawaii, Department of Oceanography
Bill Kloos, University of Hawaii, Pacific Urban Studies and Planning Program
Chip Landmesser, University of Hawaii, Department of Oceanography

Ken Lowry, University of Hawaii, Pacific Urban Studies and Planning Program
Mike McElroy, University of Hawaii, Pacific Urban Studies and Planning Program
Glen Sicks, University of Hawaii, Department of Oceanography
Randy Wong, University of Hawaii, Pacific Urban Studies and Planning Program

Concluding Remarks

James E. Andrews

CONCLUDING REMARKS

By
James E. Andrews
University of Hawaii
Honolulu, Hawaii

It has been a great honor for Hawaii to host this Symposium/Workshop. The papers presented here by internationally distinguished authorities in the fields of exploration and utilization of manganese nodule deposits in the Pacific have provided an excellent, up-to-date review of this field. Many of the speakers have also indicated their views on Hawaii's potential role concerning manganese nodules, which we naturally appreciate. And the Assessment Workshop provided a priority listing of urgent needs in the major areas covered.

It is our hope that this Symposium/Workshop and its Proceedings will provide added impetus to all activities in the manganese nodule field, and will stimulate increased support for Federal agency and University laboratories across the nation.

Hawaii will continue to serve as a support base for vessels exploring for manganese nodules in the Pacific. The University of Hawaii's Institute of Geophysics has a continuing research program on manganese nodules and HIG research vessels have assisted various organizations in exploration. We hope that our University research program will grow and that it will receive continued support from the State of Hawaii and from Federal agencies. Tapping the rich mineral resources found in manganese nodule deposits can be of great value to our nation, the world, and Hawaii.

List of Conferees

MANGANESE NODULE DEPOSITS IN THE PACIFIC

A Symposium/Workshop

October 16-17, 1972

LIST OF CONFEREES

A

Dr. Agatin Abbott
Professor of Geology
Department of Geology and Geophysics
HIG 233
University of Hawaii
Honolulu, Hawaii 96822

Mrs. Helen Altonn
Honolulu Star-Bulletin
605 Kapiolani Boulevard
Honolulu, Hawaii 96813

Mr. Anthony F. Amos
871 River Road
Piermont, New York 10968

Dr. George Andermann
Associate Professor of Chemistry
Chemistry Department
Bilger 218
University of Hawaii
Honolulu, Hawaii 96822

Dr. James Andrews
Associate Professor
Department of Oceanography
HIG 339
University of Hawaii
Honolulu, Hawaii 96822

Mr. Ben Asakura, Director
Office of Economic Development
County of Kauai
P. O. Box 111
Lihue, Kauai 96766

Dr. F. M. Auburn
University of Auckland, Private Bag
Auckland, New Zealand

B

Mr. Burton B. Barnes
National Oceanic and Atmospheric Administration
Marine Minerals Technology Center
3150 Paradise Drive
Tiburon, California 94920

Mr. Meyer Bogost
Office of Environmental Quality Control
Room 436, State Capitol
Honolulu, Hawaii 96813

Captain Jesse B. Burks (USN ret.)
Director, Naval Undersea R&D Center
Hawaii Laboratory
P. O. Box 997
Kailua, Hawaii 96734

Mr. E.E.S. Burns, Jr.
Amfac, Inc.
P. O. Box 3230
Honolulu, Hawaii 96801

C

Mr. John F. Campbell
Jr. Geophysicist
HIG 206
University of Hawaii
Honolulu, Hawaii 96822

Mrs. Mary Chapman
Associate Editor
Hawaii Business
P. O. Box 913
Honolulu, Hawaii 96808

Professor Keith Chave
Chairman and Professor of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Mr. David Cole
Sea Grant Office
Spalding 253
University of Hawaii
Honolulu, Hawaii 96822

Mr. Robert Cooke
International Nickel Co., Inc.
300 - 120th Avenue, N.C.
Bldg. 4, Suite 219
Bellevue, Washington 98005

C (Continued)

Mr. Wilkes Covey (Student)
Department of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Dr. John P. Craven
Marine Affairs Coordinator
c/o Liliuokalani Building, Rm. 208
1390 Miller Street
Honolulu, Hawaii 96813

D

Dr. Jack Davidson, Director
Sea Grant Programs
Spalding 253
University of Hawaii
Honolulu, Hawaii 96822

Dr. Edward M. Davin
National Science Foundation
Office of the International Decade of Ocean Exploration
Washington, D.C. 20550

Mr. Henry Dulan
P. O. Box 194
Halaula, Hawaii 96711

F

Mr. Jerry Foreman (Student)
Department of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Ms. Jane Frazer
Scripps Institution of Oceanography
P. O. Box 109
La Jolla, California 92037

Mr. Russell Freeman
Regional Director
U.S. Environmental Protection Agency
Room 423, 1481 South King Street
Honolulu, Hawaii 96814

G

Dr. Robert D. Gerard
Coordinator, Ferromanganese Program
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

Professor Hans Gerritsen
Chairman Ocean Engineering
Keller 219 A
University of Hawaii
Honolulu, Hawaii 96822

Dr. Geoffrey P. Glasby
New Zealand Oceanographic Institute, D.S.I.R.
P. O. Box 8009
Wellington, New Zealand

Dr. Eugene M. Grabbe, Project Manager
Hawaii State Center for Science Policy
and Technology Assessment
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

Dr. James Greenslate
Scripps Institution of Oceanography
P. O. Box 109
La Jolla, California 92037

H

Mr. Sheldon Hall
Kennecott Exploration Inc.
10306 Roselle Street
San Diego, California 92121

Mr. John Hance
Amfac, Incorporated
P. O. Box 3230
Honolulu, Hawaii 96801

Mr. Raymond C. Harbert
General Manager, Pacific Test Division
Holmes & Narver, Inc.
531 Ohohia Street
Honolulu, Hawaii 96819

Mr. Dan Ho, Executive Intern
Office of the Lieutenant Governor
State Capitol
Honolulu, Hawaii 96813

H (Continued)

Mrs. Barbara Horn
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

Dr. David R. Horn
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

Mr. Bill Huijnen
Occidental Mineral Corporation
6073 W. 44th Avenue
Wheat Ridge, Colorado 80033

I

Mr. Robert T. B. Iversen
Fisheries Research Biologist
National Marine Fisheries Service
P. O. Box 3830
Honolulu, Hawaii 96812

J

Mr. Raymond W. Jenkins, President
Dillingham Mining Co.
1441 Kapiolani Boulevard
Honolulu, Hawaii 96814

Mr. David L. Jones
Executive Officer
Hawaii Technological Information Center
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

K

Mr. Raymond Kaufman
Deepsea Ventures, Inc.
Gloucester Point, Virginia 23062

Mr. George Kent
Department of Political Science
Hawaii Hall 23 B
University of Hawaii
Honolulu, Hawaii 96822

K (Continued)

Mr. Isao Kikuchi
Mitsui & Company, Ltd.
Technical Development Center
200 Park Avenue
New York, New York 10017

Mr. Arnold Kishi
Science Writer
The Honolulu Advertiser
P. O. Box 3110
Honolulu, Hawaii 96802

Mr. Bill Kloos (Student)
Pacific Urban Studies Program
Building No. 11
University of Hawaii
Honolulu, Hawaii 96822

Dr. Peter Kroopnick
Assistant Professor
Department of Oceanography
HIG 314, 303
University of Hawaii
Honolulu, Hawaii 96822

L

Mr. Chip Landmesser (Student)
Department of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Mr. Francis L. Laque
Claridge Drive
Verona, New Jersey 07044

Mr. Mark E. Lawson
Hawaiian Electric Company
P. O. Box 2750
Honolulu, Hawaii 96803

Mr. Roy J. Leffingwell
Executive Vice President
Hawaii Association of Industries
Suite 411, 235 Queen Street
Honolulu, Hawaii 96813

Mr. Ken Lowry (Student)
Pacific Urban Studies Program
Building No. 11
University of Hawaii
Honolulu, Hawaii 96822

M

Dr. Stanley Margolis
Assistant Professor
Department of Oceanography
HIG 314
University of Hawaii
Honolulu, Hawaii 96822

Dr. Shelley M. Mark, Director
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

Cmdr. Yoshio Masuda
Oceanographic Unit
Japan Maritime Safety Force
Akasaka, Japan, Minataku
Tokyo, Japan

Dr. Fujio Matsuda, Director
Department of Transportation
869 Punchbowl Street
Honolulu, Hawaii 96813

Mr. Brad Matsunaga, Executive Intern
Office of the Lieutenant Governor
State Capitol
Honolulu, Hawaii 96813

Mr. Homer Maxey, Manager
Foreign Trade Zone
Pier 39
Honolulu, Hawaii 96817

Mr. Mike McElroy, Student
Pacific Urban Studies Program
Building No. 11
University of Hawaii
Honolulu, Hawaii 96822

Dr. John L. Mero
Ocean Resources, Inc.
P. O. Box 2244
La Jolla, California 92037

Mr. Maury Meylan
Department of Oceanography
HIG 339
University of Hawaii
Honolulu, Hawaii 96822

M (Continued)

Professor Ralph Moberly
Professor of Geology & Geophysics
HIG 232
University of Hawaii
Honolulu, Hawaii 96822

Dr. J. Robert Moore
Marine Research Laboratory
1341 Engineering Research Building
University of Wisconsin
Madison, Wisconsin 53706

Dr. Charles Morgan
Marine Research Laboratory
1341 Engineering Research Building
University of Wisconsin
Madison, Wisconsin 53706

Mr. Maury Morgenstein
Graduate Assistant
HIG 215
University of Hawaii
Honolulu, Hawaii 96822

N

Senator Donald S. Nishimura
Chairman, Senate Committee on Economic Development
Room 201, State Capitol
Honolulu, Hawaii 96813

Mr. Myron H. Nordquist, Attorney-Adviser
Office of Legal Advisory
Department of State
Washington, D. C. 20520

O

Mrs. Eileen O'Brien
Information Specialist
Office of Information and Public Services
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

Mr. Kyran O'Dwyer
Dillingham Corporation
1441 Kapiolani Boulevard
Honolulu, Hawaii 96814

O (Continued)

Mr. Don Overly
International Research & Technology Corporation
Suite 601, 1225 Connecticut Avenue, N.W.
Washington, D. C. 20036

P

Dr. Robert L. Pecsok
Professor and Chairman
Department of Chemistry
Bilger 118
University of Hawaii
Honolulu, Hawaii 96822

Mr. Howard Pennington
Marine Affairs Coordinator's Office
c/o Liliuokalani Building, Room 208
1390 Miller Street
Honolulu, Hawaii 96813

Dr. Edward A. Perry, Jr.
Department of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Mrs. Ginger Plasch
Hawaii State Center for Science Policy
and Technology Assessment
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

R

Dr. Louis A. Rancitelli
Battelle Northwest
P. O. Box 999
Richland, Washington 99352

Mr. Anthony Raspolic
Ocean Resources
U.S. Department of the Interior
922 24th Street, N.W.
Washington, D. C. 20037

R (Continued)

Dr. Leigh Ratiner
Director for Ocean Resources
Office of the Assistant Secretary, Mineral Resources
U. S. Department of the Interior
Washington, D. C. 20240

Dr. Oswald Roels
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964

Mr. Craig Rovzar
Foreign Trade Zone
Pier 39
Honolulu, Hawaii 96817

S

Mr. Lloyd Sadamoto, Acting Director
Department of Research and Development
County of Hawaii
25 Aupuni Street
Hilo, Hawaii 96720

Mr. Tom Sakata
Marketing Specialist
Economic Development Division
Department of Planning and Economic Development
P. O. Box 2359
Honolulu, Hawaii 96804

Dr. Ludwig H. Seidl
Associate Professor of Ocean Engineering
Kell Hall 201
University of Hawaii
Honolulu, Hawaii 96822

Mr. Toshio Serizawa
Agricultural Coordinator
Room 303, 550 Halekauwila Street
Tani Building
Honolulu, Hawaii 96813

Mr. George Sheets
Center for Engineering Research
Holmes Hall 240
University of Hawaii
Honolulu, Hawaii 96822

Dr. John W. Shupe
Dean, College of Engineering
Holmes Hall 240
University of Hawaii
Honolulu, Hawaii 96822

Mr. Glen Sicks (Student)
Department of Oceanography
HIG 342
University of Hawaii
Honolulu, Hawaii 96822

Mr. Tom Stuart
Marine Affairs Coordinator's Office
c/o Liliuokalani Building, Room 208
1390 Miller Street
Honolulu, Hawaii 96813

V

Dr. H. Herbert Veeh
Assistant Professor of Geology & Geophysics
HIG 220
University of Hawaii
Honolulu, Hawaii 96822

W

Mr. Clarence H. Walker, Jr.
101 Hedges Avenue
Mermaid Beach
Queensland, Australia 4218

Mr. Conrad G. Welling
Lockheed Missiles & Space Company
P. O. Box 504
Sunnyvale, California 94088

Mr. Robert Wing
National Oceanic and Atmospheric Administration
Marine Minerals Technology Center
3150 Paradise Drive
Tiburon, California 94920

Mr. Randy Wong (Student)
Pacific Urban Studies Program
Building No. 11
University of Hawaii
Honolulu, Hawaii 96822

W (Continued)

Dr. George P. Woollard
Director, Hawaii Institute of Geophysics
HIG 131
University of Hawaii
Honolulu, Hawaii 96822

Rear Admiral E. Alvey Wright (USN ret.)
Deputy Director for Operations
Department of Transportation
869 Punchbowl Street
Honolulu, Hawaii 96813

Y

Mr. Tatsuji Yamamoto
Sales Engineer
Brewer Chemical Corporation
P. O. Box 48
Honolulu, Hawaii 96810