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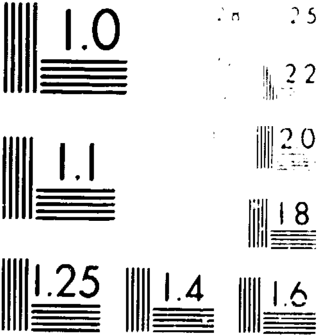
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OCEAN MINING AND DEVELOPING COUNTRIES:
AN APPROACH TO TECHNOLOGICAL DISAGGREGATION *

by

Elisabeth Mann Borgese
UNIDO consultant

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In addition to the common abbreviations, symbols and terms and those accepted by the International System of Units (SI), the following have been used in this study:

IOI	International Ocean Institute
JPL	Jet Propulsion Laboratory
MIT	Massachusetts Institute of Technology
MTBF	mean-time-between-failures
NOAA	National Oceanic and Atmospheric Administration
R+D	research and development
TV	television

CONTENTS

Page

Part I - Mining

PREFACE

As part of its programme on technological advances, the Technology Programme of UNIDO has been carrying out studies and organizing meetings on the subject of the implications of those advances for developing countries, in particular in regard to industrial development.

Several sectors have been taken up for examination in this respect such as microelectronics, genetic engineering and biotechnology, and space-related technologies.

In the case of ocean mining one study has already been brought out: "Technologies for Investigation and Exploitation of Seabed Resources: The Potential for Developing Countries".1/

The present study attempts to consider in some detail the subject of disaggregation of ocean mining technologies and technologies for processing minerals so as to facilitate greater participation of developing countries in such activities. Part I deals with mining and Part II with processing.

The study was commissioned through and co-ordinated by Elisabeth Mann Borgese who also wrote the introduction.

1/ UNIDO/IS.257.

INTRODUCTION

The second half of the twentieth century marks the beginning of a phase of history that is significantly different from all previous phases. Few, indeed, are the breaking points in the course of world history that are as sharp and deep as that presented by the post-Second World War period. The discovery of fire, or the beginning of agriculture and of urban civilization, may come to mind; the rise and fall of the Old World empires in Classical Antiquity or the Middle Ages, or the discovery of the New World and the industrial revolution may have been "breaks" of this magnitude.

Our era is characterized by the penetration of outer space and ocean space and a new phase of the industrial revolution - basically different from those phases that preceded it - which is transforming the environment, war and peace, international relations, society, and human nature itself.

The first phases of the industrial revolution, based on coal and on oil, were labour-intensive and resource-intensive. This encouraged the conquest and exploitation of the non-industrialized world by the industrialized world. As capital accumulated, resources were depleted and the cost of labour rose; cheap labour and raw materials turned into comparative advantages. Technological developments and requirements, social infrastructure, and the structure of economic international relations were closely interlinked.

The present phase of the industrial revolution, based on high technology, such as the nuclear and microelectronic industries or the bio-industries, is neither labour- nor resource-intensive. The more advanced this phase of the revolution is, the less resource- and labour-intensive it will be. As resources are synthesized, recycled, and extracted from the oceans or, eventually, the moon, and automation is substituted for labour, the comparative advantage is wiped out, and painful displacements occur, both within the industrialized societies and between the industrialized and the non-industrialized world. These displacements, linked to the introduction of the new high technologies, are at the root of the present world crisis. No economic theory, no governmental practice has been able, thus far, to cope with it. In international economic relations, this new phase of the industrial revolution may lead to the marginalization of the non-industrialized world. To call it "delinkage" does not solve the problem.

Ocean mining must be seen in this wider context. Based on highly capital-intensive technologies, it may displace the miners within industrialized countries and the land-based producers among the developing countries. If ocean mining turns out to be economically competitive; if, in an increasingly overcrowded world, it reduces conflict with competing land-uses; if it is less harmful to the environment; if it is labour-saving and lowers the cost of transportation: then ocean mining will displace land-mining over the next fifty years or so, and no one should be deceived by the apparent slow-down, due to the current economic recession.

Hence it is imperative to study the impact of ocean mining on developing countries, both in the short and in the long term. It is imperative to devise ways and means to contain the negative consequences and to maximize benefits, both for developing and industrialized countries. Technological change is like a force of nature. One can sit back; let it pass over one, and have it take its toll of destruction; or one can anticipate it: harness it to expend its force in useful work, and thereby diminish its destructive potential.

The degree and the speed, to which or at which developing countries can join this sector of the new industrial revolution depends, of course, on the degree of their internal evolution and preparedness. Every country, however, even the least developed, can do something to join this new phase of industrial revolution, in view of the long-term benefits, and in order to avoid the alternative of marginalization and stagnation. No doubt, it is the more dynamic, and more productive alternative. The disaggregation of ocean mining technology is seen as an important step in building the capacity to join the new industrial revolution.

Part I of the study was prepared by Manfred G. Krutein, consultant, Irvine, California, United States of America. It describes the state of the art of ocean mining technology. It is an attempt to demystify the mystique of a technology, supposedly so highly complex and costly that only two or three of the most advanced nations in the world can master and own it. Here this arcane technology is disaggregated into its numerous component systems and subsystems, from oceanographic exploitation through mining, shipping, port management, processing, data processing, and systems management.

The charts of disaggregated technologies presented in Part I, showing the degree of complexity - from simple to highly complex, and the stage of development - from "available" to "requiring R and D" - indicate to the planners in developing countries at a glance what their countries can contribute, and how they can benefit from joining an ocean mining venture. This should contribute to a better understanding of the potential role of non-industrialized countries in the new industry, and the potential of the new industry for their development.

Part II extends the same type of investigation to the problems of processing where, as will be shown, land-mining developing countries can make a special contribution and draw special benefits, although transportation costs as well as environmental problems will have to be taken into due consideration.

According to one school of thought, processing, with the attendant downstream manufacturing industries, should in fact be the starting point for the International Sea-bed Authority and for developing countries. It is there, according to this theory, where a comparative advantage could be created, utilizing existing facilities for the processing of land-based resources. Once developing countries, and the Authority, play an important role in the processing sector, industrial development is rolled back, and the "operator" gradually penetrates into the mining, exploitation, and prospecting stages.

Attractive though this theory may sound to some land-based producers, it has its draw-backs. In the first place, according to all calculations, the processing sector is the most costly sector of a.. integrated mining operation: almost 60 per cent, according to the MIT Cost Model; secondly - and much more important - there is a problem of timing. Commerical-scale processing will not get under way before the end of this century: and why should developing countries wait that long, while the industrialized countries keep moving in other sectors?

A beginning must be made towards bringing developing countries into the new phase of the industrial revolution described in the opening pages of this introduction: towards freeing them of the shackles of a post-colonial extraction economy and towards building the foundations of a truly new international order.

Part II was prepared by Dr. W. William Harvey, consultant, Arlington, Massachusetts, United States.

Annex I was written for the Training Programme of the International Ocean Institute (IOI) on ocean mining, and included in the Interdisciplinary Manual published by IOI. It contains some additional information on the advantages and problems of siting a processing plant in a developing country.

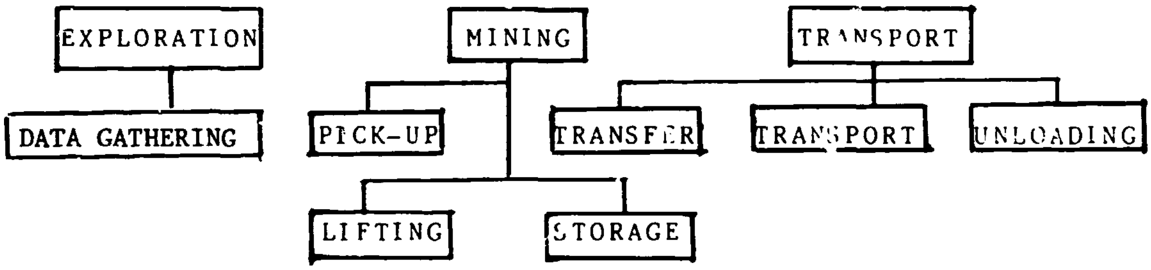
PART I

I. OCEAN MINING

A. MINING SYSTEMS SUGGESTED BY CONSORTIA

Ocean mining involves many complex operations, but these may be subdivided into offshore and onshore activities. The onshore activities (which include on-land processing and sales) will not be discussed in this part. The offshore operations require systems for exploration, mining and transport. These basic systems may be subdivided into functional operations as shown in Figure I.

Figure I. Ocean Mining Processes



Each of these processes must be considered as part of one complete systems approach for which all subsystems and components must be designed as complementing parts. This report on subsystems and components for ocean mining will discuss initially the different mining methods developed by several ocean mining consortia. The complexity and sophistication of the methods developed by various consortia show variations in the systems and functional methods.

The four principal mining concepts utilized by consortia are:

Hydraulic systems: (a) with pumps as a lift system

(b) with an air lift subsystem.

Mechanical systems: (a) with an endless bucket line loop
(b) with numerous individual scrapers

Hydraulic Mining Concepts

This concept uses a special mining vessel that stays in the mining area continuously (two to four years) until dry-docking is required. When the mining vessel arrives in the mining area, the nodule collector and the ore lift pipe are lowered to harvest manganese nodules from the sea floor. The nodules are lifted either by pumps or an air lift system through the pipe line to the mining vessel, separated from bottom sediments, and transferred to a nearby nodule carrier transport vessel. During the time required for a replacement manoeuvre of the filled nodule carrier by an empty one, the nodules can be stored in the mining vessel's storage hold in order to continue mining activity without any interruption.

A mining pattern must be laid out in advance, based on the results of a thorough exploratory survey providing sufficient data about the nodule deposit and its bathymetry to warrant mining operations.

Ore lift pumps (when used) must be arranged in the pipe line at a considerable depth below the mining vessel. When maintenance is required on pump impellers,liners and motors, the mining activities must be interrupted to lift these components into the mining vessel. An air lift system offers the advantage of having the essential components such as compressors, motors and controls on board the mining vessel with easy access for maintenance.

The nodule collector is a crucial system component and should utilize highly reliable parts. Any failure of a critical part would require on-board maintenance which would interrupt the mining activity and reduce its profitability. Redundance of critical parts should be thoroughly considered. This concept requires a very high technical training in several professional disciplines and solid familiarity with seamanship. The operation of large vessels manoeuvering relatively close to each other at slow speed needs constant concentrated attention of the ships' crews.

Mechanical Mining Concepts

There are two concept under this group: the bucket line and the scraper concept.

The bucket line concept uses an endless rope loop which is lowered from the mining vessel to the sea floor. Numerous buckets are attached to the loop and are pulled over the sea floor, becoming filled with nodules and bottom sediments. Part of the sediments will leave the bucket through openings, the rest will be washed out on the way up to the surface. The nodules are unloaded when running over the mining vessel and are stored in its cargo holds. A smaller, second vessel serves as a line-lowering vessel that, by its chosen distance from the mining vessel, spreads the loop in a horizontal direction to guarantee sufficient length for the passage of buckets over the sea floor. After the mining vessel is filled, it drops the bucket line overboard (with an attached support buoy as a locator) and leaves for port. A second replacement mining vessel arriving empty in the mining area, picks up the bucket line and the support buoy, and continues the mining operation.

The scraper concept is the most sophisticated. It uses a fleet of individual, unmanned submarines which are handled by remote control from the mother ship at the surface. These submarines are guided down to the sea floor and crawl over it, scraping nodules and sediments into their cargo holds. After blowing out most bottom sediments, these scraper-submarines are brought close to the surface and drop their nodule loads into a below-water-receiver platform. The nodules are elevated from there to the deck of the surface ship, probably a semi-submersible with favourable sea-keeping properties, and transferred to a nearby transport vessel. The scraper-submarines are complex units with their own propulsion, buoyancy control and ballast systems, sophisticated communication and control systems for steering and handling the unit in continuously varying conditions. High maintenance requirements may be balanced by redundance of submarine units to allow a continuous mining operation.

B. FACTORS EFFECTING THE DESIGN OF OCEAN MINING SYSTEMS

A brief description of these factors is given to show why designers have tried different methods of mining manganese nodules.

Nodule Distribution

The nodules are distributed in one single layer in varying sizes (from sand to gravel to pebble) on top of extremely fine sediment particals with a diameter of 1 μm (1/25,000 inch), fluctuating between 0 per cent and 90 per cent bottom coverage. The varying distribution and size requires several tasks of the nodule collector: concentration and pick-up of nodules, separation and elimination of sediments, and elimination of oversize nodules and nodule fines.

Bathymetry

The bathymetry of a nodule deposit may show a very uneven sea floor with abyssal hills with differences in elevation of up to 200 m (600 feet). These hills may be 4 to 10 nautical miles long and 1 to 3 miles wide with their longitudinal axis generally oriented running north/south. These fluctuations of water depth in combination with micro-bathymetric features of the sea floor pose critical conditions for the design of pick-up and lift subsystems.

Water Depth

The water depth of 4,000 to 6,000 m (13,000 to 20,000 ft) requires a long lift pipe for hydraulic systems, and an extremely long, deep-reaching rope loop for a mechanical bucket line system or free-floating, individual scrapers designed for this water depth.

Surface Situation

The weather conditions at the air-sea interface, including winds, waves, swells and currents, will determine the design criteria of the mining system for operational and survival situations.

Mining Path Width

The mining path width will require a compromise between the forward motion of the mining system and the width of the nodule collector for a hydraulic system.

Mining Rate

The mining rate, expressed in millions of tons of nodules per year, will influence the sizes of the nodule collector and the lift system, the mining vessel, the transport carriers, and the transfer and unloading subsystems.

Distance to Port

The distance to port, location of the processing plant from the chosen mining area, will effect the decisions for size and number of transport carriers, cruising speed, nodule storage capacity, transfer subsystems and logistic vessels.

Reliability

The reliability of the marine system is dependent upon the reliability of the individual components of the subsea and surface equipment. Minimum mean-time-between-failures (MTBF) of the mining system will determine the number of operational days per year and will highly influence the profitability of the ocean mining venture.

Safety

The safety of the marine system, personnel and vessels essential to ocean mining operations has to be considered in the design of all subsystems by satisfying existing rules issued by regulating agencies and classification institutions in order to protect personnel and vessels from accidents.

Environmental Aspects

The environmental aspects of the ocean mining operation must be studied and anticipated in sufficient detail in order to anticipate future modifications which might be requested for the protection of the oceanic environment.

C. EXPLORATION SYSTEMS

Comparision of Exploration Methods for Land and Ocean Mining

Ore deposits mined on land are economic if they are highly enriched deposits. Geological processes have led to a high concentration of ore in a limited area of a few square kilometers with a thickness of hundreds of metres, or in veins reaching down into the earth's crust.

In contrast, submarine deposits of manganese nodules consist of one thin layer of nodules spread over the ocean floor with an average thickness of zero to 5 cm (2 inches). The area of this thin ore layer stretches over a wide region of about 50,000 to 100,000 km^2 to form a deposit that could be mined over 30 to 50 years. The specific shape of a manganese nodule deposit requires special exploration methods which are specifically determined by the liquid overburden of sea water which is 4,000 to 6,000 m thick.

Submarine Exploration Methods

Instead of systematically drilling for samples in a predetermined pattern over a small area, as done on shore, oceanographers have to lower instruments from the surface to the ocean floor to obtain samples of t[illegible]hin nodule layer. They **begin** to lower still cameras to take photo[illegible]ules from which the size and density can be estimated. Dredge b[illegible] then lowered and hauled over a short distance over the sea floor to produce physical **samples** from which ore grade data could be developed. However, generalizations about an overall ore grade seem to provide false data. Characteristics change from nodule to nodule, from hill top nodules to valley nodules in the region of abyssal hills, and even from the outer layer to the nucleus of each individual nodule. An important improvement was the introduction of a

TV camera system which is lowered and slowly towed over the sea floor providing a continuous record on video tape. Unfortunately, the TV system has to be lifted periodically when a dredge haul is made since only one line at a time can be lowered from a vessel to the sea floor to avoid entanglement and loss of equipment. Another method is the utilization of free-fall samplers that take samples on impact on the sea floor and return after dropping a ballast weight to the surface, where they can be picked up after some time by the research vessel. A multi-sample nodule collector can provide more samples of nodules during one lowering of the instrument when filling several individual nodule containers rotating on the support base.

Much effort has been made to obtain data of the bathymetry, sediments, rock and lava outcrops, trenches and escarpments. The first exact data came from the deep-tow system, consisting of a complex "fish", being towed at a certain distance above the sea floor. Its sensors and instruments sent information through a multiplex cable to the receiver station on board the research vessel. It also allowed precise determination of the sample locations by means of several transponders lowered previously to the sea floor at fixed and known locations.

Future Exploration Instruments

However, such equipment provides data only over a narrow strip and requires improvements. The trend to be followed in the future is the development of highly sophisticated equipment, using the most modern sensors to obtain data over a wide field continually moving over the sea floor. This increases the efficiency and accuracy of the exploration and reduces operating costs per unit area. The recent efforts of the Jet

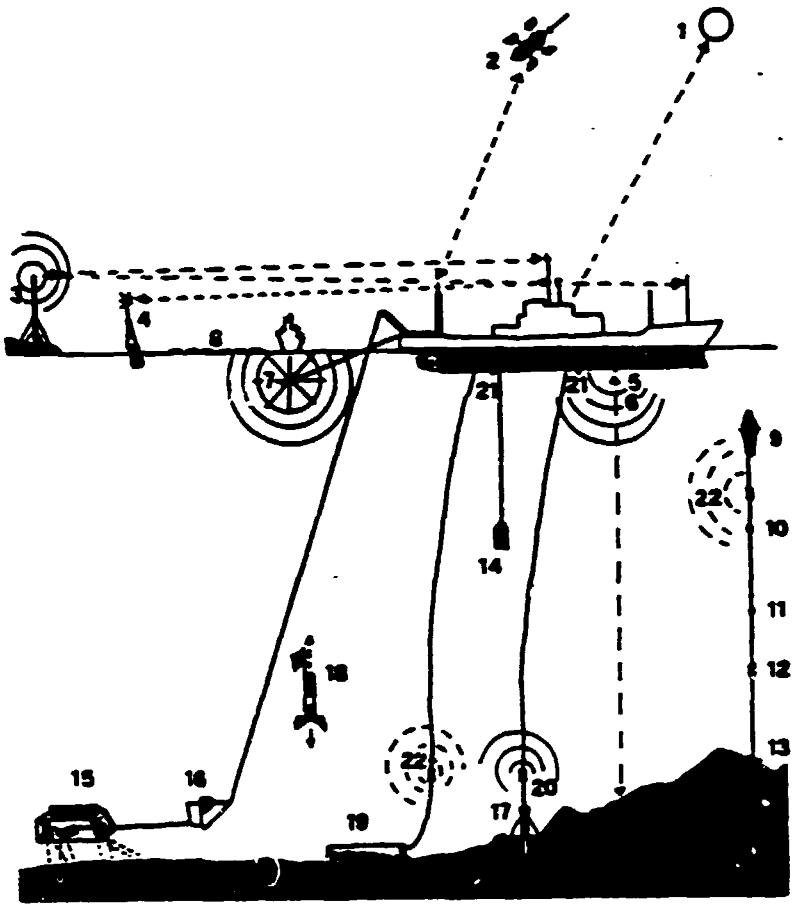
Propulsion Laboratory (JPL) in Pasadena, California, was a step in the right direction, calling experts of a variety of disciplines to a common meeting to discuss potential improvements and to specify tasks for the solution of the exploration problem for ocean mining.

Survey Vessels

The problems are strictly in the field of instrumentation and are not related to the survey vessels which are considered "existing technology". Most nations operate oceanographic research vessels successfully for different research tasks. Vessels are of different sizes depending on the regions to be covered on one leg, the crew and the scientific personnel on board. The largest research vessels are operated by the Soviet Union on research legs stretching over very long periods. The Academik Kurchatov is 124 m long, 17 m wide and has a draught of 6 m. It has a range of 20,000 miles, and carries a crew of 85 scientists and 81 technicians working in 29 laboratories.

Smaller vessels are preferred by all nations. Research vessels for manganese nodule exploration should be specialized for this purpose and should allow low-cost operations over longer extension before returning to port. The vessel's subsystems, components and subassemblies are listed in tables 1 to 4. The markings indicating required R&D, complexity and criticality show clearly that most items are considered existing technology with the exception of special exploration instruments still to be developed.

Figure II: Schematic drawing of the equipment on a research vessel (Kollwentz, 1975).



Source: <u>Ocean Mining: Report of the Training Programme for the Management and Conservation of Marine Resources (class A: Ocean Mining).</u> International Ocean Institute and Aachen Technical University, 1981.

Explanation of Figure II:

Navigation
1 stars
2 satellites
3 radio navigation
4 navigation buoy (transponder/radar)

Bathymetry
5 narrow beam sounder and sediment echograph
6 various depth recorders

Reflection seismic
7 airgun
8 streamer with hydrophones, analogue and digital registration

Oceanic Survey
9 underwater measuring chain with localizable buoy
10 current meter
11 thermometer
12 water pressure gauge
13 cut-off anchor
14 bathysonde (continuous measurement of temperature, salinity, sound velocity, pressure)

Survey of ore deposits
15 deep diving probe with TV camera, still camera and lights
16 depressor platform
17 corer for sampling sediment and nodules
18 free fall grab
19 dredge

Localization of launched survey gauges
20 pinger
21 hydrophone
22 transponder

D. TRANSPORT SYSTEMS

Regular bulk carriers or tankers may be used as carriers for the transport of nodules from the mining area to the location of the processing plant. However, they must be capable of cruising in front of or behind the mining vessel at low speed (1/2 to 4 knots). The transfer of mined and possibly on-board-partially-processed nodules must be handled through floating hoses for hydraulic mining systems. Precise station-keeping relative to the mining vessel will be necessary.

Mechanical systems, using a bucket line loop, can eliminate a specialized mining vessel by using one vessel type only, that changes its functions from that of a mining vessel to that of a transport vessel. It may serve as a mining vessel when in the mining area, handling the endless rope loop and unloading nodules from the buckets into its cargo holds. When filled, the rope loop may be taken over by the arriving empty vessel that will then serve as the mining vessel until it is released by the next vessel and is then used as a transport vessel.

Another version envisions a transport vessel that becomes coupled to a special mining vessel until the transport vessel is filled with nodules. It will then be replaced by an empty transport vessel coming to the mining area.

An analysis should investigate the pros and cons of these two approaches. The coupling of two large vessels on high seas in swell may be hazardous and a special mining vessel, designed to stay in the mining area, may increase construction and operational costs.

If individual scraper-submarines are used, regular carriers can transport nodules to the processing plant. The nodule transfer will be carried out on high sea from the mother ship to the carrier in practically non-moving mode.

II. STATE-OF-THE-ART OF OCEAN MINING SYSTEMS

The development of an ocean mining system is so complex that it requires a group of companies, forming a consortium, and thus contributing their specific expertise for the common goal.

The first data about manganese nodules were provided by scientists, oceanographers, who found these features in all oceans of the world. When mining of these nodules was contemplated, existing data were checked by mining geologists and engineers at first in the Atlantic Ocean. After finding that the metal contents of nodules in the Atlantic were low, engineers went into the Pacific Ocean. They found that possibly economically profitable manganese nodules existed in the North-Eastern Pacific. After the first data about potentially profitable nodule deposits were obtained, the design of mining equipment was started.

The first tests of such systems were made with a bucket line system from one single ship. The tests showed that the concept was workable; however, the buckets were only modestly filled with nodules when coming to the surface. This possibly was because the towing length over the sea floor was too short, or because too many bottom sediments filled the bucket and could not escape through the openings to allow more nodules to enter the bucket. A second test was made with a larger vessel, a Japanese whale factory ship, but no improvements could be made. The tests were never repeated. The French group continued working with the bucket line concept, testing improved buckets in model basin tests and showing higher filling degrees.

The hydraulic systems were developed by several consortia, who built small-scale, passive, prototype nodule collectors which were lowered by small-diameter lift pipes for a few short-period tests in deep water. These tests indicated that the hydraulic concept, using pumps or air lifts, was also technically feasible. One consortium has operated an active nodule collector for very short-term tests on the sea floor. However, no long-term testing has been done with these scaled-down units to obtain data on reliability of components and/or functional capability when being moved over longer distances over sea floor irregularities.

Most consortia have terminated the development activities and dismissed the personnel. If these projects were to be reactivated, future activities should include long-term testing of components and the design of full-size subsystems. The high costs and technological risks of these projects, as well as the economic recession and the time-consuming Law of the Sea negotiations have caused most consortia to terminate their ventures.

When considering the projected costs of development, design, construction, and operation of ocean mining systems, it was found that the bucket line system would require less capital and less complex equipment for systems with smaller mining rates. However, the low filling rate of the primitively-designed buckets during the first tests caused most engineers to abandon this concept. They directed their efforts to the development of the more complex and sophisticated hydraulic concept which, because of its high capital requirements and operational costs, demands a high mining rate to become economically feasible and profitable.

In the meantime, new mining schemes have been worked on, and a reassessment of latest developments should be done before restarting ocean mining activities.

III. OVERVIEW OF SUBSYSTEMS REQUIRED BY VARIOUS MINING CONCEPTS

This section provides an overview of the subsystems and principal components of ocean mining systems required for the various mining concepts. A set of marks ("0") after each subsystem or component indicates their technological status.

A. COMPARISON OF MINING CONCEPTS

Table 1 shows the subsystems for the mining concepts and their general complexity and the technology required for their design, construction and operation.

Table 1. Subsystems for Various Mining Concepts [a/]

Hydraulic Concepts		Mechanical Concepts			
Pumps or Air Lift		Bucket Line		Scraper-Submarines	
Mining sybsystem	00000	Mining sybsystem	000	Mining subsystem	00000
Mining vessel	000	---		Mining vessel	000
Transport vessel	0	Transport/mining vessel	0	Transport vessel	0
Transport vessel	0 0	Transport/mining vessel	0	Transport vessel	0
Logistics vessel	0	Bucket-lowering vessel	0	Logistics vessel	0
Survey vessel	0	Survey vessel	0	Survey vessel	0
Port facility	0	Port facility	0	Port facility	0

a/ Estimated level of technological complexity is indicated as follows:
0 = low; 000 = medium; 00000 = high.

Table 1 shows that the bucket line system is less complex than the other concepts and does not need special mining and logistics vessels.

B. SUBSYSTEMS AND PRINCIPAL COMPONENTS

Table 1 is amplified in table 2 which lists the principal components within each subsystem followed by X marks in two separate columns indicating if the component can be considered as part of existing technology or if new research and development(R+D) efforts are necessary to build it. The scraper-submarine concept has been excluded from these lists because it is assumed that buoyancy control, scraping on the sea floor and in situ sediment elimination will pose problems of such magnitude that considerable work is still needed to bring this concept closer to realization.

Hydraulic Concepts with Pumps or Air Lift

Table 2. Subsystems and Principal Components

Subsystem or Component	Existing Technology	R+D Required
Mining Subsystems		
Pick-up		X
Flexible link		X
Ore lift pipe		X
Subsea instrumentation		X
Ore lift, pumps or air lift		X
Collector handling		X
Ore lift pipe handling		X
Ore receiving		X
Ore storage	X	
Ore transfer	X	
Spares	X	
Mining Vessel		
Hull	X	
Power plant	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting + furnishing	X	
Navigation + control	X	
Communication	X	
Spares	X	

Table 2. (continued)

Subsystem or Component	Existing Technology	R+D Required
Transport Vessel		
Hull	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting + furnishing	X	
Navigation and control	X	
Communication	X	
Ore transfer equipment	X	
Ore unloading equipment	X	
Spares	X	
Logistics Vessel		
Hull	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting + furnishing	X	
Navigation + control	X	
Material transfer equipment	X	
Spares	X	
Survey Vessel		
Hull	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting + furnishing	X	
Navigation + control	X	
Communication	X	
Instrument handling	X	
Fixed instrumentation	X	
Portable instruments		X
Laboratories		X
Spares	X	
Port Facility		
Unloading pier	X	
Unloading buoy	X	
Port office	X	

Mechanical Concepts With Bucket Line

Table 3. Subsystems and Principal Components

Subsystem or Component	Existing Technology	R&D Required
Mining Subsystem		
Buckets		X
Bucket attachment		X
Rope loop		X
Subsea instrumentation		X
Rope handling machinery		X
Bucket unloading machinery		X
Ore receiving & handling		X
Ore storage	X	
Spares	X	
Spares handling	X	
Mining/Transport Vessel		
Hull	X	
Power plant	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting & furnishing	X	
Navigation and control	X	
Communication	X	
Spares	X	
Transport Vessel		
No special transport vessels required		
Logistics Vessel		
No special logistics vessel required		
Survey Vessel		
Hull	X	
Propulsion	X	
Ship's machinery	X	
Ship's deck equipment	X	
Outfitting & furnishing	X	
Navigation & control	X	

Table 3 (continued)

Subsystem or Component	Existing Technology	R&D Required
Communication	X	
Instrument handling	X	
Fixed instrumentation	X	
Portable instruments		X
Laboratories		X
Spares	X	
<u>Port Facility</u>		
Unloading pier	X	
Unloading buoy	X	
Port office	X	

IV. COMPARISON OF TECHNOLOGY, COMPLEXITY, AND CRITICALITY OF MINING SUBSYSTEMS

This section lists the subsystems of ocean mining systems and their principal components/subassemblies. Each component is followed by an X mark that indicates (as in table 2) if it can be considered as part of existing technology or if extensive R+D are required for its design and construction. The complexity of the equipment is indicated by 0 marks. The fourth column indicates if the equipment is critical for the ocean mining operation; its failure would mean an interruption of the operation until it is fully functioning again. Spare parts should be kept on board to reduce the loss of mining days caused by such repair activities.

A. HYDRAULIC CONCEPT WITH PUMPS OR AIR LIFT

Table 4. Subsystems, Components and Subassemblies[a]

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Mining Subsystem				
1. Nodule Collector				
Collector support assembly			00000	X
Framing structure		X	000	X
Collector deployment assembly		X	000	X
Nodule pick up assembly		X	00000	X
Nodule oversize eliminator		X	0	X
Sediment eliminator		X	00000	X
Power distribution		X	00000	X
Power cable(s), harnesses		X	00000	X
Motors, pumps		X	00000	X
Propulsion units [b]		X	00000	X
Motor [b]		X	00000	X

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Motor controls [b]		X	00000	X
Steering [b]		X	00000	X
Steering controls [b]		X	00000	X
<u>Flexible Link</u>				
Link structure	X		000	X
Nodule collector connection	X		000	X
Lift pipe connection	X		000	X
Flexible hose	X		000	X
Power cable	X		000	X
Instrumentation cable	X		00000	X
<u>Ore Lift Pipe</u>				
Lift pipe		X	00000	X
Lift pipe connectors		X	00000	X
Lift pipe instrumentation	X		000	
Power cable connectors	X		00000	X
Instrumentation cable connectors	X		00000	X
Fairing & attachments	X		000	
<u>Subsea Instrumentation</u>				
Nodule collector instrumentation	X		00000	X
Nodule flow sensors	X		00000	X
Nodule flow controls	X		00000	X
Collector propulsion sensors	X		00000	X
Collector propulsion controls	X		00000	X
Collector steering sensors	X		000	X
Collector steering controls	X		000	X
Flexible link sensors	X		000	
Lift pipe instrumentation	X		000	
<u>Ore Lift - Pumps</u>				
Pump casings	X		000	X
Pump impellers	X		000	X
Pump liners	X		000	X

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Pump motors	X		00000	X
Power cable	X		000	X
Power cable connectors	X		000	X
Pumping control board	X		000	X
Ore Lift - Air Lift				
Air lift pipe and connectors	X		000	X
Air chamber injection	X		000	X
Flexible link	X		000	X
Air control device	X		000	X
Air compressors	X		000	X
Air manifold & valves	X		000	X
Air lift control board	X		000	X
Collector Handling				
Hoists	X		000	X
Tie-down equipment	X		0	
Release devices	X		000	X
Hoists position control	X		000	
Flexible link	X		000	
Ore Lift Pipe Handling				
Derrick structure	X		000	
Gimbal platform	X		00000	X
Heave compensator	X		00000	X
Locking devices	X		000	X
Draw works	X		000	X
Pipe connecting devices	X		000	X
Pipe handling equipment	X		000	X
Power cable handling equipment	X		000	X
Instrumentation cable equipment	X		00000	X
Instrumentation & control	X		00000	X
Control board	X		00000	X
Work platform	X		0	
Ore Receiving				
Nodule receiving	X		000	X
Screens	X		000	X
Cyclones	X		000	X
Pumps	X		000	X
Motors	X		000	X
Motor controls	X		000	X

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Conveyors	X		000	X
Nodule handling pipes	X		0	X
Air/water/nodule/sediment separators		X	000	X
Main control board	X		000	X
Ore Storage				
Dewatering & pumps	X		000	
Storage distribution	X		000	
Reclaiming and pumps	X		000	
Storage instrumentation	X		000	
Main control board	X		000	
Ore Transfer				
Reclaiming and pumps	X		000	
Pumps	X		000	X
Motors	X		000	X
Material flow sensors	X		000	
Material flow control	X		000	
Transfer hoses	X		000	X
Transfer hose handling devices	X		000	
Nodule flow pipes	X		000	X
Spares				
Collector stand-by units		X	00000	
Pipe sections		X	00000	
Fairing sections	X		0	
Pumps	X		000	
Motors	X		000	
Instrumentation sets	X		000	
Instrument control sets	X		000	
Stand-by power cable	X		000	
Stand-by instrument cable	X		00000	
Cable harnesses	X		000	
Cable connectors	X		000	
Air supply pipe sections	X		0	
Air injection chamber section	X		000	
Hardware and machinery spare parts	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
2. Mining Vessel				
Hull				
Shell, frames	X		0	
Double bottom	X		0	
Bulkheads. decks	X		0	
Centre-wheel + reinforcements	X		0	
Hatches, closures, doors, bull's eyes	X		000	
Tanks for ballast & fuel	X		0	
Tanks for roll stabilization	X		0	
Holding tanks for wastes	X		0	
Sea chests & valves	X		000	
Foundations for machinery	X		000	
Deck-houses	X		000	
Bridge at bow	X		000	
Bridge at stern	X		000	
Power Plant				
Diesel engines	X		000	X
Electric generators	X		000	X
Switch gear	X		000	X
Power conversion gear	X		000	X
Power distribution	X		000	X
Emergency generators	X		000	
Main switchboard	X		000	
Propulsion				
Propulsion motors	X		000	X
Shafts, bearings and propellers	X		000	X
Thruster motors	X		000	X
Thrusters, rotative, retractive	X		000	X
Main control board	X		000	X
Ship's Machinery				
Ballast water pumps	X		000	
Bilge water pumps	X		000	
Fire main pumps	X		000	
Fire extinguishing equipment	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Sanitary water pumps	X		000	
Fresh water distillers	X		000	
Fresh water pumps	X		000	
Piping and valves for above equipment	X		000	
Steering equipment & rudders	X		000	X
Roll stabilization equipment	X		000	
Heating	X		000	
Air conditioning	X		000	
Ventilation	X		000	
Ship's Deck Equipment				
Anchor winches	X		000	
Anchors & chains	X		0	
Mooring winches	X		000	
Warping winches	X		000	
Deck cranes, rotating	X		000	
Container gantry crane	X		000	
Lifeboat hoists + davits	X		000	
Outfitting & Furnishing				
Masts and rigging	X		0	
Platforms and railings	X		0	
Lifeboats and rafts	X		0	
Living space for crew & officers	X		000	
Living space for mining personnel	X		000	
Recreational space	X		00	
Galleys and mess halls	X		000	
Ropes, lines, cables	X		0	
Workshops & repair space	X		000	
Laboratories	X		000	
Storage rooms	X		0	
Refrigerated stores	X		000	
Diver equipment stores	X		0	
Diver access devices	X		0	
Diver recompression chamber	X		000	
Helicopter deck	X		0	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Navigation & Control				
Navigation equipment	X		000	X
Satellite navigation equipment	X		00000	X
Weather recorders	X		00000	
Radar equipment	X		00000	
Sonar equipment	X		000	
Depth sounders	X		000	
Vessel distance sensors	X		000	
Subsea mining navigation equipment	X		00000	X
Long base line transponders	X		00000	X
Computer equipment	X		00000	
Ship's steering equipment	X		000	X
Propulsion control equipment	X		000	X
Thruster control equipment	X		000	X
Automatic cruise track control	X		00000	X
Communications				
Radio equipment, long distance	X		000	
Bridge-to-bridge equipment, short distance	X		000	
Internal ship's service communication	X		000	
Internal mining service communication	X		000	
Emergency communication equipment	X		000	
Spares				
Conventional spares for ship's service	X		000	
3. Transport Vessel				
Hull				
Shell, frames	X		0	
Double bottom	X		0	
Bulkheads, decks	X		0	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Hatches, closures, doors, bull's eyes	X		000	
Tanks for ballast & fuel	X		0	
Holding tanks for wastes	X		0	
Sea chests and valves	X		000	
Foundations for machinery	X		000	
Deck-houses	X		000	
Bridge	X		000	
Power Plant				
Diesel engines	X		000	
Electric generators	X		000	
Power conversion gear	X		000	
Power distribution	X		000	
Switch gears	X		000	
Emergency generators	X		000	
Main switchboard	X		000	
Propulsion				
Propulsion motors	X		000	
Shafts, bearings, propellers	X		000	
Thruster motors	X		000	
Thrusters, rotative, retractive	X		000	
Main control board	X		000	
Ship's machinery				
Ballast water pumps	X		000	
Bilge water pumps	X		000	
Fire main pumps	X		000	
Sanitary water pumps	X		000	
Fresh water pumps	X		000	
Fire extinguishing equipment	X		000	
Piping and valves for above equipment	X		000	
Steering equipment & rudders	X		000	
Heating	X		000	
Air conditioning	X		000	
Ventilation	X		000	
Ship's Deck Equipment				
Anchor winches	X		000	
Anchors, chains	X		0	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Ropes, lines, cables	X		0	
Mooring winches	X		000	
Lifeboat hoists and davits	X		000	
Outfitting & Furnishing				
Masts and rigging	X		0	
Platforms and reelings	X		0	
Lifeboats and rafts	X		0	
Living space for crew and officers	X		000	
Recreational space	X		000	
Galleys and mess halls	X		000	
Repair space	X		000	
Storage rooms	X		0	
Refrigerated stores	X		000	
Helicopter deck	X		0	
Navigation and Control				
Navigation equipment	X		000	
Radar equipment	X		000	
Vessel distance sensors	X		000	
Ship's steering equipment	X		000	
Propulsion control equipment	X		000	
Thruster control equipment	X		000	
Communications				
Radio equipment, large distance	X		000	
Bridge-to-bridge equipment, short distance	X		000	
Internal ship's service communication	X		000	
Emergency communication equipment	X		000	
Spares				
Conventional spares for ship's service	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complex-ity	Critical-ity
4. Logistics Vessel				
Hull				
Shell, frames	X		0	
Bulkheads, decks	X		0	
Hatches, closures, doors, bull's eyes	X		000	
Tanks for ballast & fuel	X		0	
Holding tanks for wastes	X		0	
Foundations for machinery	X		000	
Deck-house	X		000	
Bridge	X		000	
Tanks for Fuel for mining vessel	X		0	
Cargo holds for crates + spares for motor vessel	X		0	
Propulsion				
Diesel engines	X		000	
Electric generators	X		000	
Power conversion	X		000	
Power distribution	X		000	
Emergency generator	X		000	
Switchboard	X		000	
Propulsion motors	X		000	
Shafts, bearings, propellers	X		000	
Thruster motor	X		000	
Thruster, rotative	X		000	
Ship's Machinery				
Ballast water pump	X		000	
Fire main pump	X		000	
Bilge water pump	X		000	
Fresh water pump	X		000	
Sanitary water pump	X		000	
Piping for above equipment	X		000	
Steering equipment and rudder	X		000	
Air conditioning	X		000	
Heating	X		000	
Ventilation	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
<u>Ship's Deck Equipment</u>				
Anchor winch	X		000	
Anchors, chains	X		0	
Lifeboats, hoists and davits	X		000	
<u>Outfitting & Furnishing</u>				
Mast	X		0	
Railings	X		0	
Lifeboats and rafts	X		0	
Living space for crew and officers	X		000	
Galley and mess hall	X		000	
Ropes, lines, cables	X		0	
Storage rooms	X		0	
Refrigerated store	X		000	
Living space for mining personnel	X		000	
<u>Navigation & Control</u>				
Navigation equipment	X		000	
Radar equipment	X		000	
Vessel distance sensors	X		000	
Ship's steering equipment	X		000	
Propulsion control equipment	X		000	
Thruster control equipment	X		000	
<u>Communications</u>				
Radio equipment, long distance	X		000	
Bridge-to-bridge equipment, short distance	X		000	
Internal ship's service communication	X		000	
Emergency communication equipment	X		000	
<u>Spares</u>				
Conventional spares for ship's service	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
5. Survey Vessel				
Hull				
Shell, frames	X		0	
Bulkheads, decks	X		0	
Hatches, closures, doors	X		000	
Tanks for ballast & fuel	X		0	
Holding tanks for wastes	X		0	
Foundations for machinery	X		000	
Deck-house	X		000	
Bridge	X		000	
Sea chests and valves	X		000	
Propulsion				
Diesel engines	X		000	
Electric generators	X		000	
Power conversion	X		000	
Emergency generator	X		000	
Switchboard	X		000	
Propulsion motor	X		000	
Thruster motor	X		000	
Thruster, rotative	X		000	
Shaft, bearings, propeller	X		000	
Ship's Machinery				
Ballast water pump	X		000	
Bilge water pump	X		000	
Fire main pump	X		000	
Sanitary water pump	X		000	
Fresh water distiller	X		000	
Fresh water pump	X		000	
Piping and valves for above equipment	X		000	
Steering equipment and rudder	X		000	
Heating	X		000	
Air conditioning	X		000	
Ventilation	X		000	
Ship's Deck Equipment				
Anchor winch	X		000	
Anchors, chains	X		0	
Lifeboat davits	X		0	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
A-frame at stern for instruments	X		0	
Cranes to deploy instruments	X		000	
Winch and cable drum for instruments	X		000	
Warping winches	X		000	
Portable instrumentation		X	00000	
Outfitting & Furnishings				
Masts and rigging	X		0	
Platforms & railings	X		0	
Lifeboats and rafts	X		0	
Living space for crew and officers	X		000	
Living space for scientists	X		000	
Living space for instrument technicians	X		000	
Recreational space	X		000	
Galley and mess hall	X		000	
Ropes, lines, cables	X		0	
Laboratories	X		000	
Storage rooms for instruments	X		0	
Workshops and repair spaces	X		000	
Storage rooms for samples	X		0	
Storage room for documents	X		0	
Refrigerated store for samples	X		000	
Refrigerated store for galley	X		000	
Instrument preparation space	X		0	
Computer room	X		0	
Navigation and Control				
Navigation equipment	X		000	
Satellite navigation equipment	X		000	
Weather recorders	X		000	
Radar equipment	X		000	
Sonar equipment	X		000	
Depth sounders	X		000	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Vessel distance sensors	X		000	
Subsea mining navigation equipment	X		00000	
Long baseline transponders	X		00000	
Computer equipment	X		00000	
Ship's steering equipment	X		000	
Propulsion control equipment	X		000	
Thruster control equipment	X		000	
Automatic cruise control track	X		00000	
6. Port Facility				
Unloading Pier				
Pier structure	X		000	
Bollards	X		0	
Pier loading crane	X		000	
Container handling crane	X		000	
Piping for fresh water	X		0	
Piping for fuel	X		0	
Communication lines	X		000	
Unloading Buoy				
Unloading buoy	X		000	
Mooring system equipment	X		000	
Floating hoses	X		0	
Pipeline to shore	X		000	
Communication lines	X		000	
Lighting	X		000	
Port Office				
Office space	X		0	
Waiting room for personnel	X		0	
Communication lines	X		000	
Radio equipment, long distance	X		000	
Shore-to-bridge equipment, short distance	X		000	
Office space for vessel personnel	X		0	

Table 4 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Storage building for spares	X		0	
Storage building for consumables	X		0	
Post office room	X		0	
Sanitary rooms	X		0	

a/ Estimated level of technological complexity is indicated as follows: 0 = low; 000 = medium; 00000 = high.

b/ Additional equipment needed for an active nodule collector.

B. MECHANICAL CONCEPT WITH BUCKET LINE

Table 5. Subsystems, Components and Subassemblies a/

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Mining Subsystem				
Buckets				
Frame		X	0	
Housing		X	0	
Support		X	0	
Sediment cutter		X	000	
Net		X	0	
Bucket Attachment				
Attachment rings		X	0	
Attachment links		X	0	
Attachment mechanism		X	000	
Swivels		X	0	
Rope Loop				
Loop sections	X		000	
Section couplings		X	000	
Rope support buoy	X		000	
Buoy attachment	X		0	

Table 5 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Subsea Instrumentation				
Location indicators	X		000	
Still cameras	X		000	
Rope Handling Machinery				
Rope receiving	X		000	
Motion compensation	X		00000	
Hydraulic controls	X		000	
Ship's motion sensors	X		000	
Compensation control	X		00000	
Rope tracking	X		000	
Pressure system	X		000	
Motors	X		000	
Motor controls	X		000	
Clutches and gears	X		000	
Tension control	X		000	
Speed control	X		000	
Rope discharge	X		0	
Motion compensation	X		00000	
Bucket Unloading Machinery				
Bucket receiving	X		000	
Bucket transport	X		000	
Bucket guiding	X		000	
Bucket unloading	X		000	
Ore Receiving and Handling				
Ore receiving chutes	X		0	
Dewatering	X		000	
Desilting	X		000	
Belt conveyors	X		000	
Ore Storage				
Ore distribution	X		000	
Ore dewatering	X		0	
Ore unloading	X		0	
Spares				
Spare bucket units		X	000	
Bucket spare parts		X	000	
Machinery spare parts	X		000	

Table 5 (continued)

Subsystem, Component or Subassembly	Existing Technology	R&D Required	Complexity	Criticality
Spares Handling				
Spare bucket handling hoists	X		000	
Spare lifts	X		000	
Mining/Transport Vessel				
Equal to transport vessels of hydraulic systems, but with foundations for rope loop handling machinery, motion compensators, ore handling equipment and spare bucket handling.				
Logistics Vessel				
No special logistics vessels required				
Survey Vessel				
Equal to survey vessel of hydraulic system				
Port Facility				
Equal to port facility of hydraulic system				

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a/ Estimated level of technological complexity is indicated as follows: 0 = low; 000 = medium; 00000 = high, use of extremely sophisticated equipment necessary.

SUMMARY AND RECOMMENDATIONS

The findings of this study can be summarized as follows:

(a) Four principal mining concepts have been developed by several mining consortia with varying degrees of complexity or sophistication;

(b) The bucket line concept has been tested twice in deep water, but has been abandoned. Insufficient filling of buckets with nodules and low mining rates were the main reasons;

(c) The hydraulic concept, using pumps or air lift, were tested by several consortia for very short periods. Based on tests with small-scale prototype units, the system can be considered workable. Long-term tests are needed to prove the reliability of the equipment;

(d) The scraper-submarine concept will require extensive R+D work to solve problems related to buoyancy control, sediment elimination and nodule pick-up;

(e) An ocean mining system consists of many subsystems and components. These are listed in this study with additional information expressed in symbols indicating if they are part of existing technology, or if extensive R+D is still required. The complexity is also rated. Furthermore, the criticality of each component to mining operations is indicated. A failure of critical equipment means that mining operations must be interrupted for repair;

(f) The comparison of ratings indicates that:
    (i) The bucket line system is less complex than the hydraulic system;
    (ii) Most R+D is still required for the subsea mining systems;

(iii) The number of critical subassemblies is relatively high for a hydraulic mining system. The inaccessability of the subsea equipment is an aggravating factor;

(iv) If a critical subassembly of a hydraulic mining system fails, the lift pipe and the nodule collector must be taken aboard for repair and then redeployed;

(v) If a critical subassembly of a bucket line system fails, it can be repaired with instant access on board the mining/transport vessel. Furthermore, all subassemblies, except the rope loop, can be maintained during the journeys of the vessel to port or back to the mining area;

(vi) Many subassemblies with lesser complexity can be built in semi-industrial, developing countries; the items requiring R+D should be designed in advanced industrial countries by well-experienced firms; all instrumentation assemblies should be purchased from companies well-known for the reliability of their products;

(vii) In the case of abandoning the ocean mining venture, the retrieval value of subassemblies should be examined. Transport vessels could be used as tankers or as ore/oil carriers with some modifications if designed for transport of nodule-slurries. Survey vessels could be used as scientific research vessels. Port facilities could serve for similar tasks in the future. The mining vessel might be used after some conversion work as a drill ship for the offshore oil industry. Part of the various subassemblies of the subsea mining equipment could be resold after breaking down the numerous parts and selling them one by one. Disposing of the complete subsea equipment could be done at a lower price by leaving the disassembly of the equipment to the purchaser;

(g) In case of restarting development work for ocean mining systems, the following steps should be taken:

  (i) Reassessment of concepts and new ideas;

  (ii) Long-term testing of critical small-size prototype units;

  (iii) Additional data acquisition of nodule deposits and their environment by new surveys;

  (iv) Design of full-size units for commercial production under stressed emphasis of reliability of the components;

  (v) Long-term testing and debugging of these production units, utilizing the harvested nodules for run-in of the land-based processing facility and/or for building up a surge deposit of nodule material.

PART II

A. PRESENT AND POTENTIAL OCEAN MINERAL RESOURCES

The oceans contain mineral values in sediments and solid accumulations and as dissolved constituents of sea water. Most dissolved minerals are present at concentrations too low for economic recovery, two notable exceptions being magnesium and bromine. Solar evaporation of sea water for the production of ordinary salt can yield by-product quantities of potassium salts (potash), usually in association with sodium,magnesium and calcium. In general, the technology for recovering minerals from sea water by present processes is not highly sophisticated, and coastal countries can participate to a degree commensurate with economic considerations. Research is under way on the recovery of trace elements such as uranium from sea water as, for example, by selective absorption into titania.

Offshore dredging of sand and gravel for industrial aggregate material has long been practised by selected coastal countries. Prominent among them are Japan, the United Kingdom, Sweden and France. A surprising number of useful minerals occur in marine placer deposits on continental shelves within about five miles from the coast. The list of those marine placer minerals studied includes:

(a) heavier minerals, e.g., gold, platinum, tin oxides;
(b) heavy minerals, e.g., ilmenite, rutile, zircon, monazite, magnetite;
(c) gems, e.g., rubies, sapphires, diamonds.

Several developing countries have well-established offshore mining operations for marine placer minerals, probably the best known being those of the offshore tin areas of south-east Asia. For example, over half of Indonesia's tin production is mined by dredging, to depths of 40 - 50 metres.

Interesting as the foregoing classes of ocean mineral resources are, the focus of the present study is on minerals from the sea floor. In this category, the muds and brines from the Red Sea constitute a geographically confined copper and zinc resource, the exploitation of which will be limited mainly to Saudi Arabia and Sudan, based on technology transferred from several industrialized countries, especially the Federal Republic of Germany. The more recently discovered (and publicized) hydrothermal deposits of the Pacific, sometimes referred to as polymetallic sulphides, appear to be even more problematic than the ferromanganese nodules of the deep ocean floor. No further consideration will be given here to the Red Sea deposits or the hydrothermal vent deposits or to other presently submarginal ocean mineral resources such as marine phosphorite sediments and ferromanganese nodules that are lean in the more valuable metals, including the deposits of the Blake Plateau.

B. PROCESS TECHNOLOGIES FOR DEEP-OCEAN MANGANESE NODULES

Metal extraction routes that have been given serious consideration by the established nodule mining consortia include:

(a) reduction roast/ammoniacal leach
(b) Cuprion reduction/ammoniacal leach
(c) high-temperature sulphuric acid leach
(d) reduction/hydrochloric acid leach
(e) smelting

Close scrutiny of the recent pertinent literature and, especially contacts with the individual consortia would be necessary in order to identify more precisely those metallurgical treatments most likely to be utilized in first-generation nodules processing plants.

Present, incomplete information suggests that the Cuprion leach process, which is an improvement of the reduction roast/ammoniacal leach process, is favoured by the Kennecott-led consortium; a high-temperature sulphuric acid leach process is being developed by Ocean Minerals Company (which includes Lockheed); a smelting route is still being considered by Ocean Management, Inc. (the consortium that includes Inco, Ltd.); and Ocean Mining Associates (which includes U.S. Steel) is contemplating a hydrochloric acid leach process that will permit recovery of ferromanganese.

A critical aspect, for the purposes of this study, of updating the descriptions of the most likely processing routes is the determination whether manganese will be prodiced, that is, whether each process will be 3-metal or 4-metal. At the time of initiating the Dames and Moore study,[2] the choices seemed clear cut. More recently, however, with the greater realization of the strategic importance of manganese and of the increased revenues potentially derivable from its production, some shifting in position on the part of the consortia is detectable.

Of the identified generic processes, only high-temperature sulphuric acid leach lacks the flexibility of producing all four value metals. This is because the leach conditions are selective for nickel, copper and cobalt relative to manganese and iron, and the leach residue probably more closely resembles the original ore in mineralogical composition than is the case for the other processes. Consequently, the subsequent separation of manganese would be difficult and expensive. The ammonia leach process(es) on the other hand, reject the manganese in the form of its carbonate into the leach residue. As work by the Kennecott consortium has demonstrated, the manganese can be recovered from the ammonia leach residue by relatively inexpensive physical means, namely, froth flotation. The separated manganese compound(s) would be equivalent to a good grade of manganese ore and so would have comparable value for processing into ferromanganese and silicomanganese, i.e., the principal commercial forms. Thus, ammonia leach could be operated as a 3-metal or as a 4-metal process.

2/ Dames and Moore. Description of Manganese Nodules Processing Activities for the Environmental Studies, Vol. III - Processing Systems Technical Analysis (United States Department of Commerce, Office of Marine Minerals, August 1977).

The same may be said for the smelting (pyrometallurgical) process, although here the expectation has been that the manganese-containing slag would probably be further smelted to ferromanganese and silicomanganese. If market conditions so indicate, however, the slag could be granulated by water-quenching and sent to stockpiling or disposal. Similarly, it has been considered that hydrochloric acid leach would require the production of manganese, given that the process owes its effectiveness to the conversion of the MnO_2 (essentially) matrix to soluble $MnCl_2$. Nevertheless, cogent arguments can be put forth for a 3-metal hydrochloric acid process as follows:

> Two crippling drawbacks of the hydrochloric acid process as described in the various NOAA-sponsored studies are (a) the need for reconverting the huge amounts of product chlorine to hydrogen chloride and (b) for the specific process configuration assumed, the limited market for electrolytic manganese (from fused chloride electrolysis). A process described in a patent by Metallurgie Hoboken (connected with Union Minière, part of the consortium of which U.S. Steel is a member) avoids these drawbacks in a clever manner. The initial reaction involving attack of the manganese dioxide matrix ($MnO_2 + 4HCL = MnCl_2 + Cl_2$) is reversed, after metal separation, by raising the pH of the $MnCl_2$ containing residual leach solution and using chlorine to re-oxidize the manganese to an oxide form. The washed Mn_2O_3 oxide can then be utilized as a manganese ore or sent to disposal.

In sum, for the ammonia leach, pyrometallurgical, and hydrochloric acid leach processes, there are possibilities for producing either three value metals or four. Where three metals are produced by these processes, the manganese content of the nodules may be stockpiled in a form suitable for recovery. This could permit producers the flexibility of apportioning their outputs of manganese among the saleable product, the manganese ore stockpile, and the waste discard according to their internal needs for manganese and the fluctuations of its external markets. Because manganese is the largest elemental constituent of the nodules, the pattern of its utilization will have a major effect on the chemical and mineral composition of the process wastes.

C. DISAGGREGATION OF ON-SHORE MANGANESE NODULE PROCESSING

The on-shore processing of sea-floor minerals is only one element in a complex venture producing marketable products from raw materials which must be retrieved from great depths. For the processing of manganese nodules, however, it is the single most costly element of the overall venture [3/] and, aside from mining itself, the technologically most sophisticated. In this section, attention will be focused on the land-based processing of raw manganese nodules to produce metals in marketable forms. Partial processing of nodules, or final processing of materials which have been pretreated at sea, will be considered briefly.

As a basis for deciding which developing countries have the capability of participating in the processing of manganese nodules, "processing" will be disaggregated into its essential components. Since functioning nodules mining and processing ventures are nonexistent, no nation yet possesses fully demonstrated technology. However, elements of the technology do exist, in that much of the extractive metallurgy appropriate for nodules processing has been used on terrestrial ores.

3/ See Nyhart, J.D., el al., A Cost Model of Deep Ocean Mining and Associated Regulatory Issues, Massachusetts Institute of Technology, Report No. MITSG 78-4, March 1978.

The components of a nodules processing plant are presented in table 6, which includes estimates of the degree of technological sophistication.

Table 6. Components of a Nodules Processing Plant

Process Component	Estimated Level of Technological Difficulty a/
(a) Materials Storage, Handling and Preparation	0
(b) Nodules Reduction and Metals Extraction	00
(c) Metals Separation	000
(d) Reagent Recovery and Purification	00
(e) Metals Recovery and Purification	000
(f) Plant Services	0
(g) Supporting Services	0

a/ Low = 0; moderate = 00; high = 000.

This evaluation does not include transport of raw nodules to and rejects from the plant. Consideration will also have to be given to waste disposal as part of the processing sequence.

(a) Materials Storage, Handling and Preparation

The first component includes all operations necessary to receive, store, reclaim and put into service all raw materials and supplies consumed in the processing plant. These operations are conventional, and common to existing large integrated minerals or chemical processing plants.

Bulk nodules storage, handling and preparation facilities do not now exist, but would not require development of new techniques for their construction and operation. Location of these facilities, and indeed the entire processing facility, may be constrained by the need to be located adjacent to a deep-water port or facility constructed for nodules unloading, and with access to transportation facilities for supplies and products.

(b) Nodules Reduction and Metal Extraction

For certain process options, nodules reduction and metals extraction could be carried out with equipment and techniques similar to those used for some terrestrial ores. For example, operation of a high temperature reduction/ammonia leach process would be similar to nickel laterites processing as practised at Nicaro, Cuba, or at the Surigao Nickel Refinery off Mindanao in the Philippines. High-temperature sulphuric acid leach processes would be similar to the laterites processing practice at Moa Bay, Cuba, while nodules smelting processes would be analogous to ferronickel production from laterites as practised, for example, at Sulawesi, Indonesia. The analogies to the smelting of terrestrial sulphide ores, such as at the operations of Outokumpu Oy in Finland are somewhat less direct. The relatively greater complexity of the nodules "ore" generally requires a more complicated sequence of purification steps.

(c) Metals Separation

The mineralogical complexity of manganese nodules also requires an elaborate metals separation sequence to produce marketable products. No suitable integrated process is in operation, although elements of the technology have been practised, as in the copper liquid ion-exchange plants at Nchanga, Zaire, and at several locations in the United States.

(d) Reagent Recovery and Purification

These operations include such steps as tailings washing and ammonia recovery. As is the case with materials handling, they are common to integrated minerals processing facilities and are entirely conventional in design and operation.

(e) Metals Recovery and Purification

This is widely practised, but mainly from separated process streams. Nickel and cobalt and, especially, copper electrowinning operations are found in various parts of the world, including in developing countries. Other metals separation techniques, such as reduction and sintering of precipitated nickel carbonates, as practised at Nicaro, would not be used directly in currently proposed manganese nodules processing sequences. Manganese reduction in electric furnaces would have similarities with nickel laterites smelting as practised at Dominicana in the Dominican Republic.

(f) Plant Services

These are also conventional and common to existing integrated facilities. These services include provision and distribution of necessary utilities (water, steam, cooling, power) operational support (fire protection, security, medical facilities, etc.), on-site maintenance facilities, and general administrative support facilities (offices, laboratories, etc.) for the plant. Where these services exist at all in the aforementioned plants located in developing countries, they are usually provided to support only the needs of the existing operations and cannot be used easily for other purposes. This is particularly true with respect to the supply and distribution of utilities.

(g) Supporting Services

These include those functions which may be provided by the local community in support of the operating facility (in some cases, they may be considered as an extension of plant services). Examples of these services include: housing, schools, hospitals, stores and shops, etc. for the plant labour force; hotels, airport or harbour, and transportation networks necessary to facilitate access to the facility; satellite businesses such as contract maintenance shops, waste removal, cleaning/provisioning, administrative supply, etc., which might not be part of direct plant services. Supporting services also include raw materials supply operations, such as mining of limestone if locally available, to reduce the amount of imported materials necessary, and provision of services - particularly water and power - to the extent that they are not generated on site.

The configuration of a manganese processing complex could be simplified, and necessary support requirements decreased, if it were feasible to process nodules partially at sea and subsequently to manufacture a semi-finished product on land, or to process nodules partially in a land-based plant and ship the semi-finished products elsewhere for final production of marketable products. For example, the leach liquors from a reduction/ammonia leach process might be stripped to yield a highly concentrated, solid, basic metal (copper/nickel/cobalt) carbonate. This intermediate product, in turn, might be shipped elsewhere for redissolution, separation of the metals, and electrolytic reduction.

While the reduction and stripping operations would consume large amounts of fossil fuels, elimination of electrowinning would reduce electric power requirements by about 50 per cent compared to a fully integrated facility. If sufficient underutilized power generation and electrowinning capacity were available in the region, the savings in capital requirements would be significant. Analogous modifications might be considered for other process routes, which would provide greatly increased flexibility in considering the use of existing or modified facilities in developing countries.

Unfortunately, it does not appear that partial processing of manganese nodules at sea can be technically or economically justified, at least for first-generation plants.[4/] Furthermore, shipment of raw

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[4/] *Op. cit.*, p. 41.

nodules to developing countries not located on the rim of the Pacific Basin would increase costs significantly by virtue of the increased size of the transport fleet required. Such costs could outweigh reductions in downstream (processing) costs, with the result that overall venture costs would actually increase. It is also worth noting in this regard that published cost estimates for nodules processing have been based on the assumption that the processing plant and support facilities would be located in industrialized countries. Both plant construction and infrastructure development costs are known to be higher in developing countries, and the potentially adverse effects on venture economics would need to be considered.

The disaggregation of the operations of a nodules processing plant clearly shows that, while elements of the extractive metallurgy and direct and indirect support operations are practised in a number of developing countries, major additions would be required to support an integrated nodules production facility in any one location. Aside from required additions to existing plant facilities (if appropriate), the need to provide supplementary supporting services - particularly labour and the necessary infrastructure and energy supplies - will be a major factor in determining the practicability and desirability of siting nodules processing plants in developing countries.

In spite of the potential penalties to the venture associated with the increased costs of process plant construction and operations in developing countries, numerous possibilities exist for beneficial, synergistic effects to those countries. Thus, partial processing on land might allow more than one country to more fully utilize existing (or only slightly modified) production and support facilities, while producing products with a relatively high value added. In other cases, siting of a processing plant may provide the necessary stimulus for the development of indigenous resources which otherwise would not be utilized locally or exported profitably. For example, the geothermal resources of the Philippines could provide both low-cost power and steam to a nodules plant in amounts which would justify the development of a generation and distribution system that would provide relatively low-cost electric power to other sectors of the economy. Hydroelectric resources might also be developed in support of nodules processing as is the case at Bougainville for laterites smelting. Moreover, it may be possible to utilize a common facility to produce marketable metals from manganese nodules and compatible, locally available land ores. The resultant economies of scale and more efficient use of plant and facilities could permit the exploitation of an otherwise marginal mineral resource. Thus, it may be possible simultaneously to reduce and extract nickel and cobalt from laterities and nodules. Additional research and pilot-scale demonstration work would be necessary to confirm the validity of this concept.

The aforementioned possibilities for synergism between nodules processing and exploitation of mineral resources on land are site-specific. If adopted, co-exploitation could provide benefits both to the venture - in improved economics - and to the local economies of the countries in which they were located. A more general consideration involves the building up of support services in a developing country. Where relatively well-developed infrastructures are in place to support existing mining operations, incremental costs to the venture would not be large, but neither would be the collateral benefits to a country. On the other hand, while development of necessary support services and the training of managerial, technical, and operating personnel would be expensive and require many years to complete, the benefits which would accrue to a country where they did not previously exist can hardly be overstated. Among the benefits, the establishment of an appropriate infrastructure could provide the base for subsequent development and support of other high technology, high value-added industries.

ANNEX I

SPECIAL ASPECTS OF SITE SELECTION FOR MANGANESE NODULE PROCESSING PLANTS [1]

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[1] By Franz Diederich

SPECIAL ASPECTS OF SITE SELECTION FOR MANGANESE NODULE PROCESSING PLANTS

Introduction

This paper deals with the special aspects of site selection for manganese nodule processing plants and ventures some introductory remarks which, in the writer's opinion, should precede any discussion on ocean mining, particularly on mining of manganese nodules. The following are some specific questions and circumstances to be kept in mind:

> does ocean mining constitute a necessary addition to terrestrial mining considering a long term and global supply of raw materials?

and

> when will ocean mining be economically and technically feasible?

Ocean Mining - An Assessment

A solution to be arrived at by virtue of the efforts of the community of all nations and constituting a compromise with the largest possible measure of agreement between all nations concerned is the highly necessary precondition for ocean mining to assume its proper place as a world supplier of minerals. Should such a compromise be delayed much longer, ocean mining will reach a point of stagnation: research and development activities will come to a standstill, personnel will draft away and the years of effort expended so far will be lost.

Among the specialists in the field there is little agreement concerning the limits of land-based mineral resources. There is even less consensus concerning the rate of economic growth of all nations and in particular that of the developing countries striving towards industrialization. Substitution and recycling of materials, new technical processes, opening-up of new deposits and the further exploitation of known deposits considered today to be uneconomical would push back those limits. However, in the long run, ocean mining appears to be inevitable.

At present, it is difficult to estimate exactly when ocean mining will be required to supply additional raw materials for the world market particularly since the supply situation differs for the different metals - copper, nickel, manganese and cobalt. Indications are that ocean mining will be implemented by the turn of this century.

The Status of Ocean Mining

Considering the status of ocean mining it must be admitted that the technology has yet to be developed and does not lend itself easily to the application of anologies to experiences and approaches from other fields. This applies particularly to exploration and processing. Further techniques for collecting and lifting the raw materials constitute a major task for further development, characterized by innovative elements of a fundamental as well as an applied nature. Progress depends on co-operation and the readiness to take risks: research and development in ocean mining should be considered as a task to which all nations should pledge their individual support.

The situation in which nations and groups of companies find themselves whilst pursuing the advancement of ocean mining, can be outlined in a few sentences: it is determined by research in three main directions:

(a) Is ocean mining for manganese nodules technically feasible?
(b) Which technologies, particularly for mining, are applicable?
(c) Can ocean mining be practised keeping economic viewpoints in mind and is it economically feasible when compared with terrestrial methods and conditions?

When successfully terminated, this phase of research will be followed by a phase of industrial practice accompanied by the evolution of technologies in the form of "generations of technologies" following each other.

According to all experience so far, the beginning of the economic phase of ocean mining - from the first positive net cash flow - can be assumed to coincide roughly with the completion of the first technical generation generation.

It should be noted that there are a series of far more optimistic guesses with respect to the timing of this economic phase of operations as can be deduced from statements and publications but many of those convey the impression that only the famous "push button" need be pressed to start ocean mining on an economical scale.

It should be the task of all those involved in deep ocean resource-estimating to be as realistic as possible when dealing with decisive problems and to keep away from political opportunism: in this way reality can best be approached and practical measures conceived.

New Dimensions in Site Selection

When assessing the different aspects of ocean mining in detail, it is obvious that hardly any practical experience exists in the area of applied technologies in the field of nodule recovery from the ocean bottom and their subsequent transportation to the water surface. This alone poses significant problems.

It becomes even more evident, however, that in areas which apparently are well known and manageable, new opportunities present new problems. The determination of the site for a processing plant for ores constitutes a task which has presented itself repeatedly in the past and has been tackled using seemingly well known and proven methods. For the processing of manganese nodules new determining factors have, however, had to be taken into account for which new measures and priorities have to be chosen.

These priorities are determined mainly by the shifting global economic situation in which the availability and the use of energy becomes very important; also, limits to the intensity of industrialization and to general development or growth make themselves felt. In many economies and societies and, therefore, in the consciousness of people generally, an awareness of energy usage and the environmental quality is apparent which is translated into laws that may constrain industrial growth.

Thus, the task of selecting a site for a plant to process manganese nodules is projected into a much wider frame of reference which encompasses not only the traditional methods, taking into account technological and economical criteria, but also the critical world-wide shortage of energy and the perceived limits to the loading of the environment.

The site selection procedure of today thus differs from the older conventional method, by taking into account additionally socio-economic as well as demographic criteria, notably in connection with the growth process. The effect this new insight may have on the industrialized countries and on developing economies will be dealt with later.

The Role of Site Selection as Part of a Feasibility Study

Compared with the site selection for industrial projects with large dimensions but otherwise conventional characteristics, those for processing manganese nodules have to be viewed differently:

(a) The main point is not simply the choice of a site from among the many possible sites for the plant, but rather the basic question whether the plant is technically feasible and if so what difficulties could arise;

(b) A site selection study undertaken as part of a feasibility study concentrates less on the details of the costs involved than on the assessment of their variances and probable trends;

(c) A further and essential point of difference concerns alternatives between assessing the static conditions (i.e. values at a given time) and the dynamic representation (i.e. extrapolation of such values into the future when the investment actually takes place). The latter loses its applicability with respect to some essential factors in cases where scientifically or practically deducible parameters cannot be identified with sufficient accuracy;

(d) Of great importance, however, are considerations of trends and developments in areas such as the supply of energy and environmental protection. Often reasonable expectations can be established or anticipated and consequences derived accordingly.

Thus the task of site selection can be characterized as a problem of optimization between requirements at the site and prevailing conditions. Both categories are determined by technology, economics, markets and legislation. In other words, this means that when comparing numerous harbours situated in differing regions, comparative advantages or optimum potentials are to be found where the greatest possible degree of coincidence exists between demands on the site and its actual or potential situation.

1. Fundamental Considerations for Selecting the Site of a Processing Plant

The Present Situation: Experiences and Conclusions

Practical experiences concerning the location of large projects as they exist in enterprises and companies operating globally have not appeared in scientific publications in the form of an analytical evaluation. Instruments with proven applicability and based on a scientific approach, and covering the sprectrum of decisions as well as the methodology for selecting a site are not widely known. Judging from this state of affairs, the need to evolve a practical method for selecting a site for a processing facility for manganese nodules becomes obvious. This should take into account the unique characteristics of the project and incorporate these within the scope of a traditional feasibility study.

The traditional theory for selecting a site - as far as it is relevant to the problem being considered here - considers two basic concepts: orientation with respect to the market for purchases or inputs and the ability of the market to absorb its products or outputs.

By transferring these basic considerations to the case of a processing plant for manganese nodules the following may be concluded: the orientation in accordance with the necessary inputs and with respect to a realistic assessment of the investment required and the state-of-the-art of technology leads in an almost impossible solution, namely, a floating platform to be located on the surface above the mine site. Such a concept might become feasible partially or in its entirety as the second or third generation equipment for ocean mining becomes available.

If, on the other hand, the orientation towards the consumer or the market for the output is given preference, the reality poses a great deal of difficulty.

Limited consumer markets are difficult to assess due to the uncertain or unknown distribution of the possible consumers of the end-product: this information is hardly subject to negotiation. A location between possible mine sites and industrial concentrations which would constitute markets for the products would involve additional transportation and thus create a financial commitment of some considerable magnitude which would last for the life of the plant.

It is of interest to note that many metallurgical plants erected in different parts of the world during the past decade have been located in the immediate vicinity of a coastline. Assuming that this location was based on detailed economic analysis, it supports the view that a processing plant is ideally located at a site other than at the mine site or close to inland industrial accumulations, namely an intermediary location between the sea and the land, i.e. near the coastline.

A Procedure for Limiting Choices

It is necessary to consider comparatively large areas of reference when determining procedures for limiting choices.

These areas are those in which voyages in connection with the prospecting and exploration for manganese nodules were undertaken, i.e. in the Pacific Ocean. A particularly close scrutiny was carried out south-east of Hawaii. Judging from the results of a world-wide search for acceptable sites and in accordance with the demand for reducing costs and for avoiding or reducing negative factors, the location was finally confined to the areas of the Pacific coast. This coastal area, hwoever, does not represent a unit with respect to economic, geographical or social factors.

The question of where to start the search for a suitable site necessitates, therefore, a second step to achieve a further limitation. The circum-Pacific coast can be subdivided into several large regions, each of which can be regarded as a possible area for suitable sites. The following significant factors should be taken into account:

the geographic and ethnic uniformity
the socio-economic level of development
the techno-economic infrastructure
the conditions for investment.

With these criteria applied and by introducing acceptable simplifications, suitable areas can be deduced. From among these large areas which could be considered as potential mining sites, further detailed studies applying other criteria are necessary to clearly indicate preferred sites.

Starting with the criterion that is quite obvious, i.e. the distance, some of the American coastal regions appear most favourable. The criterion applied here, representing the distance from mine site to processing plant, is certainly of great significance since it has an impact on the financial load of the project in terms of operating as well as investment costs over its total life.

A greater distance with resultant longer turn-around-time for a given size of the vessel from 50,000 to 70,000 gross registered tons influences the following expenses:

investment costs
operational costs
costs for intermediate storage
costs for pilots, towage, demurrage and harbour fees

In addition to these expenses, others occur which are more difficult to quantify. These include the greater risks associated with transport, variability of supply, etc.

Limiting Regions for Sites

Within the chosen large area further investigation has to be undertaken, applying criteria for the selection, including:

(a) a harbour or a pier must be available or it should be possible to erect one at reasonable cost;
(b) the approach to the harbour must be capable of accommodating vessels with draughts of 40-45 ft;
(c) the technological as well as economic infrastructure has to be available or at least in the planning stages and capable of being enlarged at a later stage.

If these requirements are put forward the site selection can be reduced to a few areas even when extended areas such as the American west coast are considered.

Regional Reference Area

Proceeding to the demands which have to be met by the greater surrounding area of a processing plant near the coastline, it has already been pointed out that it should be located in the vicinity of a harbour. Here the question arises how to define "coastal area" as well as "reference area of a harbour". It is important to consider administrative structures such as the administration boundaries of the harbour and the location of county and country borders.

When weighing these factors the concept of the project in question assumes importance inasmuch as a distinction should be made between centralization and decentralization. The former refers to the areas devoted to the unloading of materials, the actual processing operation and the discharge of waste materials, all of which constitute a geographic unit; the latter to a situation where these elements are separated from each other, possibly by considerable distances. Both these basic concepts allow for a variety of changes in outlay including the element of distance to be covered. Here, for reasons of practicability, selection of a site should be limited to distances of up to 15 miles from the coastline with the possible exception of harbours located on rivers.

2. Requirements on the Site Due to the Nature of the Project

The Metallurgical Process

First, it is necessary to consider the process used by the project. To date little is known concerning the activities of companies involved with the mining of manganese nodules or whether plans for production on an industrial scale are in an advanced stage of implementation.

Basically, the question thus arises whether the processing of manganese nodules requires a completely new concept and thus the evolution of novel technologies or whether existing technology can be used.

Much can be said in favour of reverting to well known processes for terrestrial ores with characteristics similar to manganese nodules. Portions of these processes might be singled out and used, perhaps in various combinations, to establish a set of processes suitable for working nodules.

In the following, some assumptions are outlines on which to base requirements for processing. These are:

(a) a nodule processing technology can be built up using a combination of unit processes currently in use in plants;
(b) the annual capacity of the plant should be 3 to 4 million dry metric tons of nodules;
(c) a four-metal-plant should be assumed.

Criteria for Carrying out the Process

The most important requirements for the project can be summed up and quantified as follows:

Area

The area needed, if the conception of a centralized general arrangement is accepted, amounts to 1.5 to 2.5 square km which includes a waste disposal area of 0.5 to 1.0 square km. The specific topography defines in detail the preparatory work to be undertaken, while the original zoning arrangements determine the possibility of erecting a plant there. In addition, ownership of the area has to be considered and this could lead to negotiations for purchase. Unit cost for the ground together with preparation cost would add to the overall project cost.

Infrastructural Approaches

Infrastructural requirements must take into consideration approaches to the site from both land and sea. With respect to transportation, connections and distances to already existing facilities have to be examined together with financial implications. The continuous supply of operational materials for running the plant falls into this category. In addition, fees for piloting and towing of ships and costs for the establishment of repair facilities must be taken into account.

Personnel

The requirements for personnel, i.e. the number of persons to be employed at the plant directly, can be assumed to be between 1,000 and 1,500 persons, roughly equally distributed among skilled, semi-skilled and unskilled categories. When analysing the labour market the level of wages must be considered in addition to the work hours and the number of work weeks per year. Attention should also be paid to the percentage of people organized in trade unions, and influence and structure of unions. The rate of unemployment carries an additional and quite considerable weight.

Operation Materials

First the requirements for water are quite stringent: for cooling water 10 to 40 million cubic metres per year - this means, 30,000 to 120,000 cubic metres per day - would be needed in addition to processing water amounting to 3 to 6 million cubic metres per year - 10 to 20,000 cubic metres per day. The purity of the water and the temperature increase through to discharge are important factors.

Considering other operating materials such as bunker-C-oil, coal, limestone and various chemicals, the following requirements exist in accordance with conducting the process in the plant: 60 to 300,000 t of bunker-C-oil, 0 to 300,000 t of coal and approximately 100,000 t of limestone per year would be needed. Substitution of coal for oil is a possibility.

Energy

The demand for electricity is considerable. the installation should provide consumption of between 7 and 10 million kilowatt-hours per day. When judging the supply situation for existing power plants, long term expansion plans must be taken into account which include the breakdown of current consumption and an estimate of future trends. The distribution of the supply from among power plants of fossil, hydro or nuclear types should be taken into account. When judging the supply situation for energy and its reliability, importance must be attached to the power grid, its interconnections and the possibility of incorporation in a larger distribution system. In fact, the totality of organization, including the generating section, reliability and the distribution network should be checked carefully.

Environmental Protection

This area comprises essentially four aspects: air pollution, contamination and heating of water, increasing the temperature of the surroundings and ecological effects that arise from waste disposal. Specific effects on the environment caused by the process yet to be selected cannot as yet be determined.

The Climate of Investment

With respect to the climate of investment the analysis of the economic situation in its totality, the readiness to accept newcomers and the means of assisting them by fiscal measures, i.e. provisions for tax allowances, financial assistance, participation, etc. are of utmost importance. The reaction of local or state authorities to the proposal for situating the project in their respective areas of jurisdication will be decisive in qualifying a region as a potential site for the plant.

Weighing Factors for Determining Sites

The criteria cited so far for selecting a site for a metallurgical plant, although apparently of equal weight and importance, on closer examination, differ in several respects.

Expenses for ground, wages and the piloting and towing of ships can be ascertained in dollars and cents. However, the impact of taxation and the extent of financial support available cannot be assessed with any great accuracy in advance: this would be possible only after prolonged and detailed negotiations with local or state or even trans-regional authorities.

A methodological approach capable of being applied to a practical study is based on a two-fold subdivision of site selection factors which might be classified as primary and secondary factors.

The first group can be defined as follows: those factors closely linked to the specific project and its essential requirements. if these cannot be met at the intended site or established at reasonable costs, the project could not be located in the region under consideration. To this group of potentially eliminating or primary factors - both terms are used synonymously - belong the following:

supply of energy
environment and its protection
approach to the harbour
climate for investment.

The second group of factors encompasses project-specific requirements characterized by a certain flexibility. The project requirements could be harmonized with the situation at the site by organizational or financial measures of reasonable extent. To this group of factors belong:

the labour situation
the infrastructure
the supply of operational materials
the extent of grounds and the area for the plant.

From these considerations two fundamental conclusions can be drawn:

(a) The subdivision of factors of location and the list of priorities classification according to the criteria of preferences is technically speaking, not to be realized and cannot be sustained logically;

(b) From the point of view of an approach applicable in practice and, furthermore, considering the amount of time and funds available, a subdivision in primary (or project-eliminating) and secondary (or project-adjustable) factors for site selection suggests itself.

3. The American West Coast: Results of Studies and their Evaluation

Preliminary Remarks

In the following the fundamental suitability of the American west coast region is considered with respect to the selection of a site although single harbour areas are not yet included at this stage. This treatment is based on field studies and material analysis dating back to 1975. This year has been chosen also for any data quoted. The representation deals first with secondary factors and thereafter, with the primary factors for the selection of sites for a manganese nodule processing plant.

Secondary Factors

Availability of Suitable Areas

Even if a feasibility study is the first objective, it is still necessary to specify precisely the required properties of the plant site. Studies undertaken to date have arrived at certain results:

(a) If limiting factors concerning a suitable harbour are accepted and a limitation of the extent of the area to 15 miles is [illegible]ed, many sites could be classified as fundamentally suitable;

(b) Such sites are normally already earmarked for industrial utilization or it can be assumed that under the pressure for further development such utilization can be expected in the future;

(c) A multitude of such areas represent untouched land and preparatory levelling must be undertaken;

(d) With respect to sites that have good locations - in the immediate neighbourhood of a river or at the shore - development would necessitate expensive preparatory work, such as the construction of heavy foundations.

Practice has shown that the basic problem does not lie in the lack of suitable ground not its cost ($1,000 to $10,000 per acre) but in the dimensions of the project. Even if industrial utilization is generally agreed to, approval by authorities at several levels - county, state, federal governments - is still required. The time required in these negotiations can be prohibitive and cannot be estimated accurately.

Infrastructual Approaches

A judgement on the accessibility to the site from the open sea is based on the actual distance to be covered while transporting the nodules, on details of the passage and on the infrastructural provisions such as the pier, unloading and storage facilities and the means for transporting nodules to the plant. Investigations have shown that:

in most harbours these provisions are not available, and

if available, they are fully utilized already, or

where these harbour facilities are available, an appropriate site for the plant is missing.

Thus the centralized model of the plant, with its different components brought together into one unit - loading, intermediate storage, processing and waste disposal - is difficult to find. As a consequence, new facilities specifically meant for the project will have to be installed.

Integration of the sites investigated with public road and rail systems already available, can be achieved at all of them - costs, for the additional connections, vary greatly.

From the above it can be stated quite generally that, contrary to what had been expected, large harbours situated near centres of economic concentration do not offer the best prospects. Instead, these are offered by the smaller and medium-sized harbours located in areas where opportunities exist for economic development and expansion.

Labour

Investigation of the labour market for each of the sites investigated revealed the following:

within a range of 20 to 30 miles around the investigated locality the size of the population was, on the average, 30,000 to 50,000 inhabitants.

Thus, each locality should be able to support a working force of 1,000 to 1,500 persons. Considering a multiplier factor of from 5 to 10 resulting from the establishment of forward and backward linkages, total employment opportunities for 5,000 to 15,000 people should result from the establishment of the plant.

A certain easing of the strain on the labour market may be expected from migratory labour. This makes it unnecessary to limit the search for a suitable location to regions where heavy industries exist already.

Wages vary between $5 and $8 per hour. From this and by taking into account fringe benefits amounting to about 25 per cent of the total, expenses for labour will be $15 to $20 million per year. Wages in highly industrialized areas exceed those in less industrailized regions by about 30 per cent. This can hardly be construed as an advantage for the latter since within a comparatively short time the unions would cause a levelling of these wages at the higher rate.

Erecting a plant in a region away from cultural centres where climatic conditions add to the complexities of life, would create difficulties for labour recruitment. Comparable circumstances resulted in fluctuations of 50 - 70 per cent. This clearly would endanger the safety of the operation of the plant and cause additional expenses for labour and outside investments.

The relatively high unemployment rate regionally, running at 6 - 10 per cent does not allow the conclusion that a policy aimed at the creation of work might ease the strict demands for environmental protection.

On the whole, one can conclude that considering the circumstances outlined above, the supply of working personnel is not likely to be a problem.

Operation Materials

In those areas investigated the supply of operating materials can, at the present time, be regarded as being reliable. The supply of bunker-C-oil must be watched however, since it constitutes a significant proportion of the operating costs ($20 to $25 million per year).

Taking note of the world-wide recession and particularly the situation concerning availability and consumption of crude oil, it is evident that in the long run other forms of energy will have to be found or alternative processes be applied which are independent of primary fossil energy.

The supply of cooling or process water from existing networks is, with one exception, impossible in all locations. Thus, the projects need to have their own water supply together with the necessary treatment plants. Although drawing water from rivers or lakes does not present any technological difficulties, the consequences for the environment need to be assessed.

All sites examined pose problems associated with the supply of water when they are situated in arid zones, in areas with diminished water resources, or generally, at distances from natural sources of water.

Primary Factors for Site Selection

Climate for Investment

The problem of the climate for investment plays a decisive role when regarding the primary factors for the selection of a site. Within the whole region under study a general policy trend towards decentralization was evident. This tendency suggests that further growth and expansion of areas of concentration should be avoided and development should aim at small industrialized cores in economically weak regions. Instruments to achieve this are at hand, particularly for infrastructure development.

As a result of the investigation, some conclusions may be drawn concerning the suitability of various regions and ways for reducing project costs:

(a) Comparatively isolated locations provide certain advantages when compared with sites in areas with a high concentration of industrial activities. In the latter case, establishment of the new project must conform with established economic and political targets for that area;

(b) Fiscal concessions to relieve the financial burdens accompanying the new project can be gained only by negotiation which must be taken up at an early stage.

The availability of fiscal relief and subsidies is dependent on the positive consequences of the project in terms of its ability to promote the growth of secondary industries - establishment of economic linkages. Thus, a project which comprises only one element of production such as smelting, the output of which is processed elsewhere, may not be considered a sound proposal, economically speaking.

Based on the interest expressed by the authorities and their concern with general economic development, it is concluded that the climate for investment in processing facilities for ocean nodules is positive.

Environmental Protection

Protection of the environment is provided by a body of laws comprising requirements and standards established at different levels, i.e. federal government, state government and local authorities.

The basis for establishing the possible effects of a new industrial project on the environment is the "Environmental Impact Study" which must be undertaken by the project applicant. In the case of a nodule processing plant, the following areas of investigation are: protection of air, water and landscape.

The studies undertaken so far have had the following results:

(a) The prevailing or base standard for the quality of the air is determined by measuring the quantities of poisonous or otherwise dangerous materials present in the air. The minimum standards set, however, have been exceeded already in practically all areas with high industrial concentration so that additional emissions cannot be permitted. The operation of the proposed metallurgical plant would further adversely effect air quality in these areas and consequently its construction would not be permitted;

(b) Spoiling or heating of rivers may effect the ecology of the river system itself, as well as the waters surrounding the area into which it ultimately discharges. This in turn may adversely effect the socio-economic structure of communities which rely on fishing for their livelihood. Industrial water thus requires pre-treatment to reduce its temperature to the level of that of the river before discharge into the system;

(c) The provision of a water disposal system close to a plant situated near or at a river or a coastal area is practically impossible since the ground as well as the ground water will almost certainly be affected. Preferably the disposal system should be located in arid and uninhabited areas;

(d) Recreational use of land is becoming increasingly important and consequently, factors adversely effecting this use or its visual value are to be avoided or at least controlled;

(d) Many groups concerned with these aspects of the environment are actively pressuring for their inclusion in "environmental impact studies". New it is almost impossible to promote a project which is not environmentally acceptable in local civic bodies and other groups even when assisted by high-level political pressure. For this reason, a number of locations have to be eliminated as possible sites, and the site selection has to be carried out on areas which are not densely industrialized but which have the potential for economic and operational activity.

The above considerations allow for the following conclusions:

(a) The maintenance of environmental quality constitutes for first priority and ranks higher in importance than cost considerations;

(b) The time needed to undertake the necessary environmental studies and to obtain the required construction and operating licenses can be as much as four to six years. This fact must be taken into account when evaluating and planning the project.

For example:

In January 1977, Dow Chemical Co. suspended its plan to build a $500 million petrochemical complex in Solano County in northern California, **because of underestimating the time and cost of California's licensing** procedures. They were required to obtain 65 permits; 5 from the federal government, 40 from the State of California and 20 from the three counties. By the end of 1976, after two years of effort, costing a total of $4 million, the company had succeeded in obtaining only four of the required licenses.

The Supply of Energy

The results of studies undertaken along the American west coast illustrate the enormous increase in energy requirements expected over the next 15 to 20 years (about 100 per cent). Requirements based on average usage, on the whole, show a deficit. This situation is expected to worsen due to the fact that private consumption, which accounts for the largest portion of total comsumption is increasing at a proportionately higher rate than the industrial sectors.

Since hydro-resources cannot be increased further, the basic load will have to be taken over in the eighties by coal-fired or by nuclear power plants, while hydro-power would have to be made available at peak load periods. Thermal power plant construction requires high investments and long drawn-out licensing procedures. Thus, long range planning to meet further requirements becomes very risky indeed.

Proceeding to a more detailed description, the following aspects are of principal importance:

The additional energy requirements for a nodule processing plant, estimated to be between 300 to 400 MW, are not available on the American west coast and in all probability may not become available in the foreseeable future. This state of affairs is due to the present and estimated demand for an uninterruptable energy supply by existing users. The implementation time from the erection of a power plant is between 10 and 12 years according to official estimates.

When evaluating this situation, the following conclusions are reached:

In order to achieve complete reliability of supply of electric power, the plant has to be integrated into the national supply system. Planning for this requires at least 8 to 12 years. This interval can be shortened only if the plant can be integrated into an underloaded system, or can take over an existing allocation contract.

A reasonably safe energy supply could be obtained by direct investment in energy-generating facilities. Investment for this purpose could reach $500 to $600 million generating capacity of 300 to 400 MW.

4. Concluding Remarks and Considerations Concerning Locating the Plant in Developing Countries

From the foregoing it can be concluded that while it appears possible to find a suitable site for the location of a nodule processing plant on the west coast of the United States of America, the energy supply factor is critical and the ability to supply in doubt, particularly if considered over the duration of the plant's operation, i.e. a range from 20 to 25 years.

It should be emphasized that the project under consideration should be judged with respect to the time for its realization and the capital investment requirement and also with respect to the expenses necessary for installations peripheral to the project: a manganese processing plant exceeds the framework of conventional industrial projects.

The investigation of factors involved in locating a nodule processing plant on the coast of a developed country revealed problems of a substantial if not a prohibitive, nature. Logically then, the search to find an acceptable site should continue along coastlines belonging to developing countries.

Firstly, countries bordering the Pacific coast could be taken into account since one could expect them to provide potentially suitable sites. Additional advantages might be the comparatively low cost of transport, particularly for Latin American countries. Applying the same criteria for the selection of sites in developing countries should be done with care since they may assume different degrees of importance and of influence under these new conditions. These are discussed briefly below.

Among the secondary criteria for site selection, labour assumes a higher level of importance due to the high rate of unemployment of unskilled labour. In addition, labour costs should constitute an advantage due to their generally lower level. However, skilled labour from local sources may be in short supply. Because of this situation, training will assume an important role.

A potential problem is the need to import operational materials in addition to investment goods and spare parts. Generally, the authorities, in view of the employment opportunities created by the project, are prepared to make allowances for this.

In many potentially suitable sites, infrastructure requirements cannot be met without substantial development. Power supply together with the required reliability of supply may pose problems. However, approaches to the site from the sea with the necessary provisions are, in most cases, comparable with those in industrialized countries.

Among the primary factors, the climate for investment and its assessment assume the greatest importance. Most developing countries are working towards a level of industrialization as a means to accelerate their economic advancement. Thus, a project carrying with it modern technology and employment opportunities represents a means to this end. Thus, the possibility for the establishment of forward and backward linkages exists.

For the investor, the climate for investment is characterized by opportunities for direct financial assistance from the host government including that for establishing the necessary infrastructure. Taxation allowances, fees and unrestricted transfer of profits constitute major considerations for the investor apart from the basic problem of a guarantee for the investment in its totality.

The fact that some developing countries have rather lax environmental laws should not be construed as a "go-ahead" for uncontrolled pollution, or lack of vigilance by operators in the treatment of waste products and chemical residues. In addition, developing countries are still in a position to plan the location of industrial activities and distribute them in such a way that harmful effects might be avoided.

Deficiencies in the supply of energy pose a problem of world-wide dimensions and are a concern for industrialized as well as developing countries. Latin American countries, however, have a considerable potential for the further development of hydrocarbons and hydroelectric resources which could be expanded readily.

Ultimately, the decision whether a nodule processing plant is to be located in a particular country rests with the government and people of that country. If the benefits for the host country prove to be socially, environmentally and economically practical then obviously, that country would consider such a proposal favourably. However, because all benefits and costs are not measured in monetary units and because politics and other non-quantifiable value judgements are important elements in the final decision to be made, the outcome of negotiations cannot be taken for granted even when economic indications appear to be favourable.