The Dilemma of Deep Ocean Mining

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University of Rhode Island

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THE DILEMMA OF DEEP OCEAN MINING

by

Paul W. Dillingham, Jr.
Commander U. S. Navy

Submitted in partial satisfaction of the academic requirements of the Marine Affairs Department and the Marine Affairs Seminar (MAF 652).

9 April 1974
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CHAPTER I

INTRODUCTION

Mineral substances and materials derived from them, whether in the form of fuels, construction materials, metals for fabrication, tools, chemicals, or fertilizers, are the foundation of our technological civilization. The industrial revolution, which brought on the most dramatic cultural changes in man's history, was due in large measure to the mastering of energy and mineral resources. The world is still moving from an agrarian and a craft economy into a new form of society in which industry is the driving force in the attainment of an unprecedented high level of national and individual well-being. The modern industrial civilization depends upon the continued availability of mineral raw materials.

However in today's society, the United States as well as the rest of the world is seeing the prices of raw materials and industrial commodities from rubber and oil to scrap steel and copper spiral higher with supplies of everything becoming increasingly more difficult to obtain. To many professional observers, such as economist Lester Brown of the Overseas Development Council, all of these events point to the same underlying reality: "The United States and the world are moving from an age of relative resource abundance to an era of
relative resource scarcity." The shift has many profound implications for international relations and American business.

The problem is not one of actual scarcity; the raw materials are there in the ground and in the sea in great supply. The question and the uncertainty is economic: How will these resources be recovered and by whom? This proposition becomes the central force in order to adjust to the new resources climate. The question is reenforced by the currently observable shift in the world-wide resources outlook which is the result of long-term trends such as: the continuing world-wide exponential growth of demand for raw materials, the rise in price of many minerals and industrial commodities after decades of relative price stability, the growing dependence by the United States on foreign sources for many basic raw materials, and the intensifying world-wide plunge by consuming nations to firmly secure sources of supply, with the greatest rewards being returned to those companies and countries with the greatest flexibility and foresight.

What is seen is the expansion in tandem of the free world's major industrial countries as well as many developing nations, and together they are consuming huge amounts of raw materials in the process. The magnitude of the changes and the degree to which they are spread across the world's economies, when coupled with the timing and size of recent price hikes is
evidence that a fundamental change in resource availability has taken place. The immense blocks of raw materials capacity which were added during World War II and after the Korean War in the middle 1950's, have finally been absorbed by world-wide population growth and economic expansion. The problem of resource management, which until recently has been one of managing surpluses, will require new policies which take into account the requirement to manage scarcities. This requirement is emphasized by the fact that in the United States and in many parts of the world, we have already mined or are mining the richest and most accessible ore bodies and now we are being forced to look farther, dig deeper and find ways to mine lower grade ores. This will involve tremendous capital investment and long lead times as well as require creative management.

If one accepts these assessments as accurate, then the world is facing supply constraints just as it is experiencing an explosive increase in demand. For the past two decades, world mineral consumption has been growing at a rate close to five percent per year--and the demand is not only increasing in the United States but is rising at a faster rate overseas. By the year 2000, the world's appetite for minerals is projected to be five times greater than it is today. Over the long-haul, pressures for growth are not likely to let up and some anticipate disaster ahead when arguing from the position
that the earth contains only a finite supply of substances and minerals are essentially non-renewable. While it would be foolhardy to lightly brush aside such long-term projections and their possible ramifications, they must be placed in context recognizing they tend to rely heavily on estimated reserves of minerals known to exist at the time. Yet reserves, the identified deposits of minerals that are exploitable at current levels of technology and prices, are constantly being revised as a result of exploration, technological advances, and price hikes. Therefore, the essence of the problem confronting the United States and the rest of the world is to develop potential resources efficiently when consumption is growing by unprecedented amounts. In the past, this has been accomplished primarily by the market mechanism, i.e., when rising demand or supply constraints have pushed up the prices, the market has spurred technology to develop new sources or substitutes. However with the intensity of the demand, lack of excess capacity and the long lead times currently required to bring in new sources, the question arises whether the market mechanism can function smoothly.

Recently the market mechanism has been influenced by political considerations in that the Organization of Petroleum Exporting Countries (OPEC) have consolidated their position to drive up the price of oil and selectively deny consumer access. This remedy is also available to other developing
countries upon whom the United States is dependent for materials that it lacks, notably nickel, bauxite, tin, chromium, and manganese. Table I sets forth some dramatic changes in United States imports of resources and emphasizes this country's dependency on foreign sources for strategic materials.4

TABLE I

THE SHIFTS IN U.S. IMPORTS OF MINERAL RESOURCES

<table>
<thead>
<tr>
<th>Material</th>
<th>Imports as a percentages of U.S. Consumption</th>
<th>Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1950</td>
<td>1972</td>
</tr>
<tr>
<td>Iron ore</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>Manganese</td>
<td>77</td>
<td>85</td>
</tr>
<tr>
<td>Bauxite and Alumina</td>
<td>71</td>
<td>87</td>
</tr>
<tr>
<td>Zinc</td>
<td>37</td>
<td>51</td>
</tr>
<tr>
<td>Platinum</td>
<td>91</td>
<td>93</td>
</tr>
<tr>
<td>Cobalt</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Chromium</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tin</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Nickel</td>
<td>99</td>
<td>90</td>
</tr>
<tr>
<td>Lead</td>
<td>59</td>
<td>25</td>
</tr>
<tr>
<td>Copper</td>
<td>35</td>
<td>8</td>
</tr>
<tr>
<td>Tungsten</td>
<td>80</td>
<td>44</td>
</tr>
</tbody>
</table>

Data: National Commission on Materials Policy, 1973
International Economic Report of the President, 1974

As Table I indicates, the United States depends on imports to meet a large share of its mineral requirements. Other industrial nations, many of which have few if any domestic resources, must import an even larger share of their needs. As the industrial nations have increasingly completed for raw
material supplies, the producing nations have found that they can utilize their resources to achieve economic and sometimes political gains. Some producers have sought higher prices for their products, some have demanded increased or full domestic ownership of production facilities, and some have pressed for having the raw product processed further at home rather than abroad in order to achieve a greater added value to the exported material.

For some mineral supplies, the nation's dependence on imports has actually lessened in the past 22 years. Higher prices and improved technology have given domestic copper producers an economic advantage and rich new discoveries have helped lead producers. In the case of nickel, which is imported from rich Canadian sources, the security of future supply is virtually assured. However and perhaps most important, raw materials are an essential element in international trade and provide a vital source of income to developing nations, i.e., much of what is spent for raw materials overseas will return to the United States as payment for our goods and services. Therefore it is considered unrealistic and probably prohibitively expensive to try to reverse the trend toward greater dependence on imports. What should be considered as alternative strategies is the overseas search for new supplies, the application of research and development to the extraction and recovery of minerals from low grade ores and the entry into
the sea as a potentially unlimited source of manganese, copper, nickel, and cobalt in the form of billions of nodules which cover many parts of the ocean floor. Of the alternatives, the exploitation of the deep ocean floor is considered most promising from the technological viewpoint but it is fraught with more problems than land mining because of the political risks, large capital investment requirements, and uncertain business cycles for marketing the final product. These risks will be discussed in subsequent chapters.
NOTES TO CHAPTER I


2. Ibid.


4. Strategic material or critical material is material required for essential uses in a war emergency, the procurement of which is adequate quantity, quality, or time, is sufficiently uncertain for any reason, to require prior provision of the supply thereof. Dictionary of Military and Associated Terms, JCS PUB 1, (Washington, D.C.: The Joint Chiefs of Staff, 3 January 1972). p. 286.

CHAPTER II

THE MINERAL POTENTIAL OF THE OCEAN AND THE MANAGANESE NODULE

As a source of minerals, the deep ocean has been little exploited relative to its potential. The major reasons for this are lack of definitive information as to the nature of the mineral deposits of the sea, no developed technologies for extracting the many useful minerals found therein, and no pressing need for exploiting the resources. Until recently the minerals of the pelagic ocean were considered uneconomical to exploit when compared to those in continental deposits, but that has changed rapidly and technology is being developed to recover some of the potential mineral wealth contained in the manganese nodules which are found in such abundance in the major ocean basins of the world.

It was just over 100 years ago that John Young Buchanan, the staff chemist during the scientific voyage of H.M.S. Challenger (1872-76) discovered that the nodules from Challenger's dredge of the Mid-Atlantic Ridge were an almost pure oxide of manganese. As later described by Sir John Murray, who assumed the leadership of the expedition after the death of Charles Wyville Thomson in 1882, the nodules ranged from the size of a mustard seed to that of a cricket ball, and most of the larger ones had a bit of volcanic glass, a shark's tooth, or the ear bone of a whale for a nucleus. The sharks' teeth
were particularly interesting, for they had not worked loose from the jaws of contemporary animals, but were fossilized teeth of Miocene sharks which had lived several millions of years before. That these teeth, overlain by a coating of manganese were still lying on the surface of the sea floor led the scientists to the justifiable assumption that such deep-sea deposits were collecting with unimaginable slowness.

The manganese deposits are distributed on the ocean floor as grains, nodules, slabs, coatings on rocks, impregnations of porous materials, replacement fillings of coral and organic debris. They range in size from about 0.5 to 25 cm., but generally average about 3 cm. in diameter. Although the nodules from a particular locality often exhibit group resemblance in size and appearance, nodules from different parts of the ocean tend to have unique physical characteristics. When compositional data is plotted on a map of the Pacific Ocean, definite regional variations in the composition of the nodules can be noticed. Near the continents, the nodules are characterized by manganese to iron ratios of less than one. In the Gulf of California, off the southeast coast of Japan, and near the west coast of South America are zones in which the nodules display very high manganese to iron ratios ranging from 12 to 62 and averaging about 30. In areas farthest removed from land, both continental and island, are found nodules which display relatively high nickel and copper assays. Centered on
topographic highs in the central part of the Pacific is a region in which the nodules are relatively rich in cobalt. Between primary zones, there appears to be a transitional region in which the nodules show compositional characteristics of the two adjacent zones.5

In order to determine the volume of manganese nodules in the Pacific, bottom photographs were taken and then the nodules recovered from that area by coring and dredging. Using the information from the samples, measurements were made at over 100 separate stations. The average of the measurements is about 11 kg. of nodules per square meter of sea floor or an estimated 1.6 trillion metric tons presently at the surface of the Pacific Ocean pelagic sediment interface.6 It has also been estimated that the nodules are presently being formed at the rate of six million metric tons per year in this ocean.7 While this amount is staggering, the total volume of nodule tonnage is hard to conceive when one considers that the growth of the nodule is one of the slowest chemical reactions in nature with rates of accumulation being on the order of atomic layers per day. Yet these deposits are vast and despite their exceedingly slow rate of accumulation (1 mm. per 1,000 years), they appear to be growing faster than we could ever expect to mine them.8 Even at this rate, one can see that manganese nodules can be considered a renewable resource.9
While oceanographic voyages which started with the Challenger trip have added to the store of knowledge about manganese nodules, it is not until the advent of the modern survey that the final picture on the world-wide distribution of ferromangene deposits was obtained. When all the reports of the occurrence of ferromanganese on the sea-floor are plotted on a world chart, the jigsaw puzzle is complete and is portrayed in Figure 1. The Atlantic and the Indian Oceans include relatively poor provinces of nodular manganese.

The reasons for the poorer development of major provinces of nodules and crusts are (1) these regions receive considerable quantities of continental and biogenic debris; (2) rates of sedimentation are high and preclude development of the nodules; and (3) potential nuclei of the nodules are removed from the sediment-water interface through burial before accretion of ferromanganese can take place.10

The situation in the North Pacific is different. Here there is little addition of debris and the sediment-water interface of the sea floor has remained exposed for millions of years. As a result, nodule development can proceed uninterrupted for extended periods and what ensues is the largest development of nodules in the world ocean.11 It is not difficult to recognize the value to a prospective nodule miner that a chart of nodule density would be, especially if the copper and nickel content of the nodules were also displayed.
Figure 2 represents the belt where mining site locations for copper and nickel could anticipate optimal returns.
Figure 1 | Worldwide distribution of ferromanganese deposits. Provinces of nodules exist in the Atlantic and Indian Oceans, but the most extensive deposits lie within the north-central South Pacific and North Pacific Oceans.
Mining sites are restricted to areas where nodules contain high values of copper and nickel. The most promising area in the world ocean is the east-west belt within the southern portion of the North Pacific. Here copper- and nickel-rich deposits occur over relatively large and continuous areas. Factors such as low topography favor mining in this region. The most potential is offered by mining sites located from 8°30'N to 15°30'N, 102°W to 124°W.
NOTES ON CHAPTER II


3. Ibid., p. 151.


5. Ibid., p. 225-234.


7. Ibid., p. 175.


11. Ibid.
CHAPTER III

POTENTIAL ECONOMIC VALUE OF DEEP SEA NODULES

It was just over fifteen years ago that the results of a study conducted in 1957-58 by scientists from the Scripps Institution of Oceanography indicated from analysis of the cobalt rich nodules dredged up from the Western Pacific near Tahiti, that the technical and economic aspects of mining the sea floor appeared to be highly favorable to development.

David Brooks, Chief, Division of Economic Analysis, U.S. Bureau of Mines, established a more definitive perspective five years later when he discussed the transition of the manganese nodule from a "scientific phenomenon to a world resource." From the time of their discovery during the Challenger voyage to the Scripps study, these black potato-like nodules were of interest to but a few oceanographers. Today, their presence on most of the ocean's floors is known and studied intensely by geologists and mining men and debated heatedly by international lawyers and diplomats. The general public, through the many articles in the news media, are also generally aware of the significance of this new source of manganese, nickel, copper and other metals important to the economic base of the industrial world. The interest of several natural resource companies is such that they have been willing to make capital investments on the order of $100-300 million in the development of the nodules as a source of metals.
There are many factors involved in the determination of the economic value of a deposit of manganese nodules; the more important ones being grade of nodules, concentration of nodules per unit area on the ocean floor, size-distribution of the nodules, physical characteristics the assorted sediments, depth of the water, distance to port or processing facility, topography of the ocean floor in the deposit area, weather in the deposit area and so on. Figure 3 shows the scope of the considerations in the form of a loop diagram which also takes into account the requirement for information feedback so that the mining operation and the metal recovery process can be continually optimized with respect to market conditions which are the primary long-run considerations. Of the considerations, the most important factor is the grade of the nodules and because of this consideration, it is the nodule deposits of the Pacific Ocean which are of the greatest interest at this time. As established in Chapter II and specifically identified in Figure 2, it is the nodules in a band between the equator and 20° north latitude and between the North American continent and about 180° longitude which of the greatest interest for it is in this area that the nodules of highest economic value are to be found.

**Exploratory Technology.** Exploration of the nodule deposits can be generally accomplished for economic purposes, by
EXPLORATION

POTENTIAL MINE SITES

MINE SITE

SELECTION

DISTANCE

& WEATHER

MINING

METHODOLOGY

TRANSPORT

& STORAGE

HYDROMETALLURGY

MARKETING

REFINING

METALS

DESIRABLE

LOCATION

PROCESSING

SITE
ocean mining potentially rich deposits with a television camera and periodically sampling with a dredging device such as a free-fall grab-sampler or other methods such as attaching a scoop onto the television support stand as seen in Figure 4. The camera and tripod are towed at about two knots a few feet off the ocean bottom. The small quantity of nodules recovered in the sample-basket are brought onboard for chemical analysis. After a television survey, large wire basket sampling for nodule tonnage density may take place to ascertain the site potential for long-term mining. Figure 5 shows exploration vessel bringing aboard a large nodule sample some of which will be analyzed onboard for metal content for a more generalized description of the site and its potential. The development of an adequate mining site also includes detailed study of the ocean-floor topography of any area of potential interest because of its critical importance to the engineering design of a recovery system. Fortunately, extremely accurate precision depth recording devices are available. These devices have a scale shifting capability permitting a 20-inch chart to portray 240 feet of ocean bottom. It is therefore possible to accurately delineate the sea floor and prepare maps showing lines of equal bottom elevation for any given mine site. The need of this detail is reinforced by the relationship of surficial mineral deposits in which the mining companies are interested, to geologic features on the sea floor. When this
capability is added to the ongoing photographic studies by Lamont-Doherty Geological Observatory, then mining efforts to locate adequate sites can be narrowed considerably. For example, over the last seventeen years, Lamont-Doherty has made twenty-eight oceanographic cruises, developed 3,000 camera stations with more than 50,000 individual photographs taken. This effort has resulted in the mapping of the distribution of manganese nodules and crusts on the various ocean floors. In an associated study, similar maps were prepared from an examination of data from 6,000 piston cores obtained from the ocean floors over the last 25 years. These two studies disclosed the varying concentrations of manganese with respect to various major submarine topographic features which will certainly contribute significantly to resolving the problem of where to mine. There are efforts in other fields of applied science which can be transferred directly to the mining of deep sea nodule deposits and which greatly reduce the risk involved in establishing a mining claim. One such technique is provided by a unit under development by Battelle-Northwest Laboratories. The technique is called "in situ seabed neutron activation analysis" and the device which is a nuclear probe which can detect and quantitatively analyze up to thirty different elements on the sea floor in a period of 3-5 minutes. A shipboard computer produces a complete printed report on the concentrations of minerals present.
Recovery Technology. While knowledge about the mining site in general is still being refined, sufficient is known to enable each of the major industries who intend to enter the market to have selected secret areas desirable for the conduct of their mining operations. Concurrently, the specific mining system to be used is undergoing tests and further development. Although numerous systems have been conceived for the recovery of nodules from the ocean floor, only two seem to receiving serious consideration based on their economic merits. These systems are the continuous-line bucket (CLB) and the hydraulic lift system.

The continuous-line bucket system is a mechanical system developed by Mr. Yoshio Masuda of Japan. It is a very straightforward approach and consists of a loop of cable to which are attached ordinary drag buckets at about 25 to 50 meter intervals. A long continuous loop is hung over the side of the mining ship and the bottom end of the loop is allowed to touch the bottom. When the loop is caused to rotate, the buckets in their passage across the sea floor will excavate the nodular material and carry it to the surface where the material is deposited. One can see that if the platform on which the CLB system is mounted moves in a direction at right angles to the plane of the loop, then a path equal in width to the length of the platform should be swept across the ocean floor. Rotation of the loop is generated by two traction engines which

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are mounted on the mining ship at the forward and after ends. The cable is a neutrally buoyant line and because of this it tends to eddy out in a direction opposite to the direction of the moving ship. As the loop and buckets make contact with the bottom and the buckets are filled, the increased weight and drag causes the loop to become more directly aligned with the lifting force. The overall effect of this in three dimensions is to preclude the loop from fouling upon itself. Tests were successfully conducted in water depths up to 12,000 feet and tests to 17,000 feet are contemplated.

The continuous-line bucket system has the advantage of simplicity and low capital cost, but there are several drawbacks which the Japanese are working at to overcome. The bottom topography will be extremely important and a flat or gently undulating plane which is free of potential snags would be most desirable and ensure most efficient interaction between the bucket line and the bottom. In addition the system capacity is limited by the size of the buckets and the load of nodules that they will be able to bring up to the surface. While there are no firm figures on what it takes in the way of mining volume to have an economically viable operation, estimates are on the order of 2 to 3 million tons of nodules per year per unit. This varies with mining system and processing methods, but it would seem imperative for an industry utilizing the CLB system to operate in a multi-mining ship mode in order to achieve the necessary volume necessary to meet costs.
The second method is the hydraulic lift method which in practical application by two American companies can be further divided into the pneumatic lift system and a hydraulic dredging system.

In the pneumatic system the principle applied is that similar to the use of the water straw. Air is injected into a pipe. The upward movement of this air creates a partial vacuum, which in turn creates a flow of whatever is in the pipe and around the bottom opening of the pipe. The manganese nodules and some surrounding sediment is literally vacuumed off the ocean floor, and transported by the flow of water and injected air up the pipe to the mining ship on the ocean surface. In principle it would seem that this method is constitutes a relatively simple and reliable system. In practical application there are some complicating problems. The most complex problem is embodied in the fact that the pneumatic lift system is a three-element technique. That is, solids (manganese nodules), liquids (water), and gases (compressed air) are all present in a single system. This mode places some high demands with narrow tolerances on the reliability and effective operation. The amount and injection point of air, diameter and length of pipe, amount of water transported, and the amount of solids transported per unit time are more critical than in a single or dual element system. In application, this means that a mining operation using this method must optimize the parameters for each particular mine site.
In the design or the collecting device on dredgehead, it appears that simplicity was the prime design factor. The dredgehead associated the pneumatic lift is a simple rake type device. A modest nodule discrimination capability has been built into the dredgehead in the form of rake tines surrounding and supporting the device. These act to physically allow passage into the dredgehead only those nodules of a certain size or smaller. This is important for two reasons: first to prevent clogging of the transfer pipe by oversize nodules, and second; to ensure smooth operation of the airlift, only nodules which are capable of being lifted by the air/water stream are passed. The dredgehead itself appears to act much like a very large vacuum cleaner. It simply sucks the surface nodule deposits and a small amount of associated sediment up into the pipe. Separation of the nodules from the unwanted portion can be accomplished by a simple centrifuge technique onboard the surface vessel.

Movement of the dredgehead across the nodule deposit is accomplished by moving the entire ship, pipe and dredgehead system. While lateral movement appears possible it is severely limited. Associated control systems appear to be minimal and the entire system is geared for simplicity and ruggedness. This is obviously an important advantage and contributes to the likelihood of success. A prototype was successfully tested in 1970 by Deep Sea Ventures, Inc., a Tenneco subsidiary, off the Blake Plateau in 2,500 feet of water.
The second type of hydraulic dredging is closely linked with technology developed in the production of off shore oil. This is a method believed being considered by the Hughes Tool Company in conjunction with Lockheed Missiles and Space Company, and Global Marine, the international off shore drilling contractor who has participated in many pioneering undertakings in deep ocean, such as Phase I of MOHOLE, and the successes enjoyed by the Deep Sea Drilling Project aboard the Glomar Challenger. The Hughes approach differs from the Deep Sea Venture airlift in three key areas (as derived from patent assigned to Global Marine in 1969).

1. The transport pipe is stationary. A rotating arm attached to the base with a moveable carriage on the arm acts as the collecting device. When a particular area is mined out, the entire rig is lifted and transported to an adjacent area.

2. Provision is made in the patent for use of activated crushers situated at the base of the pipe. Sun Shipbuilding and Dry Dock Company is reportedly building a large pressure sphere to operate dry on the bottom. It might be concluded that when pressurized, this vessel could be come a nodule crushing device prior to vertical transport.

3. Application of off shore oil technology to vertical lift requirement could well mean that a mud slurry will be used and the pumping method will be totally hydraulic not airlift.
The crushed manganese nodules will be transported to the surface as part of the slurry where separation can take place.

As can be seen in Figure 6, which is the Hughes Glomar Explorer, a full prototype mining ship, no expense was spared to provide her with the capability and flexibility to determine the requirements needed in a universal mining system. In addition to the basic ship, there is an auxiliary barge HMB-1, Figure 7, which will provide mining support to the Glomar Explorer. It is reported that the HMB-1 carries several versions of bottom devices to be tested during her initial cruise which is going on now. The barge further acts as an undersea launching platform because of the size of the bottom device and the need for stability in getting it into place. Other features which are built into the ship-system to permit a comprehensive test and evaluation of its potential application to ocean mining, include:

1. A Honeywell dynamic positioning system that permits the Glomar Explorer to move slowly and precisely during mining operations.

2. A sophisticated navigation system which permits precise location determination at all times with pinpoint accuracy.

3. A complete laboratory which can run assays to determine mineral content of the recovered nodules.
4. A second and complete bridge designed for use when mining operations are in progress.

5. Because the 36,000 ton ship is an experimental vessel with new and untried systems, the number of accommodations has been extended to 125. This will take care of the operating crew plus those who are onboard during the testing and debugging stage.

In addition to shaking down the ship and its systems for suitability to ocean mining, there are two objectives which will have important impact on operations when commercial ends are desired:

1. A determination of the harvest rate for which the ship is optimally suited. This will have a strong bearing on the economics of the operation.

2. A study of the impact of deep ocean mining on the environment. Preliminary tests made by independent researchers have indicated that ocean floor mining will have minimal effect but this will have to be thoroughly demonstrated and documented in the early stages if the fledgling industry is to operate without hampering law suits and needless delays.

Mr. John E. Flipse, President of Deep Sea Ventures, Inc., has a high regard for the Hughes team and their "total system—no expense spared" approach to the problem. He recognizes that Hughes may have a technical lead in the field of mining
equipment but also believes that Hughes' concentration of mining large daily volumes of nodules will do him little good if he has no process outlet to take them off his hands. The Deep Sea Ventures approach has been a modest, long-term, and comprehensive approach which started in Newport News, Virginia in 1962. The approach was to develop a capability which could mine on the order of one million tons of nodules per year rather than Hughes' 3 to 4 million tons, but which would also include a processing capability to extract all the metals, i.e., copper, nickel, and cobalt, in addition to the manganese. Since manganese represents such a large volume in the nodules, fewer are needed to yield a marketable amount. The decision to include manganese impacts not only on the design of the mining and processing systems but also on the business strategies of the firm since markets must be found for the product.

Most other companies are awaiting the outcome of the Hughes' tests and his subsequent direction before committing themselves to mining systems. Other major efforts include these by Kennecott Copper which contributed its 10 year's study in the "field of nodule deposits and research and development of economic methods to bring nickel/copper rich nodules to the surface, transport them to land and process them to extract metals" to a new $50 million international consortium of major metals producers. The others partners include Rio-Tinto-Zinc Corp., Ltd., (London), Consolidated Gold Fields Ltd. (London), Mitsubishi Corp. (Tokyo) and Noranda Mines Ltd. (Toronto).
There are also major programs going on in West Germany in research on hydraulic mining designs; Japan in both recovery and extraction methods and the Soviet Union where extraction technology may be high but incentives in ocean mining are low due to available land resources.

**Extraction Technology.** The processing of nodules into marketable products of copper, nickel, cobalt and manganese by standard land mine extraction technology will not work because of the unique nodular chemical structure. However standard hydrometallurgical leaching techniques will result in a differential separation of the elements which can be further reduced to their metallic forms. Kennecott Copper has operated several pilot plants and is proceeding with the design of a full-scale system. It is anticipated that the processing plant will account for more than half of the capital investment cost of a complete mining operation; the requirement to select the best extractive method is paramount. There are four processes which are actively under consideration but only one of which includes a very high recovery rate, provides for extraction of the four desirable metals as well as provides options to recover others of interest and is recycleable. This is the method developed by Deep Sea Ventures and provides the basis for their commercial plans.

This method utilizes hydrogen chloride gas reacting with the crusted nodules at an increased temperature in order to
the oxygen state of the manganese and produce soluble chlorides of the metals. The product of this process is then leached with water and the leach liquor containing manganese, nickel, cobalt, copper and minor metal chlorides is separated from the solid residue. (See Figure 8 for Flow Process). The solid residue is treated as waste and contains inert silicates, sulfates, and oxides. The leach liquor is then passed through a proprietary ion exchange process to separate the desired metal ions. The intermediate liquor is then reexposed to water where the desired metal is rehydrated before passing to an electrolytic cell where the metal is removed by electrolysis. The remaining solution which contains manganese is concentrated and the manganese chloride is precipitated and dried. Upon heating with an unidentified metal, the chloride of that metal is formed with a resulting production of high purity manganese metal as an end product. Using their one ton per day pilot plant at Gloucester Point, Virginia, Deep Sea Ventures has obtained 95% recoveries of manganese, nickel, copper and cobalt from Pacific sea floor nodules.

While there are other metals contained in the leach liquor, such as silver, molybdenum, vanadium, zinc, cadmium, etc., processing required for extraction has not yet been developed but is actively under investigation.

The cycle is then closed by reclaiming the hydrogen chloride by recycling the leaching agents. It will be noted
FIGURE 8

HYDROCHLORINATION PROCESS PILOT PLANT
DEEPSEA VENTURES, INC.

Nodules

Crushing Drying

Hydrogen Chloride

Reactor

Chlorine

Leaching

Solid Residue

Liquid Ion Exchange Separation

Purification

Copper Electrolytic Cell

Nickel Electrolytic Cell

Cobalt Electrolytic Cell

Manganese Metal Production
from the simplified flow diagram that chlorine gas is generated as a marketable by product. There are restrictions which must be considered when choosing a processing site location.

1. The plant must be near a source of hydrogen chloride.

2. The plant must be near a plentiful supply of water.

3. The plant must have access to inexpensive electric power.

Unfortunately these conditions in combination, rule out many of the developing countries as potential processing plant locations. But locations within the United States are also limited. The economics of the processing site location are obvious and its proximity to potential markets must be a primary consideration. Since all of the initial United States effort in developing a marketable product from the nodules take place in the Pacific, it would seem appropriate to consider Hawaii as a potential site for the first commercial plant. It meets all requirements. It is closer to the most widespread and potentially richest deposits of commercial ferromanganese on the sea floor. It also lies mid-way between the major markets in Japan and the United States which is an important consideration.
Overall economic value of nodule mining. It is beyond the competence of the author to develop a coherent presentation of the potential economic value of the nodules of the ocean. The variables are numerous and the assumptions to be made too presumptuous. Benefit-cost analyses are available from a variety of sources as are developmental arguments on the return-on-investment for the various mining systems. One can say, that by and large the effort which will be put into mining the nodules from the ocean floor will be on the order of $200 million worth of capital investment to develop a complete system which will compete in the market place. There seems to be a sufficient number of firms who are willing to accept the business risk and who believe they will at least be competitive with land mining. Mr. G. W. Sheary, Technical Coordinator, Ocean Mining Division, Summa Corporation has stated his company's position when he said that if they did not consider exploitation of the nodules and recovery of their metal values economically feasible they would not be spending the time or the money on the project.16

However notwithstanding the fact that the manganese nodules may eventually represent an apparently less expensive and an essentially inexhaustible source of many important industrial metals for all populations of the world, there are extremely sensitive international political considerations which have essentially foreclosed any consideration of a private industry
exploiting the manganese nodule in the open market. The majority of the representatives of the peoples of the world believe that the nodule in the open ocean is a resource that belongs to all mankind and until some decision can be made at the Law of the Sea Conference this summer in Caracas, Venezuela. The United Nations Moratorium on deep sea mining will remain in effect and the majority of industries now engaged in developing a capability to mine the nodule will cease their efforts rather than accept a high risk venture with no investment guarantee.
NOTES TO CHAPTER III


8. Copy of undated press release provided in response to author's query to Ocean Mining Division, Summa Corporation.


CHAPTER IV

THE DILEMMA IN DEEP SEA MINING

Since the awakening in United States firms of commercial interest in the manganese nodules, they have approached their exploitation for profit in a methodical and well developed program designed to ensure a reasonable rate of return on investment. Fifteen years ago, the manganese nodule and its constituent elements were of primary interest to the geologist and oceanographer; today, millions of dollars have been invested in developing a capability to recover the nodules from the sea floor and to extract the major metals of copper, nickel, cobalt, and manganese from them. As has been shown above, the practical application of scientific knowledge has been made and potentially high-yield mine sites identified. The mining machinery has been designed and is undergoing test and evaluation. Commercial recovery processes have also been tested in at least one pilot plant. It is also fair to conclude that production plants have been designed to produce nodules at a rate which will ensure the marketability of their metals. It is also clear that for nodule production to be profitable, the metals will have to compete favorably in the open market and that prices therefore will roughly correspond to the present market prices.

Mr. John E. Flipse, President of Deep Sea Ventures, has remarked recently that the development of new mining industries,
particularly ones that are this risky, depends not only on thorough preparation and availability of capital, but also on the momentum of the development itself.\textsuperscript{1} For several American companies, deep sea mining is at a point where the next step, the development of production capabilities, must be taken or the momentum will be lost.

However as alluded to in the previous chapter, there are many arguments presented by parties vitally interested in the deep sea resources who do not concur with the position taken by American industry—that in the absence of an international convention clearly forbidding exploitation of the resources of the sea floor and in order to provide a degree of security to the business risk involved, interim national legislation should be passed authorizing the recovery and processing of the manganese nodules and guaranteeing the risk undertaken.

Those who would be against any interim action being taken of course include those nations who export those metals found in the nodules as well as those others who believe that the benefits to be derived from the mining of the deep ocean belong to all mankind and should be specifically identified as a means of closing the economic gap between the rich nations and the poor nations. The dilemma is further compounded by the fact that American policy in the mining of the sea bed does not wholly support the industry's argument nor does it discourage continuing mining activities in the sea just short
of production for commercial purposes. These three positions, United States industry, United States policy and the United Nations approach will be discussed below.

United States Industry. Industry argues that the United States is dependent on imports for the metals found in the manganese nodules and that the nodules represent a major source of nickel and copper which can be kept available without subjecting it to the political manipulations by any one country or group of countries. Since most of the producing countries are developing countries, industry argues that it would be irresponsible for the government to favor any position which might transfer control to any body which might not have the best interest of the United States at heart.

Industry also argues that to the extent that United States mining companies invest in deep sea areas rather than in land-based minerals in foreign nations and to the extent that these minerals are processed in the United States, the market value of these minerals will help improve the balance of payments position.

Thirdly, industry argues that if the United States wants to see these metals developed, it must not take action through its political process to discourage private incentive, i.e., it must not submit itself to a treaty negotiating process which will change the law of the sea bed from a known and accepted high seas regime to an unknown system. What this
argument means then is that the industry had considered itself prepared to make major investments and begin a new metals industry until the United States, for reasons of national policy, decided to negotiate a treaty which has cast doubt on the legal basis for their investment. To recover their position, industry is asking the United States to accept financial responsibility and guarantee their investment in ocean mining. Furthermore industry argues that the Law of the Sea negotiations have already been in progress for four years and have produced virtually no agreement on any substantive aspect of a deep sea beds regime or administering machinery. With this record they have little confidence in the treaty negotiating process. Industry is well aware of the almost relentless persistence for negotiation shown by the developing countries and predict that it will be difficult if not impossible to reconcile their extreme position with any position taken by the United States.

Fourth, industry argues convincingly that passage of an interim mining legislation by the United States will accelerate the negotiation of a treaty that the United States can ratify. Industry clearly believes that if the developing countries see that the United States intends to develop these resources immediately, they will realize that time is running against them and begin to negotiate seriously. It also believes that the developing countries are not capable of preventing the development of these resources since in the deep sea areas the
clout with which they have been able to operate in coastal situations does not obtain. In addition and perhaps most persuasively the developing countries are acutely aware of the fact that without an acceptable deep sea regime, there will be little incentive for revenue sharing (no matter how small), technology transfer, or the creation of educational institutions, concepts which have been specifically developed to assist them in their own development process.

United States Policy. The United States position on mineral resources is found in President Nixon's Ocean Policy Statement of May 23, 1970. 3 The main issue is whether the oceans will be used rationally and equitably and for the benefit of mankind or whether they will become an area of unrestrained exploitation and conflicting jurisdictional claims in which even the most advantaged states will be the losers. The United States, recognizing that it had an option to object to the establishment of an international legal regime and international institutions to govern the exploration and exploitation for sea bed resources based on its own industrial capability to accomplish it, chose to negotiate an international treaty. This action would provide for long-term rational exploitation of the resources with the added advantage of international recognition of mining claims which would be possible only through a widely accepted international agreement. It is considered justified when the primary objective
is a sincere desire to help achieve a fundamentally new and equitable legal order in ocean space. The creation of viable international institutions with world-wide participation offers to all mankind the opportunity to work cooperatively with resources whose potential value is great and it furthers the probability of ensuring a more stable and secure world order which is the United States' national interest. The United States position surely recognizes that if an international regime could be created which provided a sound investment climate for American industry and at the same time achieved loftier goals as well, the practical result would be better than simply permitting American industries to develop these resources just for the profit and economic security of the United States. In order to provide the necessary protection for all nations with interests in the resource area, the United States also considers it imperative that a system of decision-making be assured that provides for compulsory settlement of disputes. This tribunal will generate a climate in which reasonably secure investment conditions will exist for a nation.

United Nations. There are at least eleven proposals before the United Nations Sea Bed Committee which address in one form or another, the structure of any resulting regime on the regulation and use of the sea bed. There exists a basic difference in approach to the powers of the proposed authority
NOTES TO CHAPTER IV


5. Ibid., p. 6.

6. Ibid., p. 7.

7. Ibid.


9. Ibid., p. 201.

10. Ibid., p. 208.

CHAPTER V

CONCLUSIONS

Just as nature abhors a vacuum, it is the nature of man to abhor something of value not being owned by an individual or by groups of individuals organized into business, social or political entities. So it is with the resources of the deep sea bed and the pressure is on man to establish a rational use of the sea and its resources in order not to spoil this last frontier through ignorance and greed.

There is still some time left to work out the problems identified in earlier chapters. There is not much time however, and the delegates to this summer's Law of the Sea Conference must recognize this.

Nor is the technology development for completing the process of metal recovery from manganese nodules yet in being. For example, only prototype engineering systems have been developed and tested for the recovery of nodules. Also the processing plant and techniques developed by Deep Sea Ventures, Inc. for extraction of the metals from the nodules is only a pilot plant. Current estimates are that it takes three years to construct a processing plant and none are under construction now. This means that late 1977 would be the earliest that a limited operation could get underway.
In the meantime, it is considered in the national interest to continue to develop the necessary technology needed to harvest the manganese nodules efficiently. This effort will maintain the current level and degree of technical momentum needed to complete the program.

In addition, demands being placed on the metals in the nodules are increasing and are expected to increase at a faster rate when economic growth in the developing countries reaches the stage where industrialization is possible on a larger scale. For example, in copper alone, the expected world requirement for the year 2000 is expected to triple from the current 6.5 million metric tons to over 19.7 million metric tons, with the poor lands increasing their demand 5 times.¹ As the supplies of minerals from land-based mines runs low, the cost of obtaining the metals from leaner ores and in more remote places will increase. Eventually, land mining costs will become so high that the mining companies will turn to the oceans. The nation that has developed a long-term program before the resource is required will be in an economically advantageous position in that the technology will be ready.

The United States dependence on developing nations of Third World for its mineral needs is further evidence that development efforts to mine the manganese nodule should continue. As stated in Chapter I, this nation is dependent for 95% of its manganese, 92% of its copper requirements on foreign
suppliers. While there has been little effort to form a commodity cartel in these strategic minerals, the threat is always present and may become more credible as prices rise and competition for secure sources increases.

However the above notwithstanding, the most important objective for the United States to keep in mind is the establishment of a viable international ocean regime which will regulate exploitation of the ocean's resources as well as the ocean's many potentially conflicting uses. It is not considered to be in the best national interests to establish an "interim" regime along the lines recommended in United States Senate Bill S. 2801 because of the de facto precedent that would be established should the Law of the Sea Conference fail. Instead, the United States should concentrate its efforts in getting a treaty that accommodates the various interests involved. From this point the United States would be in a position to support provisional application for the deep sea bed prior to waiting for the completion of the ratification process. Adequate precedent has been established and the mechanism is available. ²

When the provisional regime is established it will be required to work very closely with the potential ocean mining industries in order to establish a modus operandi of bringing the metals extracted from the nodules onto the world market. It is considered most appropriate that the volume of nodules
to be mined be determined by what the market will bear based on which key metal is to be gained and projection forecasts can be developed with some degree of long-range reliability then constraints can be relaxed. However the objective will always be to maintain market stability in order to encourage economic growth in the developing countries.

Mankind needs a success in the law of the sea very badly. If ever an area was suited for international regulation, revenue sharing for community purposes, technical assistance and technology sharing, it is the sea bed. Returns may be initially small and a long time in getting large but the potential for developing an international and interdependent environment is now available.
NOTES ON CHAPTER V


which divides the proposals into two groups: recommendations that the international authority be primarily a licensing agency, and recommendations that the authority have jurisdiction overall activities relating to the sea bed within the international area. Of special note is that the matter of the ultimate distribution of revenues received from sea bed activities is alluded to only in general terms.

This is considered significant in that it is over the basic question of the "vast wealth" of the sea bed and its distribution to the benefit of mankind that much of the conflict has been generated. There appears to be little doubt that any revenues accruing to the authority will be for the benefit of the developing countries, however both the United States and the United Kingdom believe that a portion might be devoted toward activities relating to the marine environment, such as research or pollution control. However, if some of the preliminary studies are correct in their approach, there will be very little money available to the authority to support itself let alone make any distribution to the developing nations.

One such study was done by Dr. Raul Branco, an economist with the Ocean Economics and Technology Branch of the United Nations Secretariat. Basing his study on the recovery of nickel as the king pin of the nodule industry and the likely volume of metal recovery from one 1,000,000 ton/year nodule operation which is the Deepsea Venture, Inc. approach, he
calculated that by 1985 estimates, the resulting "take" would range from a conservative $22 million to an overly optimistic $1.2 billion with the most likely outcome between 50 and 150 million dollars. Dr. Branco's final conclusion is stated:

Regardless of the actual level of tax revenues from nodules by 1985, it will not transform the scenario of world resource distribution and financial availability for development promotion in developing countries. Even in the unlikely event that the high assumption proved correct and all revenues collected from nodules were to be channelled to the developing countries, less than $.30 per capita would be netted in 1985.

Dr. K. O. Emery, et al. of Woods Hole Oceanographic Institution arrived at much the same conclusion using copper as the key metal. They noted that the total annual value of copper, nickel, manganese, and cobalt production is less than $6 billion. Assuming optimistically that 10% of this market could come from the sea and that 10% of that output could be taxed by an international authority less than $60,000,000 would be realized to be divided amongst the 90 or so developing countries.

In view of the above and the formidable task of accommodating the perceived requirements and national interests of nearly 150 nations within a regime which will attempt to regulate activities throughout 70% of the earth's surface, it is no wonder that negotiations on a legal regime for the deep sea bed have been frustratingly slow. Furthermore, developing countries' proposals have offered little encouragement and
little real progress toward achieving negotiated treaty articles is in evidence. It is therefore not surprising that the mining industry in the United States is asking for some sort of interim authorization to mine the sea bed while the Third Law of the Sea Conference takes place this summer in Caracas and in 1975 in Geneva. The dilemma is still present and without some sort of investment security, the business risk is considered unacceptable under current conditions.
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