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Economic implications of sea-bed mineral development in the international area: report of the Secretary-General

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Provisional agenda of the second session of the Conference

[Original: English]
[9 May 1974]

1. Opening of the session by the President of the Conference
2. Minute of silence for prayer or meditation
3. Address by the President of Venezuela
4. Adoption of the rules of procedure
5. Organization of work
6. Consideration of the subject-matter referred to in paragraph 3 of General Assembly resolution 3067 (XXVIII) of 16 November 1973
7. Consideration of a decision, if necessary, to convene a further session or sessions of the Conference, to be submitted to the General Assembly for approval pursuant to paragraph 4 of General Assembly resolution 3067 (XXVIII) of 16 November 1973
8. Adoption of a convention dealing with all matters relating to the law of the sea, pursuant to paragraph 3 of General Assembly resolution 3067 (XXVIII) of 16 November 1973, and of the final act of the Conference
9. Signature of the convention and the final act

DOCUMENT A/CONF.62/25

Economic implications of sea-bed mineral development in the international area: report of the Secretary-General

[Original: English]
[22 May 1974]

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Preface

This report was prepared in response to General Assembly resolution 2750 A (XXV) of 17 December 1970 as a follow-up of two previous reports on the economic implications of sea-bed mining submitted to the Committee on the Peaceful Uses of the Sea-Bed and the Ocean Floor beyond the Limits of National Jurisdiction in 1971[3] and 1972.[4] It responds in particular to the operative paragraph of this resolution, which requested the Secretary-General to:

"(*a*) Identify the problems arising from the production of certain minerals from the area beyond the limits of national jurisdiction and examine the impact they will have on the economic well-being of the developing countries, in particular on prices of mineral exports on the world market;

"(*b*) Study these problems in the light of the scale of possible exploitation of the sea-bed, taking into account the world demand for raw materials and the evolution of costs and prices;

"(*c*) Propose effective solutions for dealing with these problems;"

Following past practice, the Secretariat of the United Nations Conference on Trade and Development (UNCTAD) made some comments and suggestions on an earlier draft of this report. Moreover, the findings[5] of UNCTAD's report on manganese ore (TD/B/483 of 23 April 1974) were also taken into account.

The first section, "Review of sea-bed mining activities", updates a previous report[6] presented in 1973. In the second section, an analysis is made of the probable impact of sea-bed mining on world metal markets and on developing country exporters of minerals, during the period 1976–1985. The final section deals with a number of policy questions, with special emphasis given to the objectives of minimizing the impact of nodule mining on mineral exports of developing countries and of maximizing revenues for the International Authority.

The only resource studied in this report is manganese nodules. Hydrocarbons were not considered because very little production is expected in the foreseeable future from the deep sea-bed, and in any case the possible impact of such production is likely to be minimal. Nor were other minerals such as phosphorites, metalliferrous muds and brines and deposits in the bedrock taken into account in this study.

It should be borne in mind that the materials and observations contained in this report are based on available information on future market conditions and the technology being developed for nodule exploitation. Considering the nature of long-term market forecasts[7] and the limited knowledge of nodule technology outside the few groups engaged in research and development work, the analyses and observations should be considered as tentative and as calling for periodic review. It should be clearly understood that the ideas put forward are merely illustrations of the policy implications of some of the possible mechanisms which could be employed under the international régime.

Summary of report on economic impact of sea-bed mining

This summary provides a brief review of the contents of the report. In view of the complexity of the subject, however, it necessarily omits much of the analyses and accordingly should not in any sense be taken as a substitute for the text of the report itself.

[3] "Possible impact of sea-bed mineral production in the area beyond national jurisdiction on world markets, with special reference to the problems of developing countries: a preliminary approach" (A/AC. 138/36).

[4] "Additional notes on the possible economic implications of mineral production from the international sea-bed area" (A/AC.138/73).

[5] Although its projections were based on somewhat different assumptions, the conclusions reached in the UNCTAD report on the impact of nodule mining on manganese markets are essentially similar to those in this report.

[6] "Sea-bed mineral resources: recent developments" (A/AC. 138/90).

[7] For example, it is possible that the actions of organizations of mineral exporting countries might result in metal prices considerably different from those assumed in the report. Some of the recommendations of the General Assembly at its sixth special session on raw materials could also change the existing perspective of future mineral markets.

Manganese nodules are the most likely deep-sea minerals to be exploited in the foreseeable future. Nodules are composed of fine-grained oxide material and are distributed widely over the floor of the world ocean. They vary widely in their composition, as well as in their physical and chemical properties. There is now considerable commercial interest in exploiting them for their component metals, chiefly nickel, copper, cobalt and manganese.

Only about 3 per cent of the sea floor has been extensively surveyed. However, intensive exploration in recent years has revealed enough about the extent and location of deposits to permit commercial exploitation of nodules. Potential commercial deposits exist in the Pacific and Indian Oceans, while none has yet been located in the Atlantic Ocean.

Various commercial groups have completed the exploration or prospecting phase and are now evaluating potential mine sites. Site evaluation focuses on estimating the average concentrations of the constituent metals in nodules and on the nodule density per unit area of the mine site. These are the key parameters which, with bottom topography, affect the potential profitability of a mine site. There is great interest in the central Pacific region, which contains extensive concentrations of higher value nodules. Within this region, some evidence suggests that nodules with the highest potential value are concentrated in a belt between 6°N and 20°N latitude and extending between 110°W and 180°W longitude.

The physical problem of recovering the nodules from the sea floor is proving to be a difficult one. As surficial deposits, nodules will be dredged and either pumped or hoisted from the sea floor. At the surface facility the nodules will then be loaded into barges or ore carriers for transportation to a processing plant. Under hydraulic lifting systems the nodules must be concentrated within a relatively small area so that the suction system can operate efficiently. This gathering process seems to be one of the most serious stumbling blocks in test operations.

Several national Governments have been and are involved in nodule mining through various forms of direct and indirect subsidization of mining activities. They have funded research on exploration, offered tax relief and the use of governmental facilities for research on processing. In some cases Governments are contemplating direct participation in mining ventures.

By most estimates, it appears that nodule mining will prove to be a commercially profitable operation. Although the physical, technical and logistic problems are formidable, the existing technological capability can allow the industry to work. The question of the probable impact of sea-bed mining on world markets centres on the degree of competitiveness between marine and land-based sources of metal supply. To be rigorous, a study of this question would require a comparison of the relative supply costs of these two sources. This is not practicable for the following reasons: (*a*) most information on estimated costs of individual firms or consortia is still proprietary and closely guarded; (*b*) as the industry matures costs will drop from initial levels due to a "learning-by-doing" effect. Also, technical progress in engineering, materials, and design will serve to further reduce costs over time; (*c*) the range of costs among land-based producers is extremely wide, making it difficult to find a uniform supply price for land-based producers as a whole; (*d*) the profitability of nodule mining, the volume of production, and the impact on prices will be affected by the nature and extent of any regulation of the industry by a Sea-Bed Authority.

Therefore, in order to approximate the likely impact of nodule mining, certain assumptions must be made to facilitate the analysis. In this report, the assumptions made are based on the latest information available, on the discernible trends and on the known plans of sea-bed miners.

Given the state of preparedness of the industry, commercial metal production from nodules could commence towards the end of the decade, though nodule mining might start as early as 1976.[8] The decision to begin production will depend on whether: (*a*) the firms feel that their mining and metallurgical processing technology is economically viable; (*b*) that they are on safe legal grounds with security of investment and assurance of exclusive access to their chosen mine sites; and (*c*) that they have adequate financing for their ventures. Once the decision is made, it is assumed that commercial operations can commence within three to five years.

Perhaps the most critical assumptions deal with the expected rate of development of the nodule industry, the average grade of nodules processed, the constituent metals to be recovered and the metallurgical yields. Metal production from nodules will be affected by the pattern in which new operations enter the field each year and by increases in capacity of existing operations. Economies of scale will dictate the size of individual operations; the likely sizes being of 1 million and 3 million ton capacities. Six groups are expected to be in operation by 1985, the total volume of dry nodules being processed in that year amounting to 15 million tons.

According to most experts, nickel will be the mainstay of the nodule industry. Copper, cobalt and nickel will be produced jointly, with manganese and several trace metals probably being produced as by-products from the tailings. As a guideline for their own planning, nodule miners look for a combined nickel and copper content equal to 3 per cent of the dry weight of nodules. Other metals will be recovered if the additional costs of processing are covered by the additional revenues from these metals, which in turn depends on their prices. Thus, there can be no uniform, industry-wide assumptions about production of other metals. For example, industry plans vary widely with respect to manganese production, not only regarding its volume but also its form, i.e. ore, ferromanganese or manganese metal.

For nickel, a minimum 6 per cent per annum long-term growth rate is assumed. In 1972, the share of developing countries in world production of nickel was only 13 per cent, although this share is expanding rapidly. Production from nodules might amount to 18 per cent of the total world demand in 1985. This volume of production would depress prices somewhat, but the impact would be lessened by the good growth prospects for nickel, and by the fact that production in developing countries accounts for a small share of the total market. Nickel production from nodules might cause some high cost laterite projects under consideration to be abandoned, but it should not have a serious effect on land-based production as a whole.

The world market for copper is huge compared to that for nickel, being about 14 times the size of the nickel market in 1972. Copper prices rose dramatically from 1970 to 1974, reaching a record level of $US 1.10 per pound in early 1974. Of the metals contained in nodules, copper production is the least concentrated among producers. It is expected that the demand for copper will show an annual percentage growth rate of 4–5 per cent to the end of the century. Production from nodules might supply about 1.3 per cent of world consumption in 1985 and would displace only 5.5 per cent of the net import requirements of developed countries by that time. Copper production from nodules is expected to have a minimum impact on a relatively large, growing and somewhat diffuse market.

Manganese might be recovered from nodules in two forms, either as pure metal or as ore-equivalent. More than 90 per cent of the manganese produced is used in the form of ferromanganese in the manufacture of steel; thus the rate of growth in its consumption will tend to parallel that of steel production. Yet, the market for manganese metal is relatively small. Metal production from one operation of 1 million tons per annum in

[8] The assumed timing of entry of nodule operations is shown in figure 6 on page 16.

1985 might amount to twice the volume of projected demand. Therefore, manganese metal supply from nodules would depress prices. Depending on the form and volume of manganese recovery from nodules, the export earnings of developing country producers might drop significantly. However, with just one exception, developing countries are not dependent upon manganese exports to a great degree.

Cobalt is a relatively expensive metal with a small market and its value in world commodity trade is rather small. By 1985, production from nodules could account for about half the volume of world output while effecting a drop in price to about two-thirds of current levels.

The long-term prospects of the nodule industry are tied closely to nickel and copper. In the long-term, if capacity expansion in sea-bed mining was sufficiently large to depress the price of nickel to approximately the price of copper, it would open up some important substitution possibilities of nickel for copper. In this case, the prospects for the industry might warrant a large second-round expansion. This scenario is somewhat speculative and possible only in the absence of any form of regulation.

Although everyone agrees that nodule resources should be developed in a rational manner, opinions differ on what specific objectives come under this very general goal. In the sea-bed Committee, several policy objectives were proposed and discussed, in particular: to encourage nodule development so as to enlarge the world resource base, to minimize the impact of nodule exploitation on developing countries exporters of minerals, to ensure the participation of developing countries in sea-bed mining activities, to promote the conservation of nodule resources and to preserve the marine environment.

Some of these objectives and the conflicts between them indicate the need for a trade-off between efficiency and equity, which is one of the fundamental issues under any form of economic organization. Some would argue that the nodule industry should be free to operate without restraint, since under conditions of competition and free entry, the nodule resources would then be developed at minimum cost. Others contend that unrestricted nodule exploitation would benefit primarily those countries developing the necessary technology which are also the largest consumers of minerals; thus the mineral exports of many developing countries might be harmed by nodule exploitation.

Two approaches are examined in the report for balancing the objectives of efficiency and equity: the compensatory approach, whereby the nodule industry would be allowed to operate with little or no explicit regulation, but some form of compensation would be paid to developing countries if they experienced a loss in export revenues; and the preventive approach, which would involve some form of direct regulation of the nodule industry by an International Authority. The second approach only is discussed in detail in the report.

Under a general preventive approach, many specific regulatory formulas would be possible, depending on what the Authority chooses as the basis of regulation. The report considers the effects of choosing nickel as the basis for regulation. In this case, the Authority would permit new ventures and the production from nodules to proceed so as to supply part or all of the increase in demand for nickel in each year. This type of scheme would recognize the complementary nature between land and marine sources, since production from both sources would be growing. It would also recognize the need for the industry to remain viable. Since nickel would be one of the main generators of industrial revenue, this would be assured.

Metal production from nodules could, for example, be geared to supplying between 50 and 100 per cent of the increase in demand for nickel, with possible additional restrictions on recovery of other component metals, such as manganese. Assuming that the demand for all these metals would be growing at their long-term rates by 1985, and that the maximum production is authorized, sea-bed mining could make considerable inroads into the cobalt market, accounting for 66 per cent of world demand. The share of world demand for nickel supplied by nodules could be 28.6 per cent by 1985, under these assumptions.[9]

Even taking into account a share of revenues for the International Authority, it appears that nodule mining would still show a financial return commensurate with that of other investments. On the basis of a wide range of analytical assumptions, some estimates are contained in the report. If, for example, the Authority were to take a 50 per cent share of net revenues, the medium estimate of the take from a single mining operation of 3 million tons per year would be $96 million. This would still allow the miners a 36 per cent return on total investment after payment of the Authority's share. This is more than commensurate with the average return on investment in mining in the United States of America which was 10.4 per cent in 1972.[10]

Whatever specific form regulation by the Sea-Bed Authority might take, the régime must have sufficient flexibility to adapt its mode of operation to the changing conditions of world markets and of the industry itself. Without this flexibility, the Authority would be severely hampered. It would be extremely difficult to ensure that the objectives discussed under the goal of rational development would be achieved. A more practical problem will be to determine on which stage of production the income of the Authority would be based. If the value of nodules on board ship were to be used as the base, then the larger share of the benefits from the common heritage of mankind would accrue to the producing countries. Nodules on board ship would represent only 6 to 10 per cent of the value of nodules after the processing stage. The Authority must be able to acquire some of the value added by processing, since the significant benefits from establishing the processing plants will again go to the producing countries.

One possible way to tackle the objective of conservation of nodule resources would be to employ a grid system for the demarcation of the area of potential mining operations. Within the grid system, only selected blocks might be auctioned by the Authority to potential producers in any year. The income of the Authority might, for example, consist of two parts: the proceeds from the auction plus a levy on net or gross revenues. The highest bidder would acquire control over the mine site for a fixed period which would be long enough to allow him to recoup his investment, after which the site would be returned, in a specified condition, to the Authority. Certain blocks would not be auctioned immediately, but reserved for future use.

The range of possible policy alternatives open to the International Authority is quite large. The regulatory options discussed in the report are by no means the only feasible alternatives. For example, it is not necessary that the Authority license commercial exploitation of nodules by private companies. Alternatively, the Authority might enter into joint ventures, or it might choose to undertake the entire operation of sea-bed mining by itself.

In any case, it appears that even after paying the levies of an International Authority, sea-bed mining will be a commercially profitable operation. There are concrete policy options which can balance the interests of the mineral producing and consuming nations. Some of these possible options are discussed at length in the report. It should be emphasized that the pace of change in world economic affairs—especially of exchange rates, commercial policies and inflation—can significantly alter the economic picture within a few years. Any form of interna-

[9] Detailed presentation of hypothetical production from nodules, following these guidelines, is found in table 8 on page 26.

[10] The detailed estimates of revenues per mining operation of the Authority are given in table 11 on page 34.

tional regulation of sea-bed mining must be sufficiently flexible to adapt itself, its methods and objectives to the changing economic order.

I. Review of sea-bed mining activities[11]

Deep sea-bed mining is a complex, multifaceted undertaking. Exploitation of nodules may be classified into three broad stages, namely: (1) the search for nodule deposits, (2) mining, and (3) metallurgical processing. A summary of the most important steps involved in each stage along with the most recent activities of companies and other institutions involved in research and development is presented below.

1. *The search for nodule deposits*

In the search for nodules, activities of a scientific character can generally be distinguished from the stages of exploration and evaluation because of their different objectives. Together they form a continuum in the accumulation of knowledge about sea-bed resources needed prior to commencement of commercial mining operations, and it is difficult to define where the scientific inquiry ends and the stage of exploration begins and where this stage ends and evaluation starts.

(a) *Procedures used*

Exploration is the broadly based survey using all available methods: the search generally begins over a large area and progressively narrows down to sites with mining potential.[12] This stage is generally referred to as "prospecting". It requires mapping, sampling of surficial and sub-bottom materials and making geophysical and geochemical measurements, and is best approached as a phased programme of increasingly more detailed surveys.[13]

A large array of scientific instruments and devices are required to collect the necessary data (see figure 1). Exploration vessels must carry sophisticated positioning equipment (satellite, celestial) and computers to correlate all sample data and other observations with precise co-ordinates. Acoustic and magnetic systems are used to obtain geophysical information about the nature of the sea bottom. The actual search for nodule deposits is made through optical systems such as closed-circuit television and still and movie cameras.

The spacing at which samples are taken depends on results obtained, and generally range from 5 to 50 miles. The devices most commonly used for collecting samples are the free-fall sampler also called boomerang, gravity-corer, piston-corer and dredge. The free-fall sampler is extensively used by institutions and industry groups such as Kennecott, Centre national pour l'exploitation des océans (CNEXO), Preussag and Global Marine. These free-fall devices grab a small sample of nodules from an area of about 1 square foot.[14] Corers are used to derive information on the sediments underlying the nodule deposit. Dredge sampling is used to collect a large volume of nodules for metallurgical testing from areas known to contain attractive nodule deposits.

A detailed appraisal follows the discovery and outlining of a potential mine site. The objective is to provide information upon which to base feasibility studies.[15] Recoverable nodule grade and concentration estimates are the key parameters sought in evaluation surveys. The equipment required for evaluation is similar to that needed for the exploration stage. However, greater attention must be given to the precise correlation of sample data and other observations with their geographic location.

(b) *Recent activities*

Given the difficulty of differentiating in practice between the activities of exploration and evaluation, they will be described jointly. Most of the major groups involved in manganese nodule mining investigations have completed the exploration stage and are aware of a number of potential manganese nodule mining sites.[16] Some groups are believed to have virtually completed the evaluation stage.

Deepsea Ventures has carried out 33 cruises in the Pacific with the research ship *Prospector* in three and a half years of work at sea. Kennecott Copper sponsored exploration cruises before initiating its own surveys in 1967.[17] The company has dredged about 250 tons of nodules for processing research. Global Marine has been conducting nodule surveys on behalf of Summa Corporation. International Nickel has undertaken several cruises in recent years using chartered vessels.

The Arbeitsgemeinschaft Meerestechnischgewinnbare Rohstoffe (AMR) group of the Federal Republic of Germany has carried out a number of cruises in the Pacific since 1971. This group chartered for two years Deepsea Venture's research ship *Prospector* and has been using since 1972 the well-equipped research ship *Valdivia* (see figure 1). The AMR group plans five expeditions south-east of Hawaii in 1974. The CNEXO group of France, in association with Le Nickel, has undertaken surveys in the South Pacific since 1970. CNEXO has established an oceanographic centre in Tahiti which supports its extensive nodule programme in the general vicinity of French Polynesia.[18]

The Sumitomo—(Deep Ocean Minerals Association) (DOMA) group has carried out extensive nodule surveys in the Pacific and has dredged nodule tonnage for processing research. DOMA, which is made up of 27 leading Japanese companies, completed an advanced vessel specifically designed for sea-bed resource exploration. The Soviet Union has conducted several cruises using the research ship *Vityaz* and has reported a number of interesting nodule grades from the South Pacific.[19]

2. *Nodule mining technology*

The mining systems under development comprise four major components: the mining/loading head; materials elevation/hoisting system; surface facility; and production transportation to shore plant. A schematic presentation of the major components of deep-ocean mining systems is given in figure 2.

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[11] Since no official communication or information on recent sea-bed mining activities was available, this section was prepared on the basis of publications, such as journals, technical periodicals and company press releases. Accordingly, the Secretary-General cannot vouch for the accuracy of all the material covered in this report.

[12] *Report of the* Ad Hoc *Committee to Study the Peaceful Uses of the Sea-Bed and the Ocean Floor Beyond the Limits of National Jurisdiction (Official Records of the General Assembly, Twenty-third Session,* document A/7230), p. 25.

[13] See J. E. Flipse, M. A. Dubs, and R. J. Greenwald, "Pre-Production Manganese Nodule Mining Activities and Requirements", *Mineral Resources of the Deep Seabed,* Hearings of the Subcommittee on Minerals, Materials and Fuels of the Committee on Interior and Insular Affairs on Senate Bill 1134, May-June 1973 (Washington, D.C., Government Printing Office, 1973), pp. 607-614.

[14] The operation cycle of these devices is approximately three hours. It is reported in French and German expeditions that up to 10 per cent of the devices may be lost during a cruise. W. Kollwentz, "Exploration Methods and Techniques—Experiences with R. V. Valdivia", *Meerestechnik,* December 1973, p. 192.

[15] *Mineral Resources Development with Particular Reference to the Developing Countries* (United Nations Publication, Sales No. E.70. II.B.3) pp. 3-5.

[16] A. J. Rothstein and R. Kaufman, "The Approaching Maturity of Deep Ocean Mining—The Pace Quickens", *Offshore Technology Conference, 1973* (Preprints) vol. 1, pp. 323-344.

[17] Kennecott Management Communication, vol. 2, No. 10, November 1970, p. 1.

[18] CNEXO, Annual Report, Paris, 1972.

[19] N. S. Skornyakova and P. F. Andrushchenko, "Iron Manganese Nodules From the Central Part of the South Pacific", *Oceanology,* vol. 8, No. 5, 1968, pp. 692-701.

Figure 1

OFFSHORE EXPLORATION OF NODULES

Offshore Exploration of Ores

Navigation

1 Stars
2 Satellites
3 Radio navigation
4 Navigation buoy (transponder/radar)

Bathymetry

5 Narrow beam sounder (NBS) sediment echograph
6 Various depth recorders

Reflection Seismic

7 Airgun
8 Streamer with hydrophones, analogue and digital registration

Oceanographic Survey

9 Underwater measuring chain with localizable buoy
10 Current meter
11 Thermometer
12 Water pressure gauge
13 Cut-off anchor
14 Bathysonde (probe) continuous measurement of

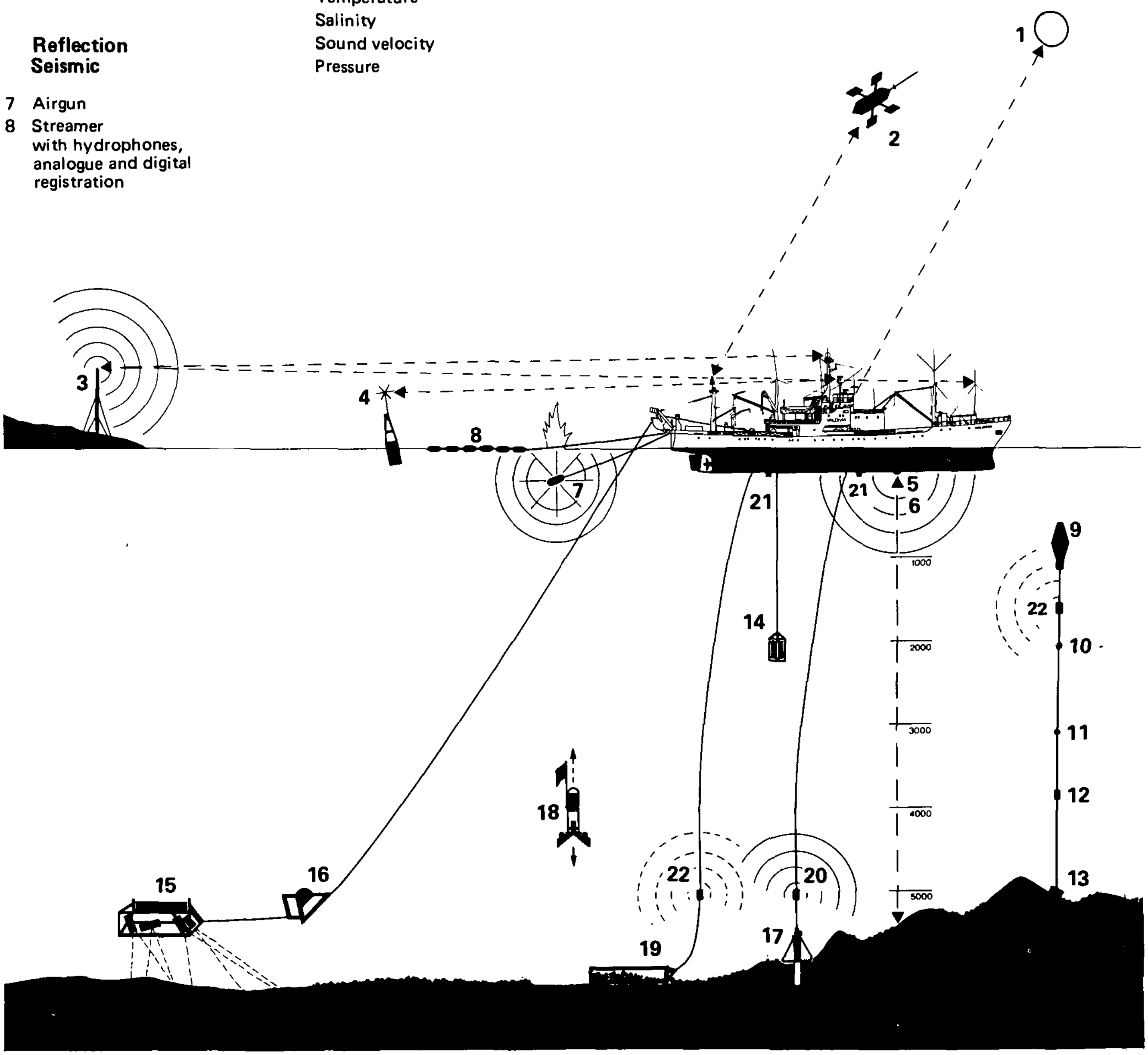
Temperature
Salinity
Sound velocity
Pressure

Survey of Ore Deposits

15 Deep diving probe with TV camera, still camera and lights
16 Stabilizing platform
17 Corer for sampling sediment with nodules
18 Freefall sampler
19 Bulk sampling of nodules for metallurgical tests

Localization of launched Survey Gauges

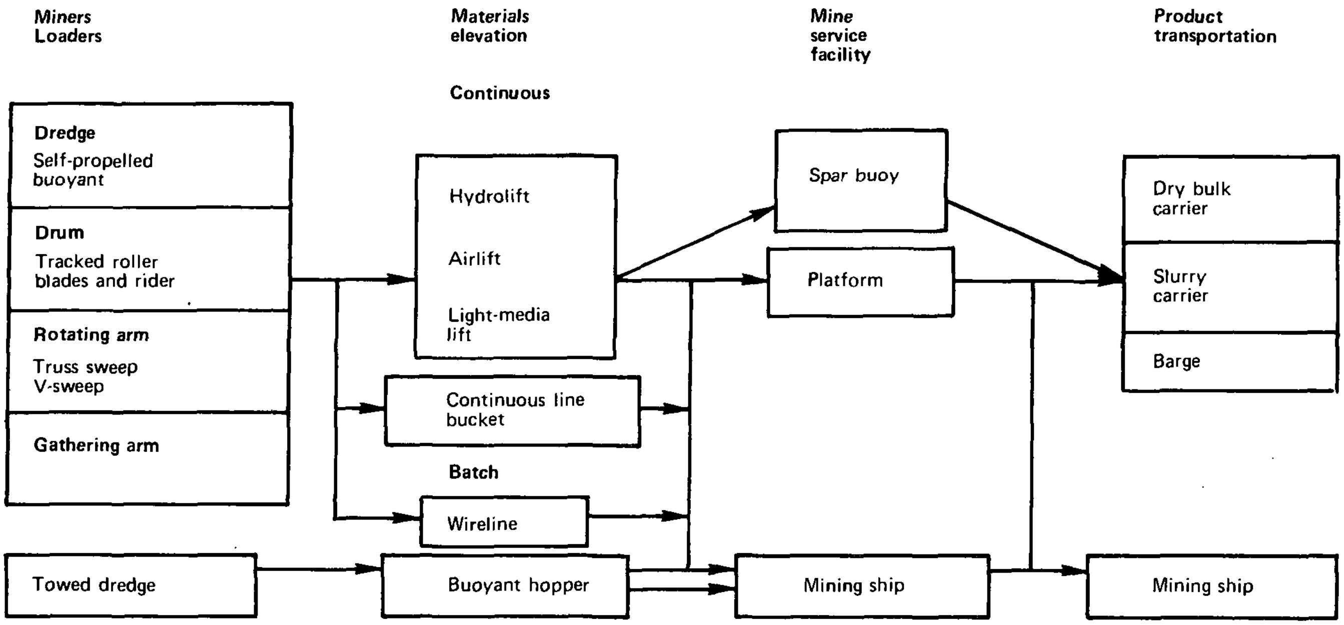
20 Pinger
21 Hydrophone
22 Transponder



Courtesy of Arbeitsgemeinschaft Meerestechnischgewinnbare Rohstoffe, the Federal Republic of Germany.

Figure 2

COMPONENTS OF NODULE MINING SYSTEM



(a) *Nodule collection*

Several forms of nodule gathering apparatus are under development. The dredge variety currently is thought to have the best potential for use in commercial production. Typically the dredge incorporates a sizing system to pick up nodules within a certain size range while excluding very large pieces as well as fine bottom silt. It is usually sufficient to drag the dredge head across the ocean floor to loosen the nodules from the substratum. The mining equipment must be kept as mechanically simple as possible to minimize maintenance. One problem encountered, however, is the construction and operation of the very wide dredge head needed to collect the desired volume of nodules per hour (200 to 400 tons). The large dredge size is required because of the relatively low nodule concentration at the sea floor (1.5 to 5 pounds per square foot) and the maximum practical speed for operation of the system (1 to 3 knots).

Three miner/loaders are shown in figure 3. The Deepsea Ventures and the AMR are both airlift systems with mining heads of the towed dredges type. The bottom crawler has a tracked drum for nodule pick-up.[20]

(b) *Materials elevation*

Another critical factor in nodule mining is the materials elevation/hoisting system. Continuous systems can be based on: air lift, hydrolift (hydraulic hoisting), light-media lift and mechanical lift such as the continuous line bucket (CLB) system. Batch systems include wireline dredging which, although useful for collecting tonnage samples, is not regarded as an economic large-scale production system due to its high cost when used at great depths. A buoyant hopper (submersible hopper) system has been proposed.[21,22] Whether this system is being developed for materials elevation is not known, although the concept is somewhat akin to the Summa Corporation barge.[23]

[20] G. W. Sheary and J. E. Steele, "Mechanical Deep Sea Nodule Harvester", United States Patent 3,480,326, 25 November 1969.

[21] G. W. Lehmann, "Submersible Mining, Lifting, and Towing Barge", United States Patent No. 3,220,372, 30 November 1965.

[22] J. C. Wenzel, "Systems—Development Planning", *Ocean Engineering* (New York, John Wiley & Sons, Inc., 1968) p. 110.

[23] *Business Week*, 16 June 1973, pp. 47, 50.

An air-lift is technically a three-phase flow—air, nodules and water. Compressed air is injected into the main pipe at various water depths to sustain the lifting action. Deepsea Ventures successfully tested an airlift device in 2,500 feet of water over the Blake Plateau in 1970. On 6 May 1974, Tenneco, Inc. announced the formation of a new consortium with three Japanese companies: Nichimen Co. Ltd., C. Itoh and Co. Ltd., and Kanematsu-Gosho Ltd. An additional European partner will be announced shortly. The five companies will have an equal equity participation in Deepsea Ventures. They will invest about $US 20 million over the next three years to test mining and processing systems and to evaluate an ore body in the Pacific Ocean.

A hydrolift is technically a two-phase flow—nodules and water. The pump can be located close to the bottom or at an intermediate depth[24] (see figure 3). The technology for hydraulic and hydrolift pumping is well-developed and is used, for instance, in the coal industry. However, working at such depths and lifting such volumes as required in nodule mining represent giant steps beyond current capability. The hydrolift technique seems to be favoured by Kennecott,[25] which has recently announced the formation of a multinational group including, in addition to Kennecott (50 per cent equity), Rio Tinto Zinc (20 per cent) and Gold Fields (10 per cent) of the United Kingdom, Norande Mines (10 per cent) of Canada and Mitsubishi Corp. (10 per cent) of Japan. They announced plans for a large-scale mining test as part of a $US 50 million, five-year mining and processing development programme.[26]

The Hughes system is thought to operate on the hydrolift principle. The major components of the system are the 36,000-ton Hughes Glomar Explorer and a sea floor mining vehicle which is connected to the ship by a string of 16-inch pipe and an umbilical cable that supplies electric power and control circuits. A large submersible barge plays a key role in the

[24] J. L. Mero, "Dredge Underwater Pick-Up Head Assembly", United States Patent No. 3,226,854, 4 January 1966.

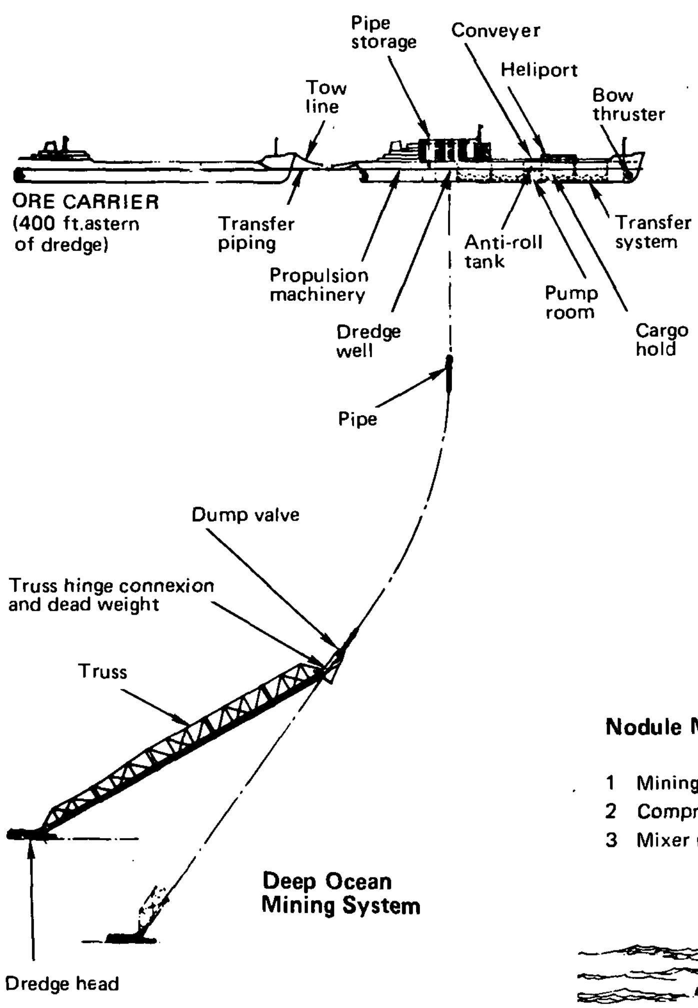
[25] C. R. Tinsley, "In Search for Commercial Nodules, Odds Look Best in Miocene-Age Pacific Tertiary System", *Engineering and Mining Journal*, June 1973, pp. 114-116.

[26] *Metals Week*, 4 February 1974, p. 6.

Figure 3

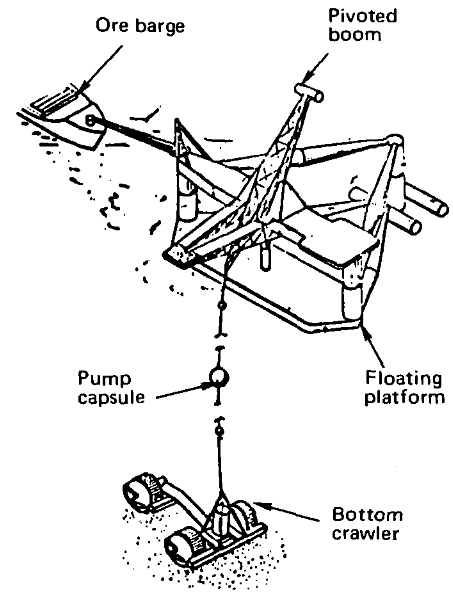
ARTIST'S CONCEPTION OF THE LIKELY OPERATION OF THREE SYSTEMS PROPOSED FOR MINING NODULES

Deepsea Ventures Ocean Mining System

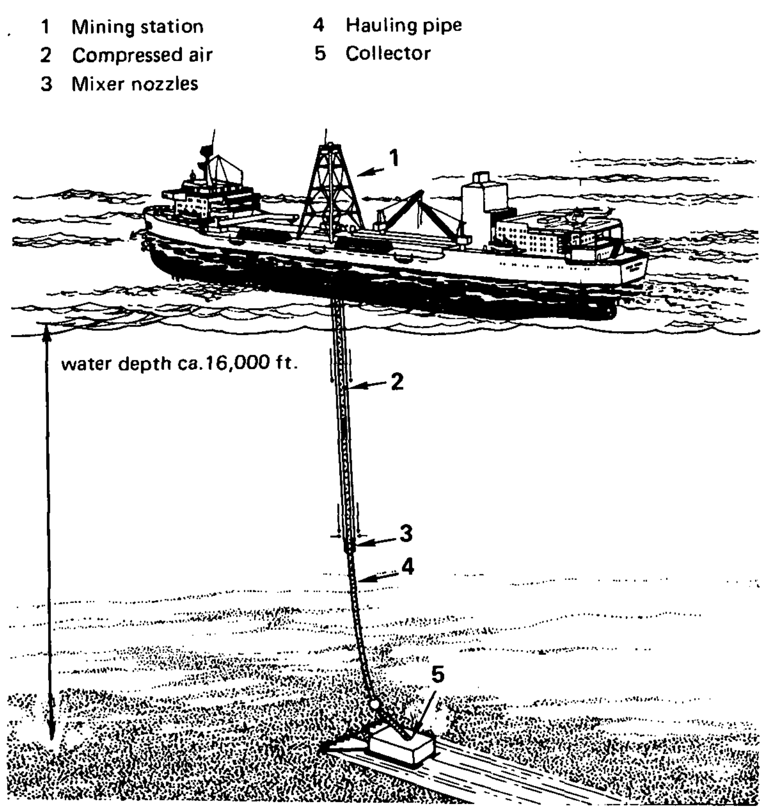


Courtesy of Deepsea Ventures

Bottom Crawler/Semisubmersible Surface Facility Concept



Nodule Mining by Airlift System



Courtesy of Arbeitsgemeinschaft Meerestechnischgewinnbare Rohstoffe system. The mining vehicle is too large and heavy to be handled by the ship's gear in a conventional manner and must be installed from beneath the ship. The unit is loaded onto the submersible barge which meets the ship in calm waters of a specified depth. There, the barge submerges and the docking legs of the ship engage the mining vehicle which is then connected to pipestring lowered from the ship's rugged derrick.[27] The Hughes ship (figure 5) left the west coast of the United States in January 1974 to join the barge for tests off Baja California.[28] Actual mining on a pilot scale may begin in late 1974 or early 1975.

[27] "Hughes Glomar Explorer begins sea tests of mining systems", *Ocean Industry*, March 1974, pp. 32-34.

[28] *Ocean Science News*, 11 January 1974, p. 1.

The CLB system uses a continuous polypropelene braided rope with dredge buckets attached. At the top, the loop is wound through traction motors while the bottom part of the loop drags along the ocean bottom. The CLB system was tested off Tahiti in August 1970.[29] A later CLB test in August/September 1972 recovered seven tons of nodules off Hawaii.[30] Several participants of the CLB consortium under the leadership of CNEXO of France are continuing work on a modification of the CLB,[31] which would use two ships working in tandem (see figure 4); the main components of this modified

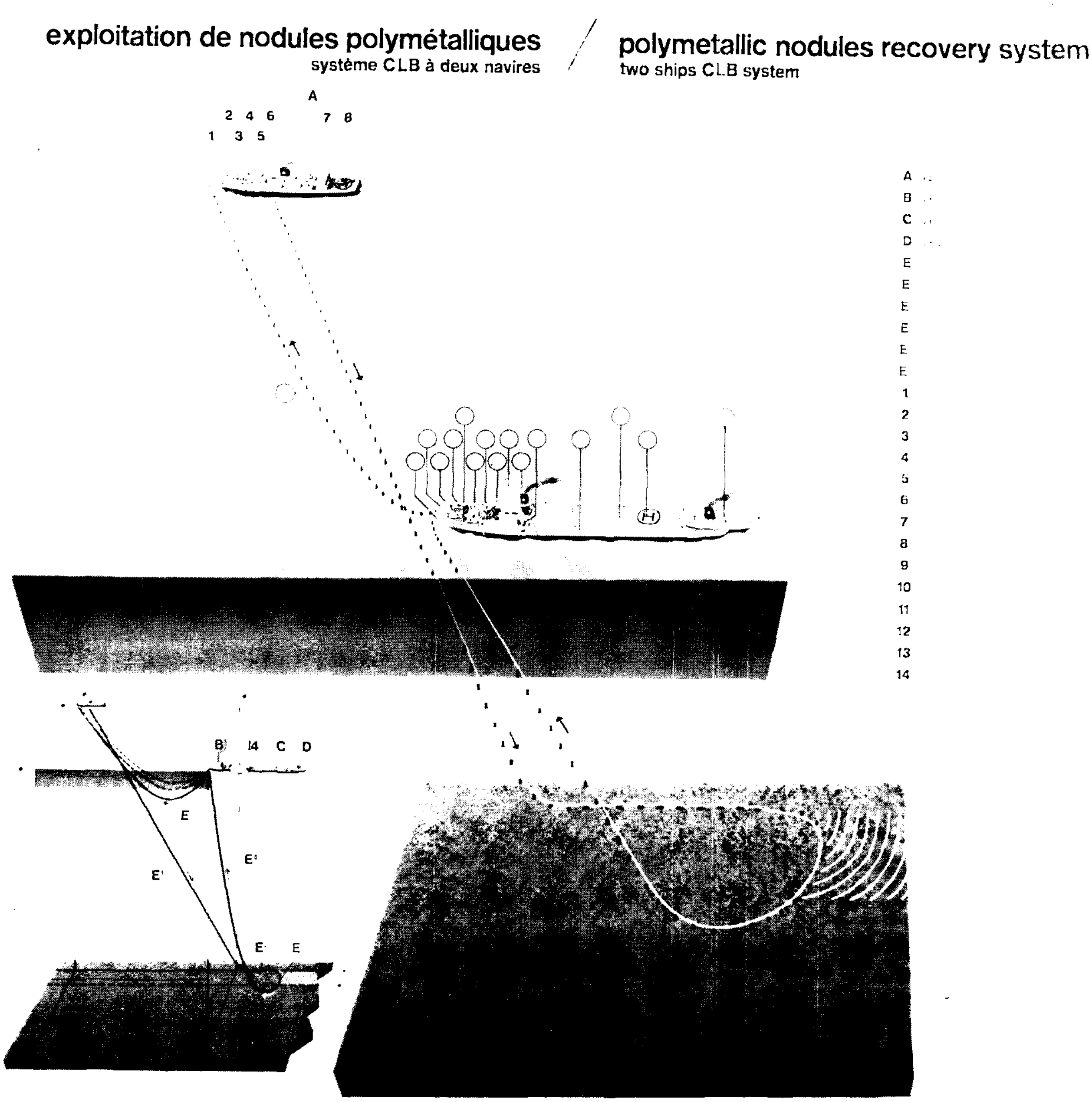
[29] Y. Masuda, M. J. Cruickshank and J. L. Mero, "Continuous Bucket-Line Dredging at 12,000 Feet", *Offshore Technology Conference, 1971*, Paper No. 1410.

[30] *Mining Magazine*, January 1973, p. 7.

[31] CNEXO, Annual Report, Paris, 1972.

Figure 4

TWO-SHIPS CONTINUOUS LINE BUCKET (CLB) SYSTEM



Courtesy of Centre National pour l'Exploitation des Océans and Société Le Nickel

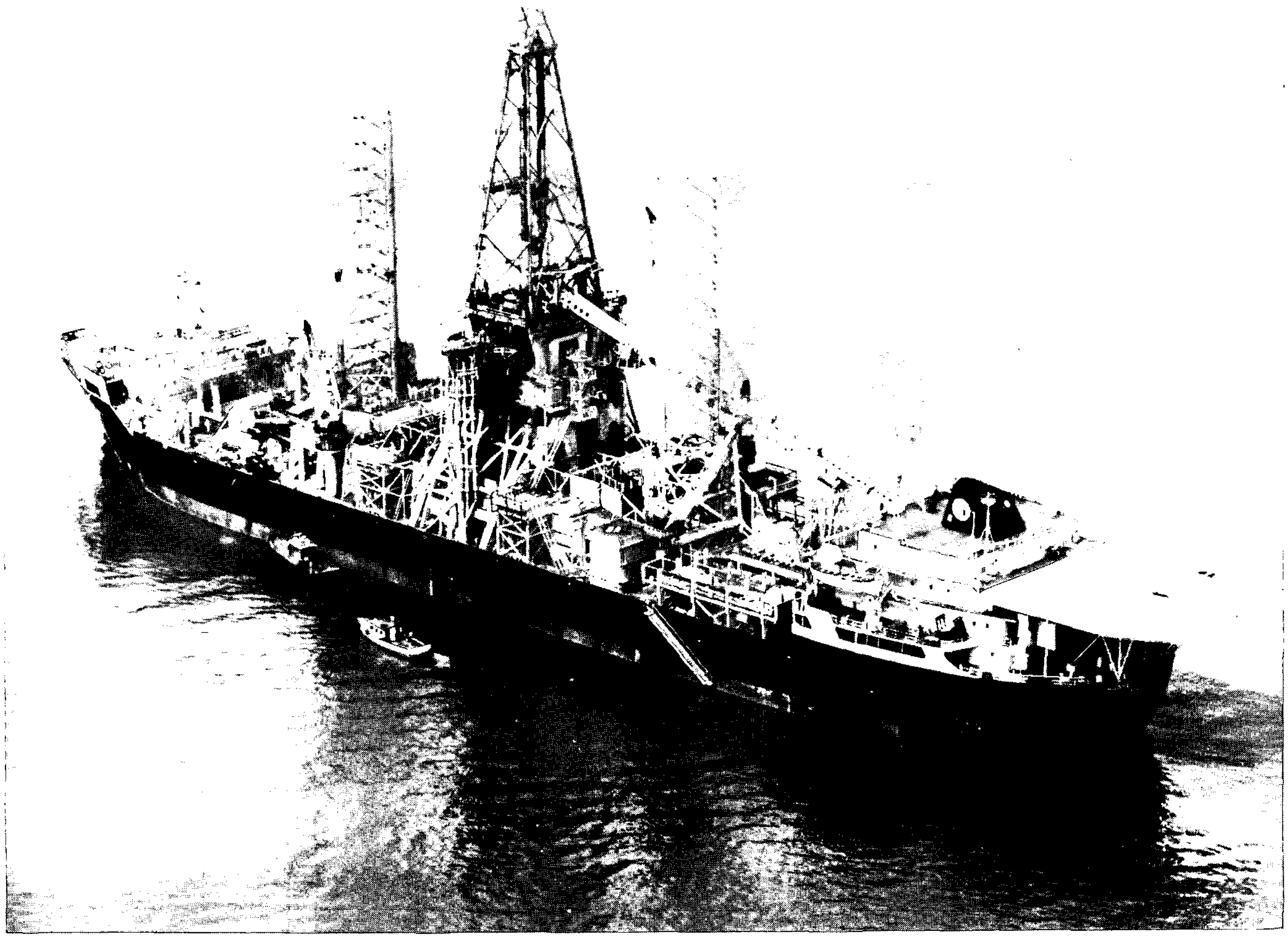


Figure 5

PROTOTYPE MINING SHIP—HUGHES GLOMAR EXPLORER

system are expected to be ready for tests in 1974.[32] Sumitomo is developing continuous ship handling equipment for the dredge baskets and is also doing additional research in the operation of the CLB system. The participants of the CLB consortium met in Houston, Texas, in early May 1974 to plan the financing and construction of the modified two ship system, which is expected to be ready for tests in late 1975. The system will be built in France by Ateliers et Chantiers de Bretagne.[33]

The Sumitomo group in co-operation with MITI is now proposing a large-scale manganese nodule venture with possible commercial operations by 1980.[34] Sumitomo would probably use the CLB mining technique.

(c) *Surface vessel*

The so-called first generation mining systems are likely to use the mining ship itself as the surface platform. Tug assistance may be used for directional movement in some systems. A pipe system for nodule lifting will require a derrick on board ship. Alternatives to a mine ship are a spar buoy or a semi-submersible platform. A spar buoy is a long cigar-shaped semi-submersible which when tilted on one end creates a small but highly stable working platform on its other end.[35] Semi-submersible floating platforms are extensively used in the off-shore oil industry for work in deeper waters (figure 3). Both the spar buoy and the semi-submersible platforms, however, have a poor capability for lateral movement.

The first generation of mining ships will do minimal processing at sea—perhaps crushing and/or drying the nodules—and the nodules will be transported in bulk by the mining ship itself (particularly a CLB mining ship)[36] or transferred at sea to a dry or bulk carrier.

3. *Metallurgical processing*

Nodules have a complex microscopic structure and are composed of fine-grained oxide material.[37] They can vary widely in chemical and physical properties according to location, e.g. Blake Plateau nodules from the Atlantic are high in calcium, whereas those from the North Pacific are more silicious. As a result, processing technology and costs for one type of nodule may not apply elsewhere.

[32] CNEXO, *Bulletin d'Information,* No. 61, January 1974, p. 5.

[33] *Ibid.*

[34] *Metals Week,* 11 June 1973, p. 2.

[35] D. M. Taylor, "New Concepts in Offshore Production", *Ocean Industry,* February 1969, pp. 66–70.

[36] J. L. Mero, "Recent Concepts in Undersea Mining", American Mining Congress, 1971 Mining Show, Las Vegas, Nevada, 4 August 1971.

[37] P. H. Cardwell, "Extractive Metallurgy of Ocean Nodules", *Mining Congress Journal,* November 1973, pp. 38–43.

Kennecott, Deepsea Ventures and Inco are thought to have completed nodule processing research.[38] Other groups—Summa Corp., AMR, DOMA—are fairly advanced in their process development programmes. Kennecott has operated a half-ton per day pilot plant for over a year. Inco has been carrying out laboratory tests at its Sudbury plant in Canada. Deepsea Ventures has completed a phase of its tests in a one-ton per day pilot plant and plans to build a larger pilot plant, possibly in 1974.

The two basic approaches to nodule processing can be classified as pyrometallurgical and hydrometallurgical, the latter based on chloride, ammonia or sulphur-oxide reaction. Some of these processes are considered technically possible, but not necessarily economically feasible. Heavy emphasis is being placed on the development of hydrometallurgical nodule processing systems.

4. *Government activities*

Government activity can take several forms, such as in particular: (1) direct sponsorship or funding of research and development; (2) direct venture in mining or processing; and (3) indirect sponsorship through use of government facilities, taxation advantages, or university aid. A brief review of the activities reported in recent years is given below.[39]

Australia's Bureau of Mineral Resources used the Navy vessel research ship *Diamantina* to dredge for nodules along a 200-mile stretch of the 39th parallel in June 1972. In New Zealand, the Department of Scientific and Industrial Research is giving increasing emphasis to studies on the distribution and chemical composition of manganese nodules and coatings.[40]

In France, CNEXO has been conducting extensive exploration for nodules and is sponsoring engineering research for a modification of the CLB mining system.[41] Research on nodule processing is being done by the French Atomic Energy Commission.

The Japanese Government has been very active in the sponsorship of exploration programmes and development of mining and metallurgical processing. Its Science and Technology Agency subsidized Sumitomo Shoji and Sumitomo Shipbuilding and Machinery to conduct tests of a small-scale CLB system in 1968.[42] MITI subsidized the Sumitomo group in 1970 to carry out research[43] and conduct a 1/10-scale CLB test off Tahiti.[44] MITI again subsidized Sumitomo in 1971 to develop automatically detachable buckets for the CLB.[45] In mid-1972, the Industrial Science and Technology Agency gave a subsidy to Sumitomo Metal Mining to assist the construction of a $106,000 test plant which would be partially used to conduct research and development on nodules processing.[46]

Governmental participation will increase with MITI's proposed creation of a large semi-public venture for nodule mining and processing called Deep Ocean Mining Association (DOMA). Funds would be allocated by industry and Government starting in 1976 or 1977.[47] MITI has subsidized the construction of a sophisticated new vessel which should be ready to conduct manganese nodule surveys by mid-1974.

In the United Kingdom, the Department of Trade and Industry has offered financial support of up to $US 1.8 million to Rio Tinto Zinc and Consolidated Gold Fields, which are two British members of the recently created—five company—Kennecott group. These funds would be repaid if the project proves commercial. These companies have, in turn, agreed that British firms would have first call on their 30 per cent share of the metals to be produced by the Kennecott group.[48]

In the United States, governmental activity in nodule research has been carried out by the United States Bureau of Mines, the United States Geological Survey and by the National Oceanic and Atmospheric Agency (NOAA). However, the only federal research centre dealing solely with marine minerals was closed by NOAA in March 1973. The United States Geological Survey maintains an active nodule programme. The United States National Science Foundation is sponsoring a $500,000 a year interuniversity programme under the auspices of the International Decade of Ocean Exploration. The money is being spent primarily in studying the origins and chemistry of the nodules. The programme's financial commitment is due to be expanded to $1 million per annum in the second phase. The University of Hawaii will receive some United States Government support for nodule exploration and environmental impact surveys in 1974.

The USSR has been actively engaged in nodule research and prospecting since the early 1950s. Large numbers of photos and samples of nodules have been obtained.[49] A Marine Geological Prospecting Board was formed in early 1971 to promote better co-ordination of activities in marine minerals. A COMECON meeting in Riga discussed geological prospecting and greater use of ocean resources.[50]

The Government of the Federal Republic of Germany granted support for a Preussag-Metallgesellschaft joint venture to study and explore for nodules in 1969. In 1970 and 1971 the Government provided funds to charter Deepsea Ventures' research ship *Prospector* for Pacific nodule exploration cruises. Private firms converted a stern trawler to the deep-ocean exploration vessel R/V *Valdivia*, which is now used for nodule surveys. The Federal Ministry for Education and Science has chartered this ship for four years, thus providing substantial support for a comprehensive nodule survey programme. It is reported that a sister ship is being built with the help of a government subsidy.[51]

The AMR group—Preussag, Metallgesellschaft, Salzgitter and Rheinbraun—has received a $US 3 million subsidy for a feasibility study on the mining of manganese nodules.[52] The AMR group is spending about $3.1 million a year on nodule research and development with $700,000 annually coming from the Bonn Government.[53]

Fiji, Tonga and Western Samoa have shown great interest in locating commercial grade nodule deposits close to their shores. The United Nations Economic Commission for Asia and the Far East (ECAFE), through its Committee for Co-ordination of Joint Prospecting for Mineral Resources in

[38] *Metals Week*, 21 January 1974, p. 10.

[39] See also A/AC.138/90.

[40] *Report of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas*, First session, 7-13 November 1972 (E/CN.11/L.343), annex III, para. 11.

[41] CNEXO, Annual Report, Paris, 1972.

[42] Sumitomo Shoji Kaisha, "Historical Review of Manganese Nodule Development by the Sumitomo Group", 25 September 1972.

[43] J. E. Flipse, M. A. Dubs and R. J. Greenwald, "Pre-Production Manganese Nodule Mining Activities and Requirements", *Mineral Resources of the Deep Seabed*, op. cit., in foot-note 13, pp. 602-700.

[44] Y. Masuda, "Development Work to Deep Sea Resources of Manganese Nodule Using Continuous Line Bucket System (CLB) by Japanese Group and its Future". *Second International Ocean Development Conference, Tokyo, 5-7 October 1972* (Preprints).

[45] Sumitomo Shoji Kaisha, op. cit.

[46] *Japan Metal Journal*, 26 June 1972, p. 8.

[47] *Metals Week*, 15 January 1973, p. 9.

[48] *Metals Week*, 4 February 1974, p. 6.

[49] N. S. Skornyakova and P. F. Andrushchenko, "Iron Manganese Nodules from the Central Part of the South Pacific", *Oceanology*, vol. 8, No. 5, 1968, pp. 692-701.

[50] *The New York Times*, 24 April 1971, "Soviet Bloc Plans Big Sea-Bed Study".

[51] D. R. Horn, B. M. Horn and M. N. Delach, "Ocean Manganese Nodules Metal Values and Mining Sites", Technical report No. 4, International Decade of Ocean Exploration, N.S.F. Washington, D.C., 1973.

[52] *Metals Week*, 18 December 1972, p. 3.

[53] *Metals Week*, 12 March 1973, p. 10.

South Pacific Offshore Areas, is sponsoring two nodule survey projects in this area.[54]

5. *Proposals for Government legislation*

A bill before the United States Congress, usually referred to as S.2801 (now S.1134) has been the subject of hearings before the Subcommittee on Minerals, Materials and Fuels of the United States Senate Committee on Interior and Insular Affairs. The bill basically provides for the United States Secretary of the Interior to register deep-ocean mining leases of 40,000 square kilometres on a first-in-time, first-in-right basis. The 15-year lease could be held for a total expenditure of $US 6.2 million. Three-quarters of the lease would be relinquished within 10 years of the issue date or at the start of commercial production. An escrow fund established from a portion of United States taxes would be distributed to certain reciprocating developing States designated by the President. The bill would also give protection, to licensed United States companies, against possible adverse effects on their financial position that might be brought about by regulations of an international régime. The United States Government would indemnify such losses to licensed operators under this interim legislation until the fortieth anniversary of the issuance of the license.[55]

II. The probable impact of nodule mining

1. *Forecasting future production of metals from nodules: the problems involved*

The accuracy of a forecast is far less dependent on the complexity of the mathematical model used than on the quantification of the major parameters and the assumptions regarding their behaviour. It is important, therefore, to stress the uncertainties involved in trying to forecast the probable production of metals from nodules, which in itself is the first step in any attempt to assess the future impact of the nodule industry on world market in general and on the mineral exports of the developing countries in particular.

At the risk of stating the obvious, it must be recalled that the "nodule industry" is not yet an ongoing reality. On the contrary, nodule mining technology and metallurgical processing are still in the developmental stage. Considerable uncertainties therefore becloud any estimates of performance by the future industry.

It is natural that officials of firms developing nodule systems should be optimistic about the future. Indeed all available information tends to confirm the industry contention that nodule mining will be a very profitable proposition (see section III.5.b, below). Yet, one should not minimize the potential hazards involved in the continuous operation of mine ships in the high seas with sophisticated equipment for gathering and lifting nodules from about 5,000 metres water depth. The vagaries of the weather at the surface, resistance of materials subject to the high pressures and corrosion of the water column, topographic hazards at the sea-floor and the logistics of maintaining a large crew out at sea for an extended time, are some of the factors that will bear on the operational results of nodule mining once it starts on a commercial scale. It remains to be seen how attractive the economic returns of the industry will actually turn out to be.

2. *The probable scenario for the next decade*

Considering the problems involved in forecasting future production of metals from nodules, the projections presented in this section must be interpreted as orders of magnitude, based on the best information available. In order to facilitate the periodic revision of these projections, their underlying assumptions are explained below.

[54] Project CCSP-1/TG.1 "Seabed investigations for manganese nodules on the deep submarine shelf on east side of Tonga platform"; and Project CCSP/1/WS.2 "Seabed investigations for manganese nodules in oceanic areas surrounding Western Samoa"; (see E/CN.11/L.343).

[55] *Mineral Resources of the Deep Seabed,* op. cit. in foot-note 13.

(a) *The methodology used*

Estimates of metal production from nodules are attempted for the arbitrarily selected decade 1976–1985. For the purpose of these projections, it is assumed that an internationally agreed régime would come provisionally into force by 1976, thus providing the legal framework enabling the interested companies and groups to go ahead with their nodule programmes. The projections are based on an evaluation of the probable time that it is likely to take for the various groups to conclude successfully all activities in their implementation programmes and start commercial production. Assumptions are made regarding metal production per ton of dry nodules, size of projects and the schedule of start-up operations.[56]

(i) *Metal production per ton of nodules*

Metal output per ton of dry[57] nodules is a function of nodule grade and of metallurgical recovery. The figures used are a combination of data: information made public by industry officials; published scientific data; and information provided directly by geologists and other officials associated with the industry.

Some European and American geologists working for the nodule industry have suggested that their companies' targets to identify ore bodies containing over 3 per cent combined nickel and copper have already been met. Metal recovery depends on the metallurgical process adopted, but it seems that the industry might obtain a 95 per cent yield on the recovered metals.[58] *The preliminary assumptions made on the grade of ore-bodies likely to be exploited by the first generation of nodule miners and metal production, including the recovery of several trace metals (molybdenum, vanadium, zinc, silver, etc.),*[59] are summarized in table 1.

Table 1

ESTIMATED METAL PRODUCTION PER MILLION TONS OF HIGH GRADE NODULES
(*Metric tons*)

Metal	*Metal content per weight of dry nodules (percentage)*	*Approximate metal production per million tons of dry nodules** [a] *(tons)*
Manganese (if recovered)	24	230,000
Nickel	1.6	15,000
Copper	1.4	13,000
Cobalt	0.21	2,000
Other metals	0.3	2,500

*Assuming 95 per cent metallurgical recovery except for trace metals where an 80 per cent rate is assumed.

[a] The estimated metal production from nodules used in the recent UNCTAD report (TD/B/483) are different: they were based on data from a previous United Nations publication (A/AC.138/36) of 1971.

[56] Implicit in all these assumptions is that costs of metals produced from nodules will be competitive with alternative land sources of these metals.

[57] Since most metallurgical processes under consideration require the prior drying of nodules, plant capacity is generally referred to in terms of "dry" nodules. On the other hand, the capcity of mining systems is expressed in terms of "wet" nodules, since water accounts for about one third of the weight of wet nodules.

[58] "Studies to date indicate the practicality of process yields of 98 per cent plus purity manganese, nickel, cobalt and metallic copper." R. Kaufman and A. J. Rothstein, "Recent Developments in Deep Ocean Mining", *Sixth Annual Conference of the Marine Technology Society,* 1970 (Preprints), Washington, D.C. It is possible that some metallurgical processes will yield lower recovery rates than 95 per cent. These processes, requiring much lower total investments, are designed to optimize return on investment and not metal recovery.

[59] Deepsea Ventures, Inc. "Pilot plant operation of a process to produce metals from manganese nodules", mimeographed document; and *Undersea Technology,* April 1973, pp. 26 and 27.

These estimated volumes of production are confirmed by separate company statements. The volume of nickel and copper coincide with the estimates of Kennecott Copper, Inc.[60] The volumes of manganese, cobalt and trace metal recovery are the figures indicated by Deepsea Ventures,[61] which some experts think to be on the low side.

(ii) *Size of operations*

Like most mining and metallurgical operations, nodule systems are subject to considerable economies of scale. Decisions regarding the size of the total system are based on market considerations and the size relationship between the mining and processing stages.

It is known, for instance, that economies of scale are much stronger at the processing stage. As a result, unit costs are probably still decreasing for plant sizes of 3 to 4 million tons of dry nodules per year. On the other hand, it seems that mining rigs, of the hydraulic lift type, reach their optimum size at a capacity of between 5,000 to 10,000 tons of wet nodules per day, which is equivalent to 1–2 million tons of dry nodules per year. It may be expected, therefore, that most nodule systems will be designed to process 3 to 4 million tons of dry nodules per year with the use of two or three mining rigs. Deepsea Ventures is planning to recover manganese in metal form, the world market for which is rather small, and envisages a plant of 1 million tons of nodules per year.

The projections of this report assume that nodule systems until 1985 will be of two sizes: 1 million tons per annum and 3 million tons per annum.[62] This assumption is in fact an extension of the situation of American companies to companies and groups in other countries.[63]

(iii) *Entry of new nodule operations*

The timing question is likely to prove one of the most speculative in the projections equation. A multitude of factors can affect the entry of new nodule operations, more likely postponing the start of commercial production to a later date. Consequently, the timing schedule, compiled for the six companies (figure 6) or groups known to be most advanced in developing nodule systems, could be taken as a rather optimistic assumption that no major problems would unduly delay the plans of the industry.

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[60] Marne Dubs, Director of the Ocean Resources Department, stated: "One such [nodule] plant of 3 million [ton] size might produce on the order of 100 million pounds per year of nickel and 85 million pounds of copper along with other products mentioned". (This would amount to 15,150 tons of nickel and 12,880 tons of copper for each 1 million tons of nodules.) *Mineral Resources of the Deep Seabed*, op. cit. in foot-note 13, p. 109.

[61] Statement by Mr. N. W. Freeman, Chairman of the Boards of Tenneco, Inc. and Deepsea Ventures, Inc. before the hearing on Senate Bill 2801, of the Sub-committee on Minerals, Materials and Fuels of the United States Senate, on 2 June 1972. Mr. Freeman indicated that the expected metal output from a production unit of 1 million tons of dry nodules per year would be:

	Metric tons
Manganese	230,000
Nickel	11,400
Copper	9,100
Cobalt	2,000
Other metals (including molybdenum, vanadium, zinc and silver)	2,500

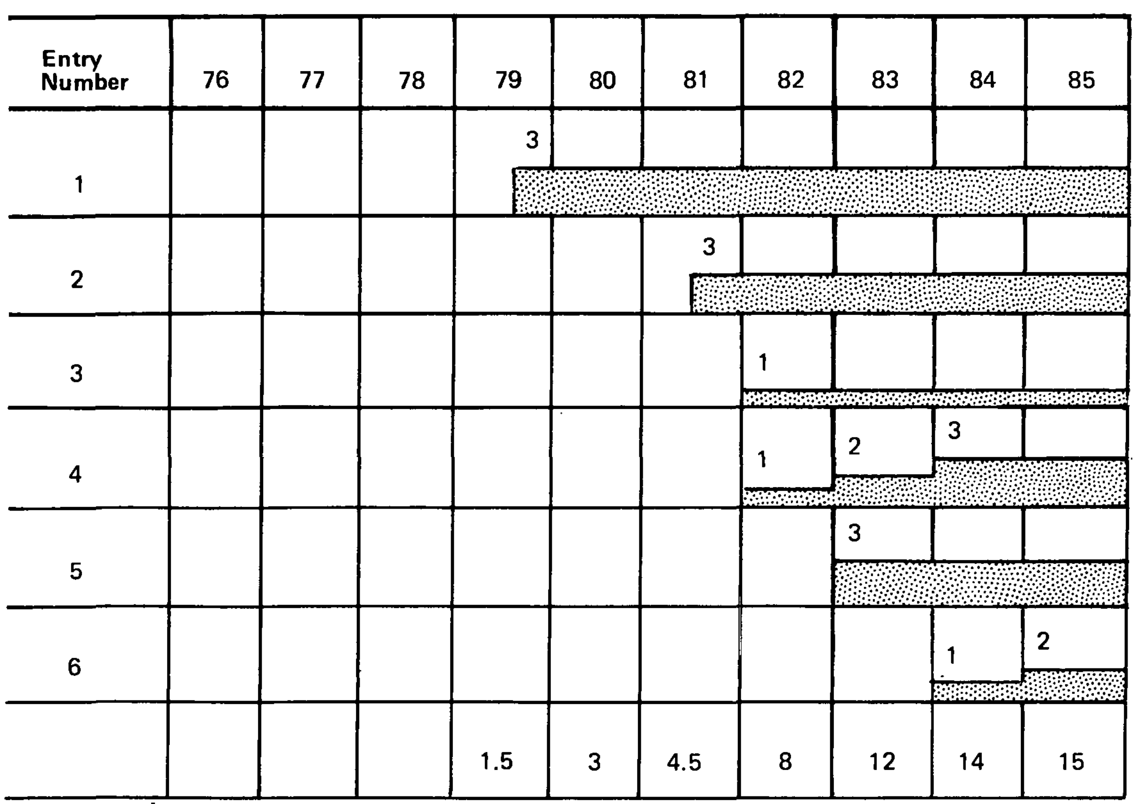
[62] It must be understood that these figures are mere approximations in the absence of extensive tests of large-scale mining rigs.

[63] "American mining companies at present are considering production rates of about 1 to 3 million tons of manganese nodules per year.", Leigh S. Ratiner, *Mineral Resources of the Deep Seabed*, op. cit. in foot-note 13, p. 27.

Figure 6

FORECAST OF ENTRIES INTO NODULE MINING: 1976–1985[a]

(*in million metric tons of dry nodules*)



[a] In UNCTAD reports TD/B/449.Add.1 and TD/B/483 different assumptions were used with alternate entry schedules, some starting as early as 1974.

The time-table was derived from an assessment of companies' stated plans and an evaluation of the most probable time for implementation of construction facilities for those companies or groups that have not publicized their intentions.[64] Some projects are assumed to start operating at full capacity. This would happen as a result of the implementation schedule of these projects: the decision to build the processing plant would have to await the successful testing of large-scale mining systems. Once the mining tests are concluded and the "go-ahead" is given for plant construction, some two to three years would elapse before metal production could start. In the meanwhile the original mine equipment would in all likelihood be used for mining nodules which would be stockpiled until processing could start. If it is assumed that a second mine ship might be commissioned around the time the processing plant starts operation, the 3 million tons per annum projects could commence production at full capacity. For the sake of simplicity it is assumed that output will be equal to a mining rig's total annual capacity, even in the first year of operation.

The timing of entry might be affected by the degree of control over the pace of nodule mining that may be exercised by the International Authority, in particular for the first few operations. The assumptions on timing of entry made in figure 6 are based on the absence of controls. If powers such as control over the pace of exploitation are exercised by the Authority, a delay of perhaps one or two years might occur for the projects assumed to enter into operation up to 1981, though the total tonnage of nodules that is likely to be mined by 1985 would probably be unaffected if the control scheme were established along the lines discussed in section III, para. 3, below. The global figure of 15 million tons of nodules likely to be mined by 1985 is therefore more meaningful than the precise timing of individual entries in the intervening period.

(b) *Forecasting probable metal recovery from nodules by 1985*

Based on the assumptions developed in the previous section, a forecast of metal production from nodules in 1985 becomes a straightforward exercise. It would amount to a multiplication of the estimated metal recovery per ton of dry nodules by 15 million tons. Considering however, that only two companies or groups have indicated their intention to recover manganese from nodules, the calculation for this metal will instead be based on 4 million tons.

It should be stressed that the estimates for production of manganese, as well as cobalt and other minor metals have a lower degree of confidence than the estimates for nickel and copper.

The latter two metals will constitute the mainstay of the nodule industry; thus the effort to locate attractive mine sites is directed primarily at the nickel and copper content of the nodules. The content of manganese, cobalt and trace metals is probably of secondary importance except for nodules that contain heavy metals of the platinum group.[65] Cobalt and the minor metals occur in varying quantities in nodules. It is known, for instance, that in some areas in the vicinity of French territories of the South Pacific extensive deposits are found with high cobalt content (above 1.5 per cent). Considering the low average cobalt content assumed for these projections (0.21 per cent), it is quite possible that the actual tonnage of cobalt output may be considerably greater than the 30,000 tons projected for 1985. Similar considerations are applicable to other minor metals.

Table 2

Estimated metal production from nodules in 1985 [a]

Metal	*Estimated production (in metric tons)*
Manganese	920,000
Nickel	220,000
Copper	200,000
Cobalt	30,000
Others	38,000

Source: Data from table 1 and figure 6 (except manganese, for which recovery is assumed from only 4 million tons of nodules).

[a] See foot-note to table 1.

A wide range of variance can also be expected in the total recovery of manganese from nodules. Only one company in the United States has publicly affirmed its intention to produce manganese metal from 1 million tons of nodules. In Japan, research in nodule metallurgy is directed at finding an economic process to recover manganese. While it is possible that only the United States company will be producing manganese from nodules by 1985, it is also conceivable that advances in process research might make it possible for three or more ventures to recover manganese by that date. Hence, the uncertainty attached to the projected figure of 920,000 tons of manganese production by 1985.

3. *The likely impact of nodule mining*

An attempt to assess the likely impact of sea-bed mining, on world markets and on the exports of developing countries, requires in addition to the forecast of metal production from nodules, a forecast of metal production from traditional sources as well as a projection of demand for these metals. From the interaction of these variables it should be possible to assess the likely effect on prices of these metals. Demand and supply, however, are in turn dependent on prices. A rather complex econometric model would be required to indicate the likely impact of nodule mining on prices, and vice versa, of prices on nodule mining and on traditional land-based mining. Given the uncertainties involving the major variables projected over a 10-year span, a similar approach is used in this report.

The degree of market penetration is used to provide a first approximation of the impact of nodule mining. The procedure involved is to estimate the share of the market for each metal which is likely to be supplied by the nodule industry. Based on the degree of market penetration it is possible to evaluate the probable influence on metal prices and to assess the implications for mineral exports of developing countries.

This approach amounts to treating the supply of metals from nodules as an independent variable. Such a method is acceptable if it is assumed that nodule mining will remain profitable throughout the period, and if the joint product and by-product nature of the nodule industry[66] is taken into account. Consid-

[64] The implementation of a project requires the successful completion of work in a number of stages. Many activities can only start once some preceding activities are completed. From the time a decision is reached to go ahead with a nodule project, it would probably take some three years of accelerated construction work before commercial mining and processing could start. But the implementation stage presupposes the resolution of a number of questions, such as: (1) the general legal framework relating to commercial operations in the international area; (2) obtaining exclusive rights for exploitation of the desired mine site; and (3) approval of the financing scheme for the whole project. The resolution of the financial question in turn, would require considerable prior progress in nodule exploration and equipment development programmes.

[65] The recently reported occurrence of heavy metals of the platinum group in some manganese nodules could be very significant, since the value of the trace elements of the platinum group might substantially exceed the value of copper, nickel and cobalt contained in nodules (see E/CN.11/L.343, annex III, para. 37).

[66] The most fundamental fact about the economics of nodules is the joint-product and by-product nature of the industry. Nodule processing will result in the simultaneous production of a number of minerals. Depending on the particular metallurgical process used, some minerals will constitute the primary output of the process (joint-products), while other minerals may also be recovered if additional

ering the drawbacks of alternative methods, the market penetration approach would seem to provide a useful first approximation to the magnitude of the problems involved.[67]

(a) *Nickel*

The most important uses of nickel are in the manufacture of stainless steel, alloys, and for electroplating. Nickel imparts certain properties to alloys, such as increase in strength and resistance to corrosion, that cannot be economically obtained by other means. New steels and alloys are constantly being developed. Over 40 per cent of nickel consumption is in the manufacture of stainless steel, the market for which has very good prospects for future growth.[68] Nickel also has many other minor uses and its application is constantly increasing. Worldwide consumption increased at the average rate of 6.5 per cent compounded annually from 1947 to 1970. A number of factors combined to make for a drop in demand in 1971, but the market has recovered since then and future prospects are for a minimum rate of 6 per cent long-term growth.

Supply is highly concentrated in a few industrial countries. Canada's dominant position, however, has been declining from some 94 per cent of the total mined in market economy countries in 1950 to 73 per cent in 1960 and approximately 58 per cent in 1970. Just three countries, Canada, France (New Caledonia) and the Soviet Union, accounted for 74 per cent of world mine production in 1972. Production of developing countries has been increasing but still accounted for less than 13 per cent of the world total by 1972.

For the purpose of evaluating the probable impact of nodule mining, a number of assumptions were made: (1) demand will increase at a cumulative annual rate of 6 per cent until 1985; (2) the share of developing countries in world mine production will increase to 20 per cent (13 per cent in 1972);[69] (3) metal production from nodules plus smelter production from land ores will equal total consumption; (4) smelter production will represent, as in 1972, 94 per cent of the tonnage of land ores.

On the basis of these assumptions, it is estimated that production from nodules might account for about 18 per cent of total demand by 1985. This substantial market penetration may tend to depress nickel prices somewhat. Some high-cost laterite projects under consideration might be abandoned, but for the most part traditional producers are not likely to be seriously affected. In fact, production from land sources would need to increase by some 70 per cent from the level of 1972 mine production, in order to meet world demand. Most of this increase, however, would be required before 1980; from that time on almost all additional increases in demand would be satisfied by the nodule industry. In view of the mounting environmental difficulties with resulting rising costs in industrial countries and the various projects under consideration in developing countries, it is possible that the share of mine production from developing countries in 1985 will in fact be larger than 20 per cent.

Table 3

ESTIMATED MARKET SHARE OF NICKEL PRODUCTION FROM NODULES BY 1985
(*Thousand metric tons*)

	*1972**	*1985(estimates)* Tonnage	*1985(estimates)* Percentage
World mine production:			
Developing countries	79.5	210[c]	(17)[d]
Industrial countries	545.6	850[c]	(65)[d]
Total	625.1	1,060[a]	(82)[d]
Total smelter production (land ores)	587.5	1,000[a,b]	82
Production from nodules	—	220[b]	18
Total consumption (not including scrap metal)	573.6[e]	1,220[e]	100

Source:* *World Metal Statistics*, January 1974.

[a] Average recovery efficiency of metal from ore same as in 1972 (94 per cent).

[b] Smelter production from land ores plus production from nodules equal total consumption (long-run equilibrium of supply and demand).

[c] Developing countries producing approximately 20 per cent of world mine output.

[d] Reduced by 94 per cent.

[e] Excludes the substantial volume of direct use of nickel in scrap form.

(b) *Copper*

Electrical conductivity and resistance to corrosion make copper invaluable in the manufacture of electrical equipment, cables and wires for communication and electrical transmission lines, electrical appliances, tubing and sheeting for the construction and chemical industries, alloys and in a number of other uses. Despite competition in certain areas from aluminium, plastics, glass and other materials, demand for copper has been growing by an average of 5 per cent per annum for the past two decades. Demand has been particularly strong since 1972 and as supply failed to keep up with the pace of demand, prices rose reaching in late 1973 and early 1974 record levels of over $US 1.10 per pound.[70]

Long-term market prospects are quite attractive. Demand is expected to grow between 4 and 5 per cent annually until the end of this century. In response to favourable demand conditions producers are expanding mine and smelter capacities. Mine capacity outside the centrally planned economies is expected to increase by 45 per cent between 1972 and 1978.[71]

Copper production is much less concentrated than is the case with the other three major metals to be recovered from nodules. Some 56 countries mine more than 1,000 tons of copper (metal content) per year. The industrial countries are the largest producers and consumers, Canada, the USSR and the United States of America alone accounting for some 3.3 million tons of copper mined in 1972 or 46 per cent of the world's total. The developing countries, accounting for 42 per cent of total mine production (1972), are by far the leading exporters. In 1971, the latest year for which comparable statistics are available, net exports from developing countries in all forms (ores, concentrates, blister and refined copper) amounted to

stages of processing are included in the plant design (by-products). The minor metals in nodules, such as molybdenum, vanadium, zinc, silver and others, could either be produced as joint-products or as by-products. In most processes under consideration manganese could be recovered as a by-product. This distinction is important in that by-product recovery must consider only the additional (marginal) cost involved in the subsequent processing of the tailings disregarding all other previous costs such as mining, transportation, and initial stages of processing. By-product recovery will only be undertaken if the additional revenue derived from the sale of these products is greater than the additional costs involved in the subsequent processing needed, after the major minerals are recovered.

[67] Refinements to this approach might warrant additional studies.

[68] In particular in the auto industry, pollution control equipment, desalination plants, chemical industry, petroleum refining, liquefied gas industry and several ocean-related industries.

[69] A comprehensive survey of planned mine capacity is not available. Considering, however, the large projects under construction or in the planning stage in the Philippines, Indonesia, Guatemala, Dominican Republic, Colombia, Venezuela, Brazil, Botswana and Burundi, it is reasonable to expect that the share of mine production from developing countries by 1985 is likely to account for at least 20 per cent of the world total.

[70] *Metals Week*, 4 February 1974.

[71] International Wrought Copper Council, *Survey of Planned Increases in World Copper Mines, Smelter and Refinery Capacities, 1972–1978*, London, 1973, pp. 6 and 7.

almost 2 million tons or 73 per cent of the world's net copper exports.[72]

Production from nodules is expected to have a very minor impact on copper markets by 1985. If demand for refined copper expands at an average rate of 5 per cent per annum, by 1985 it would amount to about 14.9 million tons. By contrast, production from nodules is expected to reach some 200,000 tons or 1.3 per cent of total consumption. Perhaps the most relevant yardstick for the probable impact of nodule exploitation on copper markets would be the production from nodules as a share of net imports of industrial countries. For example, in 1971 net imports of 2.2 million tons represented approximately 33 per cent[73] of the total consumption of these countries.[74] Assuming that net imports of advanced market economy countries would still amount to one third of their total copper consumption in 1985, production from nodules would amount to only 5.5 per cent of the required net imports. In other words, production from nodules would be displacing about 200,000 tons of the approximate 3,630,000 tons of net imports that advanced market economy countries are likely to require by 1985.[75]

Table 4

COPPER STATISTICS: MINE PRODUCTION, REFINED CONSUMPTION AND NET EXPORTS OF DEVELOPING AND INDUSTRIAL COUNTRIES, 1968–1972

(Thousands of metric tons)

	1968	*1969*	*1970*	*1971*	*1972*
Mine production	5,473.6	5,949.3	6,372.6	6,460.9	7,022.0
Developing countries	2,399.1	2,534.2	2,582.3	2,652.4	2,939.4
Industrial countries	3,074.5	3,415.1	3,790.3	3,808.5	4,082.6
Refined consumption[a]	6,500.2	7,143.2	7,248.5	7,302.7	7,886.1
Developing countries	437.7	519.5	540.3	634.7	680.7
Industrial countries	6,062.5	6,623.7	6,708.3	6,668.0	7,205.4
Net exports[b]	2,623.2	2,719.4	2,823.1	2,722.0	inc.
Developing countries	2,027.3	2,199.1	2,175.0	1,999.3	inc.
Industrial countries	595.9	520.3	648.1	722.7	inc.

Source: World Metal Statistics, August 1973 and January 1974.

[a] Includes scrap and releases from United States Government stockpile.

[b] In all forms: ores, concentrates, blister and refined.

(c) *Manganese*

As stressed before, considerable uncertainties surround the estimates of manganese recovery from nodules. Any assessment of its possible impact on manganese markets must be viewed, therefore, as a precarious first approximation.

About 95 per cent of the world production of manganese ore is used in the steel industry, mainly in the form of ferromanganese. Very large reserves of manganese exist in many countries, both developing and industrial. The opening up of a number of large modern open pit mines and the utilization of economical bulk ore carriers contributed to a steady fall in prices for the last two decades (events over the last year, however, have led to a sharp increase in manganese prices). Demand for manganese is quite inelastic and thus additional supplies tend to depress prices.

The estimated manganese content in ores mined in 1971 reached 8.3 million tons, of which 46 per cent was produced in developing countries.[76] Detailed trade statistics available for 1969 indicate that of 3.7 million tons of manganese-in-ore exported in that year, 56 per cent originated from developing countries.[77] Comparable worldwide statistics on consumption are non-existent, but given the nature of manganese markets, it would be safe to assume that total demand is equivalent to world production.[78] Assuming that manganese demand will keep expanding at an average annual rate of 5 per cent, by 1985 world demand should be approximately 16.4 million tons of manganese-in-ore.

The tentative estimate of manganese recovery from nodules by 1985 of 920,000 tons would amount to only 5.6 per cent of estimated world demand for that year. Considering, however, that the centrally planned countries as a bloc are net exporters of manganese, production from nodules would be directed at the needs of advanced market economy countries. Production from nodules might supply almost 13 per cent of the import requirements of these countries by 1985.[79] Given the rather inelastic demand for manganese,[80] and the ability of traditional suppliers to keep on expanding production for many years with only modest investments, the additional supply from the sea-bed will probably depress market prices. Moreover, if manganese is recovered from 10 million tons of nodules[81] instead of

[72] Increased scrap recovery, releases from the United States Government stockpile and a faster expansion of mine production in industrial countries resulted in a decrease in the share of developing countries' net exports out of the world total refined consumption, from 31.2 per cent in 1968 to 27.4 per cent in 1971.

[73] This share is likely to increase during the period under consideration. It is known, for instance, that of the increase in mine capacity planned for 1972–1978, 52 per cent of the expansion was to take place in developing countries. International Wrought Copper Council, op. cit., pp. 6–7.

[74] Copper trade statistics for the centrally planned economy block are not sufficiently complete for international comparison. From the figures available, net trade is small, amounting to around 20 to 50 thousand tons of imports or exports, depending on the year.

[75] By way of comparison, in 1971 net imports reached 723,000 tons in Japan, 472,000 tons in the Federal Republic of Germany, 371,000 tons in the United Kingdom, 308,000 tons in France, 260,000 tons in Italy, 130,000 tons in Belgium and 115,000 tons in the United States. By 1985 these volumes of net imports would probably double.

[76] United Nations, *Statistical Yearbook,* 1973 (Preliminary).

[77] See "Problems of the World Market for Manganese Ore" (TD/B/C.1/105).

[78] In fact, production has been somewhat lower in the past few years due to substantial releases from the United States Government stockpile.

[79] If by that time the market share of advanced market economy countries remains the same as in 1969 (57 per cent), this group of countries would consume about 9.3 million tons of manganese. Furthermore, if it is assumed that, as in 1969, about 78 percent of requirements by advanced market economy countries would be imported, this would amount to some 7.3 million tons of manganese-in-ore.

[80] See "Manganese Ore: Brief review of main problems and possible forms of action" (TD/B/C.1/131/Add.4), p. 3, and "The effects of production of manganese from the sea-bed, with particular reference to effects on developing country producers of manganese ore" (TD/B/483).

[81] One operation of 1 million tons/year and 3 operations of 3 million tons/year.

the 4 million assumed here, production from nodules could account for about one third of the import needs of advanced market economy countries. In that case the market imbalance would be much greater and prices would fall considerably.

Developing countries exporting manganese will probably be significantly affected by nodule mining. The extent of this impact is difficult to assess, in view of the existing market structure. Most trade in market economy countries involves transactions from subsidiaries in producing countries to the parent companies—generally large steel producers—in industrial countries. This large "captive market" is not likely to be much affected in terms of volume, though the recorded value of transactions will probably decrease. Some older producers with higher costs due to lower ore grades, long distances from mine to port and inadequate port facilities will be the ones most affected.

Three developing countries, Brazil, Gabon and India, each export about $US 30 million annually of manganese ore and ferromanganese. Ghana, Morocco and Zaire export less than $US 10 million each. A few other countries export less than $US 2 million each. Exports of manganese constitute an important foreign exchange earner only in the case of Gabon, where it accounts for some 20 per cent of the total value of exports. For the other major developing country producers, manganese exports represent 2 per cent or less of total exports.

(d) *Cobalt*

Cobalt is an expensive metal with a relatively small market. It is used in a variety of industrial products, both metallic and non-metallic. The principal characteristic of the metal is probably its resistance to high temperatures, but it also possesses important magnetic and chemical properties, which make it particularly suited to a number of rapidly expanding advanced-technology industries.[82] At considerably lower prices, cobalt could be substituted for various other non-ferrous metals.[83] One potential market of particular interest is in electroplating where cobalt was substituted for nickel during the 1969 nickel strike.

Cobalt is produced primarily as a by-product of copper and nickel mining. Zaire is by far the largest producer accounting for two thirds of total mine output. By selective mining of high cobalt content copper ores, Zaire has traditionally adjusted supply to demand conditions. By-product production from other countries has been increasing rapidly, and new mining projects in Australia, Canada, New Caledonia, the Philippines and Zambia are expected to increase supplies by the mid-1970s.

Statistics of cobalt production and consumption are generally incomplete and often conflicting. This is not surprising due to the by-product nature of cobalt production and its relatively small value in world commodity trade. Recorded mine production averaged 23,000 tons between 1970 and 1972 of which some 76 per cent was produced by developing countries (see table 5). Estimates of consumption must take into account the actual metal produced from ores, scrap use and releases from the United States Government stockpile. It is estimated[84] that during 1969–1971 consumption outside the centrally planned countries averaged 23,800 tons, having grown at an average annual rate of 6.2 per cent over the previous decade.

Table 5

COBALT: WORLD MINE PRODUCTION[a]
(Co content in metric tons)

Country	*1970*	*1971*	*1972*[b]
Advanced countries	5,350	5,130	5,520
Australia	470	310	740[c]
Canada	2,070	1,960	1,880
Finland	1,270	1,270	1,270
USSR[c]	1,540	1,590	1,630
Developing countries	18,500	16,600	17,740
Cuba	1,540	1,540	1,540
Morocco	600	980	1,150
Zaire	13,960	12,000	13,000[c]
Zambia	2,400	2,080	2,050
TOTAL	23,850	21,730	23,260

Source: J. D. Corrick, "Cobalt", *U.S. Bureau of Mines Minerals Yearbook, 1972* (Preprints), p. 5.

[a] In addition to the countries listed, Bulgaria, Cyprus, Democratic Republic of Germany, New Caledonia, Norway, Poland, Spain, Sweden and the United States are known to produce ores (copper, nickel, and/or pyrite) that contain recoverable quantities of cobalt, but available information is inadequate to make reliable estimates of output levels. Other nations may also produce cobalt as a by-product component of ores and concentrates of other metals.

[b] Preliminary.

[c] Estimate.

For the purpose of this exercise, a 6 per cent annual rate is assumed for the period 1972–1980, increasing to 8 per cent during 1981–1985.[85]

World demand by 1985 is projected as 60,000 tons against an estimated production from nodules of 30,000 tons. This would leave another 30,000 tons for traditional suppliers. It can be expected that cobalt prices will start falling when production from nodules reaches the market and by 1985 it is assumed that it should be about two thirds of present levels, or around $US 2.00 per pound.

If on the other hand demand fails to expand as fast as this report suggests, or if cobalt production from nodules turns out to be considerably larger than 30,000 tons, the pressure on cobalt prices will be more serious. Prices might fall then to the level of nickel since cobalt could then be used as a substitute for some uses of nickel. In fact, this situation is likely to develop in the second half of the 1980s.

(e) *Summary*

The nodule industry is expected to become an important source of minerals by 1985 (see table 6). The impact of sea-bed production on world markets will vary considerably for the four major metals. By that time, nodules will be the most important source of cobalt, supplying at least half of the world market with prices dropping to about two thirds of present levels. Many uncertainties surround the situation of manganese: recovery from nodules might account for 13 per cent of import requirements of advanced market economy countries, resulting in a drop of at least 50 per cent in the price of manganese metal, and some decline in prices of manganese ore and ferromanganese. Nickel markets will be affected by the output from nodules since it will probably account for over one

[82] The motor vehicle industry could become a major consumer of cobalt in heat-resisting alloys for the manufacture of gas turbines and as a catalyst in exhaust gases after-burners. See J. D. Corrick, "Cobalt", *U.S. Bureau of Mines Minerals Yearbook, 1972* (Preprints).

[83] In this report it was pointed out that the long-term elasticity could not be forecast without further investigation. See "Exploitation of the mineral resources of the sea-bed beyond national jurisdiction: issues of international commodity policy. Case study of Cobalt" (TD/B/449/Add.1), pp. 2–5.

[84] TD/B/449/Add.1, p. 4.

[85] For the period 1972–1980 this is a simple extrapolation of past trends based on a continuation of existing conditions (high prices, i.e., $US 3.10 per lb.; relative scarcity; similar end uses). It is obvious, however, that when a substantial output from nodules reaches the market, lower prices will result. The nodule industry will certainly strive to expand the markets for cobalt by assuring continued supply at lower prices. Thus, an 8 per cent annual growth rate for cobalt demand is assumed for the period 1981–1985, which is the period when it is expected that substantial supplies from nodules would be available.

quarter of the import requirement of industrial countries (table 6); considering the elastic nature of demand for nickel, only a gentle decline is expected in its price. The output of copper will only have a minor impact on copper markets; it might amount to 5.5 per cent of the net import requirements of the advanced market economies.

Table 6

MANGANESE, NICKEL, COPPER AND COBALT: PROBABLE PRODUCTION FROM NODULES, ESTIMATED WORLD DEMAND AND ESTIMATED NET IMPORT REQUIREMENT OF INDUSTRIAL COUNTRIES IN 1985
(*Thousand metric tons*)

	Probable production from nodules	*Estimated world demand*	*Production from nodules as a percentage of world demand*	*Estimated net import requirement of industrial countries*[a]	*Production from nodules as a percentage of net import requirement of industrial countries*
Manganese	920	16,400	6	7,300	13
Nickel	220	1,220	18	770	26
Copper	200	14,900	1.3	3,600[b]	5.5
Cobalt	30	60[b]	50	n.a.	n.a.

Source: World Metal Statistics, United Nations Statistical Yearbook; UNCTAD: Problems of the world market for manganese ore (TD/B/C.1/105).

[a] Assuming that net import requirements would be proportionately the same as in 1972.

[b] Excluding the centrally planned economies.

4. *The long-term prospect of nodule mining*

Sustained long-run development of the nodule industry will depend on its relative competitive position, vis-à-vis other sources of metal supply, namely land mining and recycling. The relative competitive position of these alternative sources of mineral supply will depend in turn on market conditions, technological developments and possible institutional constraints.

The institutional framework for the exploitation of resources of the international area might include regulations for a rational long-term planning of nodule development. This question is examined in the following chapter. It is clear, however, that the controls or regulations which may be adopted will be designed to orient nodule development along a course somewhat different from that which would emerge from the operation of unregulated market forces. What remains to be seen, however, is what would be the most likely scenario for the long-term development of nodule resources if it were governed exclusively by market forces. On the basis of available information, only some considerations of a general nature can be made about the long-term prospects of nodule mining.

The implications of joint-products and by-products recovery from nodules become apparent when investment in new projects is under consideration. In essence, nodule projects would be undertaken, under free market conditions,[86] as long as the prospective return on investment would be greater than the expected rate of return on alternative investments in traditional land mining. Available information seems to indicate that the first generation of nodule mining will be very profitable indeed (see section III.5). Once the first few ventures become operational and prove to be the financial success that is expected, investment interest will rise. But, as the first miners expand their operations and the second wave of investors make their splash, some market pressures will develop to change the profit picture of the industry.

After the first decade of operation, further expansions of the industry are likely to cause average revenues to decline by more than the possible reductions in operational costs which will probably result from greater productivity and the development of more advanced systems. How soon and by how much the price of each mineral is likely to fall will depend on the relative volume of supply from nodules as compared with their world demand and the comparative cost of land based production. Normally, as a mineral produced from nodule becomes more abundant, its price would tend to fall to the level of its most important substitute.

One of the first casualities is expected to be cobalt. By 1985 approximately half of world demand would probably be supplied by nodule producers. As new nodule projects become operational, the price of cobalt would eventually fall to the same level as that of nickel.

Drastic changes can also be expected in the market for manganese metal. Manganese metal production from just one nodule operation of 1 million tons per annum may be almost twice as large as the projected world market in 1980 for manganese in metal form. As a result the price of this metal will fall sharply and eventually it should stabilize at about the present price of ferromanganese, which it would probably replace in the steel industry. This would, of course, mean a fundamental change in the manganese industry, with serious implications for traditional producers of ore and ferromanganese.

The eventual replacement of ferromanganese by manganese metal in the steel industry will be simply a question of competitive cost. The by-product nature of manganese recovery from most systems offers an added incentive for sea-bed miners to develop new metallurgical processes that would reduce the alleged high-cost manganese separation stage. The magnitude of the incentive would be very high indeed; for example, even at $US 200 per ton[87] instead of the present $US 730 per ton for manganese metal the recovery of manganese metal would increase the gross revenues of nodule ventures by some 50 per cent. It can be expected, therefore, that before the end of the 1980s, the techno-economic problems will probably be overcome and nodules will become the major source of manganese for the world steel industry.

The sharp decline in prices expected for cobalt and manganese, and possibly molybdenum among the trace metals, is not expected to alter substantially the total profitability of the nodule industry. Nickel will remain the most important source of revenue, accounting for about 40 to 55 per cent of gross revenue, depending on whether manganese is recovered or not (*ibid.*). The real pressure on the economics of nodule mining

[86] It seems reasonable to expect that some of the major mineral importing countries might be willing to subsidize nodule miners, if necessary, to attain a minimum of self-sufficiency. In that case the nodule industry might expand beyond the levels that would be warranted by market considerations alone.

[87] $US 200 per ton is the market price for standard United States ferromanganese containing 78 per cent manganese.

will be felt when production expands sufficiently to cause a decline in the price of nickel. Even at considerably lower prices for nickel, the advent of second and third generation nodule systems, with their reduced mining, transportation and processing costs, might well retain the economic attractiveness of the industry.

The question, therefore, is what would be the most likely price floor for nickel? The demand for nickel is probably very responsive (elastic) to lower prices sustained over sufficiently long periods of time. Moreover, nickel is a substitute for a number of metals. Though it would be difficult to determine the extent to which nickel can be substituted for some applications of copper, the ultimate floor for nickel might correspond to the price of copper. Since world demand for copper is about 14 times greater than that for nickel (7,886,000 tons versus 574,000 tons in 1972), there would be some scope for absorbing large volumes of additional nickel supply in some special uses of copper. The possibility of interchangeability of nickel and copper in some markets is merely hypothetical and probably would not take place before the 1990s, if at all. If it should occur, however, it would radically change the relative importance of the nodule industry. In that case nodule mining could increase spectacularly and the industry would become a major supplier of copper as well as the largest source of cobalt, manganese, nickel, molybdenum, vanadium and possibly of other metals. This scenario, of course, is only valid if no control over the pace of nodule development is exercised by the Authority.

III. Promoting the rational development of nodule resources

A recurrent theme in official and academic statements on nodules is that they should be developed in a rational manner. This convergence of opinions is underscored in paragraph 9 of the Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof beyond the Limits of National Jurisdiction,[88] which states that "the régime shall, *inter alia,* provide for the orderly and safe development and rational management of the area and its resources and for expanding opportunities in the use thereof". In order to promote the rational development of nodule resources, it will be necessary to identify the major policy objectives, and to examine them to ascertain the extent to which they may be mutually conflicting or complementary.

1. *Identification of major policy objectives*

Several objectives have been proposed and analysed extensively in academic papers and in the discussions of the Sea-Bed Committee. They have been expressed, with varying degrees of clarity, in the Declaration of Principles and may be summarized as follows:

(a) *Encouraging the development of nodule resources*

For some time, it has been questioned whether known mineral resources are sufficient for sustained growth in material consumption. More recently, the sharp increase in raw material prices caused major consuming countries to actively seek out alternative sources of supplies. The potential of the nodule industry has prompted industrial countries depending on imported minerals to assign a high priority to its development. These countries, over a period of years, have directed a huge research and development effort to solve problems posed by nodule mining and processing, so that now technology is no longer a limiting factor on the development of this industry.

(b) *Minimizing the impact of nodule mining on mineral exports of developing countries*

Developing countries have understandably voiced serious concern at the prospect of a new industry which may have a serious impact on their markets. The need for a controlled pace of nodule development is obvious for countries like Chile, Gabon, Ghana, Peru, Philippines, Uganda, Zaire and Zambia which are heavily dependent on the exports of minerals that will also be recovered from nodules. To a large number of other developing countries exports of minerals represent an important contribution to their balance of trade position. For them, a loss of a few million dollars worth of export earnings could also be quite serious, given their perennial balance of payments difficulties. But the argument of balance of payments is not restricted to developing countries. Advanced industrial countries which are large exporters of minerals and metals such as Australia, Canada, France and South Africa have also expressed such concern. Alleviation of balance of payments pressures is also an argument used by groups in importing nations requesting unilateral legislation to govern nodule development.[89] The large measure of support expressed for minimizing adverse effects on developing country mineral exporters is thus explained.

(c) *Ensuring the participation of developing countries in the nodule industry*

Developing countries contend that the highly sophisticated nature of technology for nodule mining and processing and the heavy capital requirements involved ($US 150 to $US 250 million or more for each nodule venture) will limit the industry to the half-dozen most industrialized countries unless there are measures to the contrary. The smaller industrial nations also recognize their inability to compete with the industrial leaders in this endeavour.[90] In addition to the potential of the industry itself, considerable spinoff benefits are expected for the shipbuilding, heavy equipment and metal based industries. The pivotal importance of the nodule industry was stressed by the President of the Shipbuilders Council of America:

> "In its maturity, deep ocean mining will undoubtedly contribute to an advancement of technology not only in shipbuilding industry but in the offshore petroleum industry while similarly endowing marine science and other human activities about which we have yet no conception."[91]

(d) *Maximizing revenues for the International Authority*

From the inception of negotiations on an international régime for deep sea-bed mineral resources, it has been assumed that nodule mining would provide a new substantial source of revenue for the international community. It is argued that since the most important economic benefits from nodule mining will accrue to the industrial nations developing nodule technology —which are also the major importers of minerals—the maximum possible revenues for the international authority should be exacted from nodule miners. Such revenues would thereafter be shared according to criteria favouring developing countries.

[88] General Assembly resolution 2749 (XXV).

[89] "If S.1134 becomes law, U.S. industry will start immediate efforts to convert manganese nodules, which are now only a mineral curiosity, into material which will flow through the channels of world commerce and aid the United States in reducing its deficit balance of payments". Statement made by Mr. T. S. Ary on 17 May 1973 on behalf of the American Mining Congress, See *Mineral Resources of the Deep Seabed, op. cit.* in foot-note 13, p. 136.

[90] Indicative of this concern is alternative C of paragraph 25 of article 34 of the draft convention appearing in the report of Sub-Committee I of the sea-bed Committee, on participation of developing countries: "For the purpose of this article, States not having attained a level of marine science and technology permitting the exploration of the Area and exploitation of its resources, or not having the financial resources required to carry out such exploration and exploitation, shall be treated on an equal footing with developing countries" (*Official Records of the General Assembly, Twenty-eighth Session, Supplement No. 21* and corrigenda 1 and 3, vol. II, p. 96).

[91] *Mineral Resources of the Deep Seabed,* op. cit. in foot-note 13, pp. 87-88.

List of Documents

(e) *Preservation of the marine environment*

In a world increasingly aware of ecological interdependence, it was logical for the Declaration of Principles to include the guideline that activities in the area should be conducted in such ways as to assure "the prevention of pollution and contamination, and other hazards to the marine environment, including the coastline, and of interference with the ecological balance of the marine environment".

(f) *Conservation of nodule resources*

In recent years the rapid depletion of traditional sources of raw materials in many countries has brought into focus the need for careful husbanding of the finite resources of our planet. The Declaration of Principles, clearly identifies "the protection and conservation of the natural resources of the area" as a policy objective.

2. *Harmonizing conflicts of interests*

Some of the above policy objectives can obviously conflict. A systems approach to sea-bed resource management could provide an optimum cost-benefit solution to the harmonization of conflicts if an acceptable list of priorities for the various objectives could be determined. The establishment of priorities is indeed the heart of the matter; and the Sea-Bed Committee has examined these points thoroughly over the past five years. Some basic underlying factors seem to be emerging.

First, the policy objectives of each country or regional group largely reflect their interests as seen in the light of general market trends and the special position of their domestic industries vis-à-vis the future sea-bed mining industry. Future events may allay the fears of some countries, aggravate those of others, or change drastically their earlier perspective.

There is a great degree of confidence in the future viability and scope of nodule mining. Industry officials are already contemplating second and third generation systems including such novel concepts as on-board metallurgical processing of nodules. The prospects of a fast changing technology make it all the more difficult for the international community to conceive and determine at this stage all the appropriate methods of managing sea-bed resources. If the likely impact of the first few mining operations can only be visualized in its broad perspective, what can be said of the second and third generation mining systems? This rapid pace of technological development underlines the need for giving the international machinery enough flexibility to adapt itself to changing conditions and to adopt new resource management strategies which might be required to handle any new situation.

Given the highly dynamic nature of nodule technology and the uncertainties clouding future market conditions it would be of little use to conceive policy strategies to deal with possible situations beyond a time span of about one decade. In view of these considerations, it should be stressed that in this report, the policy implications examined reflect the framework of interests as perceived in 1974 and should therefore be periodically reviewed and the time span adopted for analysis of the implications of nodule mining covers the arbitrarily chosen decade 1976–1985.

Another point relating to the harmonization of conflicting interests concerns the nature of trade-offs. The central issue of nodule management is the degree of control, if any, over the pace of resource development. The variation in the approach to this question can be categorized somewhat simplistically as efficiency (free development of nodule resources according to market forces) versus equity (some control over sea-bed resource development). For advocates of free development, market forces would guide the nodule industry to expand as long as it would be profitable to do so,[92] thus securing the most efficient allocation of resources and benefiting consumers by satisfying their mineral requirements at the least possible cost.

This model of resource allocation favoured by western economists proceeds from a number of assumptions which are not all met in reality. It is obvious that perfect competition, free resource movement and general access to technology are not true of the nodule industry. Also it must be recalled that the competitive model of resource allocation presupposes that the existing income distribution is socially and politically acceptable. Therefore all market-oriented developments that might favour consumers in industrial countries at the expense of traditional suppliers in developing countries will need to be closely scrutinized on equity grounds.[93]

3. *Balancing nodule development against its impact on mineral exports of developing countries*

(a) *Basic approaches*

The proposals made on ways and means to facilitate nodule development while minimizing the negative effects on the mineral industries of developing countries may be classified under two general approaches: compensatory and preventive. These two approaches, though not mutually exclusive, are based on different premises. Under the compensatory approach, nodule resources would be developed with few or no controls but with some form of compensation provided to developing countries affected by sea-bed mining. In other words, action would not be taken until some disruption had occurred. The preventive approach would orient the development of nodule mining so as to keep the disruptions from occurring in the first place. There would appear to be no easy solution. The potential production of the major minerals in nodules (cobalt, manganese, nickel and copper) is in proportions quite different from world demand for these minerals. For example, the forecast of metal production from nodules in 1985 would be sufficient to supply 50 per cent of the estimated demand for cobalt; 18 per cent of world demand for nickel, 6 per cent of demand for manganese and only 1.3 per cent of demand for copper.

If the preventive approach were to prevail all across the board and no metal market were to be significantly affected by the future production from nodules, the pace of development of the nodule industry would be very slow indeed. In fact, one single nodule mining venture, of a size considered by industry as the minimum viable (1 million tons of dry nodules per year), might be already too large and could affect the market for cobalt. It seems, therefore, that the harmonization of the conflicting interests involved would require that the preventive and compensatory approaches be combined in a politically acceptable strategy for development of the nodule industry.

(b) *Long-term planning: the preventive approach*

One approach that has been supported by a number of countries is that sea-bed resources should be considered as complementary to traditional sources of supply. The translation of this general precept into practice offers a number of difficulties. For instance, it might be thought that sea-bed resources would have a complementary role if they were developed specifically to supply that part of demand that could not otherwise be supplied by traditional sources. The problem with this interpretation is that demand, supply and prices are all interrelated. If

[92] The theoretical equilibrium under free market conditions would be reached at that point where additional units of investment into nodule mining would be only as profitable as investment in land mining projects or, for that matter, as profitable as alternative investments in other industries not related to mineral production.

[93] It is generally agreed that an additional unit of income is far more important in relative terms for countries at low levels of *per capita* income than for advanced countries.

demand tended to outstrip supply, this imbalance would result in increases in prices to the extent necessary to bring demand and supply to a new equilibrium.

An alternative approach would be to define arbitrarily the concept of complementarity in a dynamic sense, namely, in terms of future increases in demand. However, if all future demand for the minerals that can be produced from nodules were to be supplied by this new source, this would amount to a policy decision to halt further growth for traditional producers. Existing producers might find it difficult to expand capacity and there would be a virtual impediment to the development of a number of land deposits which have recently been discovered or which may be discovered in the future. The exact extent to which the partition of future production from land and sea-bed sources is politically acceptable is still to be determined. Moreover the views on the specific shares to be allocated to each source will likely change with time. The most important factor in this consideration is still unknown, namely the relative efficiency (cost of production) of the nodule industry as compared with land mines.

Assuming that the complementarity approach for sea-bed production might be accepted in terms of a certain share of the increase in demand for the minerals concerned, a number of practical problems would remain to be solved. Since the likely metal production from nodules will be forthcoming in proportions quite different from the demand for these minerals, what would be the basic guideline for the optimum pace of nodule mining? On numerous occasions industry officials and Government representatives from countries developing nodule mining systems have indicated that the mainstay of the nodule industry will be nickel.[94] This position is explained in the following statement by Leigh S. Ratiner, the Director for Ocean Resources of the United States Department of the Interior:

"Our present understanding of marine miners' plans indicates that they will produce either three or four metals concurrently. Future metallurgical developments may enable the extraction on an economic scale of only the more valuable copper and nickel content of nodules. For the present, however, use of these techniques would require marketing of either three or four of the metal components. If one of these metals faces a difficult market situation and is an important source of revenue, the entire production process must be geared to market opportunities for that metal. Since nickel represents such a significant share of the gross value of marine mining production, and since its market opportunities may be restricted during the early phases of deep sea mining development by both the size and nature of nickel markets, it may be concluded that nickel will be the limiting factor on the growth of a marine mining industry for the foreseeable future."[95]

Following this argument to its logical conclusion, Mr. Ratiner, on another occasion, suggested that on the basis of projected growth in demand for nickel between now and the year 2000 some 20 to 90 production units, each producing approximately 3 million tons of nodules per year, could be in operation by the year 2000.[96]

It would seem therefore that the long-term planning of nodule development as a function of the increase in demand for nickel would be politically acceptable to countries developing nodule mining technology. The pace of growth of the nodule industry would, of course, vary depending on the share of the future increase in demand for nickel that the nodule industry would be permitted to supply. Moreover, the exact rate of growth in demand for each mineral produced from nodules will have important implications for future market penetration.

Some actual figures might be helpful in assessing the magnitudes involved in long-term planning of nodule development as a function of the increase in demand for nickel. Assuming that future world demand will increase at an average annual rate of 6 per cent (for the period 1962–1971 in the market economy countries it was 6.5 per cent), by 1976 the world demand for nickel would amount to 724,000 metric tons.[97] In that case, the expected 41,000 tons increase in demand for nickel for 1976 could be supplied by approximately 2.7 million tons of nodules yielding an average of 15,000 tons of nickel per million tons of dry nodules. This volume over time can be quite impressive. For instance, during the decade of 1976 to 1985 the increase in demand for nickel at a 6 per cent growth rate would amount to 540,000 tons. Approximately 36 million tons of high grade nodules[98] could be authorized in 1985 to supply this increase in demand. Such a volume of nodules could be sufficient to commission six mining operations of the size proposed by Deepsea Ventures (1 million tons per annum and an additional 10 operations of the size which is reported to be planned by Kennecott Copper (3 million tons per year). By contrast, industry officials estimate that by 1985 the capacity of the nodule industry should be around 15 or 16 million tons of nodules,[99] which coincides with the forecast in this report (15 million tons).

The acceptance of nickel as the pace setter for nodule mining has the very important advantage of guaranteeing the interests of copper producers in developing countries. While the demand for copper was about 14 times larger than the demand for nickel in 1972, the volume of production of nickel from nodules is likely to be some 15 per cent higher than that of

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[94] As a matter of fact, Summa Corporation refers to nodules as "nickel nodules" instead of using the term manganese or ferromanganese nodules generally employed by the academic community.

[95] Appendix by Leigh S. Ratiner, to a letter of Charles N. Brower to Senator J. William Fulbright dated 1 March 1973, copies of which were made available to members of the sea-bed Committee.

[96] See statement of Mr. L. Ratiner at the hearing of the Sub-Committee on Minerals, Materials and Fuels of the United States Senate on 15 June 1973 (See *Mineral Resources of the Deep Seabed*, op. cit. in foot-note 13). These figures were apparently derived on the assumption that a production unit of 3,000,000 tons of dry nodules per year would recover on the average 34,000 tons of nickel per year and that demand projections would be as follows:

Estimated world demand for nickel (in metric tons)

Year	*Assuming a 2.4 per cent growth rate*	*Assuming a 6 per cent growth rate*
(*a*) 1975	779,000	926,000
(*b*) 2000	1,409,000	3,974,000
(*c*) Growth in demand:	630,000	3,048,000
(*d*) Approximate number of mining units: (*c*) ÷ 34,000	19	90

[97] Demand for newly mined nickel. If direct use of scrap were taken into account, this figure would be considerably larger as in the U.S. projections presented by Mr. Ratiner.

[98] Nodules with 1.6 per cent nickel content, assuming a 94 per cent metallurgical efficiency in recovery of the metal giving an output of 15,000 tons of nickel per million tons of dry nodules.

[99] A. J. Rothstein and R. Kaufman (Deepsea Ventures, Inc.) estimate that by 1985 perhaps six nodule mining units might be in operation. Two of these with a capacity of 1 million tons would recover manganese, while the four others—average rated capacity of 3.5 million tons—would not. If all these units were to reach full capacity by 1985 about 16 million tons of nodule would be mined. See "The Approaching Maturity of Deep Ocean Mining—The Pace Quickens", *Offshore Technology Conference, 1973* (Preprints), vol. I, pp. 323-344. Mr. T. S. Ary, Chairman of the Committee on Undersea Mineral Resources, of the American Mining Congress, in answer to written questions proposed by Senator Lee Metcalf in relation to hearings on S.1134, suggested that market considerations would probably limit nodule mining to five operations of 3 million tons per year by 1986. See *Mineral Resources of the Deep Seabed*, op. cit. in foot-note 13, p. 183.

copper. Thus, the impact of nodule development on copper markets would be minor for the foreseeable future.[100] For instance, considering the unlikely possibility that by 1985 some 36 million tons of nodules would be mined, production of copper from nodules (468,000 tons) would amount to only 3 per cent of world demand.

The role of manganese is perhaps the most controversial of all metals contained in nodules. Great uncertainty surrounds the likelihood of manganese recovery from nodules, as this mineral has a very low price as compared to copper, nickel and cobalt. Only one company in the United States, Deepsea Ventures, has announced plans for recovering manganese in the form of pure metal. This company has indicated that it might recover 230,000 tons of manganese metal, from its proposed 1 million tons per annum nodule operation, which would be far more than the existing world demand for manganese in metal form. There are some indications that DOMA in Japan plans to produce manganese from nodules, probably in the form of an ore-equivalent.

It can be expected, however, that in time strong pressures[101] will be generated within the nodule industry to recover the manganese as well. Technical innovation in metallurgical processing will eventually reduce the cost of manganese recovery in the form of either pure metal, ferromanganese or a manganese ore-equivalent.

Though the commercial feasibility of large-scale recovery of manganese from nodules is still to be demonstrated, several developing countries that export this mineral have expressed grave concern for the future of their domestic mines. Since manganese may be recovered from only 4 million tons out of the 15 million tons of nodules which are expected to be mined by 1985 (i.e. 27 per cent), it would seem that a planning guideline for manganese recovery, amounting to 50 per cent of the total volume of nodules mined, might be acceptable to those countries developing nodule systems.

Considering the imponderables of long-term forecasting, it would seem preferable that any planning for nodule mining should be established in a flexible way to respond to market developments. This flexibility would be made more palatable to consumers and exporters alike if the Authority's decision were to be made according to predetermined limits. For example, the maximum level could be set at 100 per cent of the increase in demand for nickel and the minimum level at 50 per cent. On this basis, the nodule industry would know that regardless of prevailing market conditions, they could be assured of at least an annual increase in production equivalent to half of the expected increase in demand for the guideline mineral. The developing countries exporting nickel, manganese and copper, on the other hand, would be assured that the maximum increase of production forthcoming from nodules would not reduce their present volume of production since the additional production from nodules would be geared, at least theoretically, to the increase in demand.

Table 7

SUMMARY PRESENTATION OF POSSIBLE SCENARIOS OF CONTROLLED NODULE DEVELOPMENT[a]

(*a*) Basic guideline: rate of nodule mining as a function of increase in demand for nickel:
Minimum authorization rate—50 per cent of this increase;
Maximum authorization rate—100 per cent of this increase.

(*b*) Additional limitation—recovery of manganese from nodules: 50 per cent of the nodule mining authorized.

(*c*) Total volume of nodule mining which could be authorized by 1980 and 1985 if nickel demand increases by 6 per cent per annum:

	1980	*1985*
Minimum	7,700,000 tons	18,000,000 tons
Maximum	15,400,000 tons	36,000,000 tons

(*d*) Total volume of nodules from which manganese recovery could be authorized by 1980 and 1985 on the assumption of (*c*) above:

	1980	*1985*
Minimum	3,850,000 tons	9,000,000 tons
Maximum	7,700,000 tons	18,000,000 tons

[a] The figures used in the projected demand for nickel exclude the direct use of nickel in scrap form.

Time lags in project implementation could serve as an additional factor in softening the impact of sea-bed production on mineral markets.[102] If the International Sea-Bed Authority were, for instance, to start granting permits in 1976 for nodule mining (licences or joint ventures)[103] equivalent to the expected increase in world demand for nickel for that year, the volume of nodules involved would be approximately 2.7 million tons. It is obvious, however, that commercial production of metal from those 2.7 million tons of nodules would only reach the market a few years later. The enterprises involved would still have to finalize their investment projects, make the financial arrangements, build the mining system and the processing plant, and run the final tests before starting commercial production. This lead-time would be a minimum of two years in exceptional cases, but more likely of three to five years for most companies.[104]

[100] It is important, however, to keep in mind that the cumulative effect of different compound rates of growth for nickel and copper could change the proportional volumes of demand for these two metals over time. For example, the 14 times greater demand for copper in relation to nickel in 1972 could be considerably reduced by the year 2000 if demand for copper increased at lower rates and for nickel at faster ones.

RATIO OF COPPER/NICKEL DEMAND BY THE YEAR 2000 AT DIFFERENT ANNUAL RATES OF GROWTH FOR EACH METAL

Nickel \ *Copper*	*5%*	*4%*	*3%*
6%	11	8	6
8%	6	5	4
10%	4	3	2

[101] Manganese and iron would amount to over one third of the volume of tailings that must be discarded by processing plants. The reduction of waste disposal costs would be another economic incentive for the recovery of this mineral as environmental requirements affecting slag heaps become more strict. Moreover, policy considerations might play an important role in the possibility of inducing some Governments to grant special subsidies for manganese recovery from nodules.

[102] However, it might be decided that time lags in project implementation should be taken into account in the establishment of planning guidelines. The principle of complementarity would be interpreted as the granting of authorization for nodule mining in line with the expected increase in demand for the very year when commercial production would start. In the example of the text, it could mean that in 1976 authorization would be granted to supply the projected increase in demand in 1979, assuming an average three-year lead time. In that case, the figure for maximum authorization during the period 1976-1985 would be 43 million tons of nodules.

[103] If, on the other hand, the Authority were to undertake nodule exploitation directly, the question of control would obviously be greatly simplified.

[104] Furthermore, it is conceivable that once the rules of the game are clearly defined, the leaders of the industry might schedule the activities of their implementation programme in such a way as to shorten the time between authorization and commercial production.

What would be the likely impact of nodule development along the guidelines described above? A first approximation could be derived on the basis of the following assumptions: (1) the full volume of nodules (and manganese recovery) that would be authorized each year would be in fact contracted for with interested parties; (2) the average lead-time for marketing minerals would be three years from the date of the original contract (if the first contracts for joint ventures or licences are granted in 1976, then production would reach the market in 1979); (3) all ventures would start operation at their full rated capacity and would remain at that level thereafter; (4) average recovery from each million tons of dry nodules would be: 15,000 tons of nickel; 13,000 tons of copper; 2,000 tons of cobalt and 230,000 tons of manganese (if recovered).

As can be seen in table 8, the potential mineral production from nodules, within the constraints of the planning guidelines, could be quite substantial. It must be understood, however, that these are hypothetical figures. The maximum authorization would represent a potential of some 50 per cent more metal production from nodules than is likely to take place under free market conditions. Under the minimum authorization production of nickel, copper and cobalt would be approximately 25 per cent below the present plans of industry, though the estimated manganese recovery would be unrestricted (see table 2).

Table 8

HYPOTHETICAL MINERAL PRODUCTION FROM NODULES BASED ON FULL UTILIZATION OF THE PLANNING GUIDELINES[a]
(*in metric tons*)

	Nickel	*Manganese*	*Cobalt*	*Copper*
Potential production starting in 1980				
Minimum authorization	42,000	320,000	5,500	36,000
Maximum authorization	84,000	640,000	11,000	72,000
Potential production by 1985				
Minimum authorization	175,000	1,300,000	23,000	150,000
Maximum authorization	350,000	2,600,000	46,000	300,000
Estimated world demand:				
1980	914,000	12,900,000	44,000	11,650,000
1985	1,220,000	16,400,000	70,000	14,900,000
Share of world market in 1980				
Minimum authorization	4.6%	2.5%	12.5%	0.3%
Maximum authorization	9.2%	5.0%	25%	0.6%
Share of world market in 1985				
Minimum authorization	14.3%	7.9%	33%	1%
Maximum authorization	28.6%	15.8%	66%	2%

[a] See table 7. Average lead-time assumed as three years.

It could be concluded that the planning guidelines exemplified above are fairly in line with the plans of the nodule industry. These guidelines, however, would go a long way toward assuaging the fears repeatedly voiced by mineral exporting developing countries that the nodule industry will doom their domestic mining industry.

The effectiveness of any system to regulate the pace of nodule exploitation will depend, of course, on the extent of the international area. If extensive limits for national jurisdiction are adopted, it is likely that some nodule deposits of commercial interest might fall within national jurisdiction, thus outside the control of the International Authority. A number of high grade deposits have already been found in proximity to land areas.

The planning approach exemplified in this report is just one of several possible solutions. Whatever planning strategy is deemed appropriate to harmonize the conflicting interests in sea-bed resource development, it will be necessary to define the regulatory instruments with considerable precision.[105] It is clear that the international régime under negotiation cannot, even in its detailed rules, standards and procedures, predetermine every administrative procedure to be adopted by the international machinery. If that were so, there would hardly be a need for granting deliberative and executive powers to the authority. Planning, whether in centrally planned or market economies, is a continuous process that requires endless innovations and adjustments not only in methods used but also in goals.

(c) *An alternative approach—indirect controls*

A certain measure of control over the volume of mineral production from nodules could be obtained with the use of differential levies or royalties for each of the minerals to be recovered from nodules. The minerals which would be most affected by the nodule industry such as cobalt, manganese and molybdenum could be made subject to royalties higher than the average fiscal charge imposed on the recovery of nickel and copper from nodules. This method was already described in previous reports by the Secretary-General[106] and need not be repeated here. The implementation of such systems, however, would require considerable sophistication in the analysis of market trends and in forecasting the impact that different levels of royalties or levies might have on the operations of the nodule industry.

(d) *The compensatory approach*

As indicated above, it seems that the most feasible way to minimize the impact of nodule development on developing countries producing cobalt would be through compensatory payments. It is difficult to foresee the future behaviour of cobalt markets once large volumes of nodules are mined because at present the market is highly concentrated in the hands of one single producer in Zaire. In the past, Zaire, acting as a price leader, has tended to reduce output when cobalt prices were falling.[107] Whether or not Zaire continues its price leadership, the export revenue of cobalt producers is expected to decline

[105] For example, the optimum size of a nodule operation may be larger than the nodule volume authorized for a given year, i.e., a 3 million tons project versus the 2.7 million tons that could be authorized in 1976. The Authority would need to institute procedures for dealing with a number of matters in the administration of a regulated system for nodule exploitation.

[106] See A/AC.138/36 and 73.

[107] See "Exploitation of the mineral resources of the sea-bed beyond national jurisdiction: issue of international commodity policy. Case study of cobalt" (TD/B/449/Add.1).

sharply once the nodule industry matures. Compensation for these countries might therefore be in order.[108]

It has been argued that such compensation would leave very little revenue for distribution to the international community. One possible solution to this impasse would be to exact a contribution from those countries that would directly benefit from any drop in cobalt prices. This compensation might be in the form of an internal tax per ton of cobalt consumed in the industrial countries, whether derived from nodules or from traditional land sources, amounting, for instance, to half of the expected drop in price as compared to a base year.[109] In this way, consumers would still benefit from lower prices and the interests of developing countries would be protected. A similar compensatory approach might also be envisaged to complement other measures used to minimize the impact on manganese producers.

(e) *Short-term price fluctuation*

It has been suggested that the International Authority should be empowered to deal with short-term price fluctuations. One possibility would be for the Authority to limit or reduce the volume of production from existing nodule mining operations if the prices of some minerals were to fall.[110] It is apparent, however, that the compulsory reduction or suspension of mineral recovery from existing nodule operations would present a number of technical, economic and political difficulties. Moreover, it is doubtful whether an enterprise could subsist financially if it were required to suspend production even if only for a few months. An alternative approach that might be considered is the use of the International Monetary Fund and the World Bank compensatory financing schemes, which were conceived to assist countries that may be faced with shortfalls in export earnings due to unfavourable market developments.

The potential role of commodity agreements for protecting the interests of developing countries exporters should not be over-emphasized. Commodity agreements are generally directed at stabilizing market prices for a given commodity on the basis of the existing market shares of the members. In the case in point, the disequilibrating factor would be the new sea-bed producers who, without any share of the market at present, could not be expected to accept the maintenance of the market *status quo*. None the less, commodity agreements may have a future role to play that would be complementary to other measures designed to minimize the impact on developing countries.

4. *Participation of developing countries*

Some general considerations are made on indirect and direct means to promote the participation of developing countries in sea-bed mining.

(a) *Indirect methods: transfer of knowledge of resources and techniques*

It is obvious that little participation is possible in a vacuum of knowledge regarding sea-bed resources and the industrial techniques required for their exploration and exploitation. Given the nature of the industry, only a few entities in a handful of countries possess the necessary data and techniques and they are of course keeping them secret from all potential competitors. Thus, the first step in promoting some measure of participation by developing countries would be to institute a system for collecting and disseminating information on nodule resources and mining and processing techniques. As is generally known, industrial and developing countries alike require that all data on resource surveys or prospecting be divulged to the relevant authorities. It might be considered appropriate, therefore, that all information collected by enterprises engaged in the prospecting of international sea-bed resources be shared with the Authority.

It has been suggested that the Authority should organize training programmes for nationals of developing countries on the various subjects related to the exploration and utilization of sea-bed resources. The usefulness of such programmes, however, should not be overestimated. Historically, programmes of transfer of technology, more often than not, have fallen short of their objectives. In an industry just developing a new and sophisticated technology, it can be expected that almost all the experienced specialists will be employed by nodule miners, thus making it unlikely that they would be available to conduct training courses and in the process divulge proprietary information. Moreover, the rapid advance that can be expected in nodule technology would tend to outdate knowledge gained in training programmes before it could be put into practice.

(b) *Direct methods—joint ventures*

The priority that developing countries have given to their participation in sea-bed mining can be best understood in terms of the experience that some have had with their own natural resources and their ability to exercise control over their exploitation. In a number of instances, these countries were unable to effectively control investment plans, marketing practices and other managerial decisions of great importance to the local economies. This pattern has been clearly evident in the oil industry where conflicts of interests have become more apparent between the worldwide interests of the major petroleum companies and the national interests of the host State where the venture is located.[111]

Joint ventures are becoming a common feature of the international mining and petroleum industries. It has been suggested that the future of the international petroleum industry will be one in which joint ventures with State companies, or service contracts and production-sharing arrangements, will be the order of the day.[112] Participation of developing countries in the exploitation of sea-bed resources could be fostered in two types of joint ventures. One would be the association of companies from developing countries with enterprises of industrial nations possessing sea-bed technology. It is obvious that in this case participation would be accomplished in a direct manner with business groups from developing countries participating with risk capital and reaping any benefits obtained.

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[108] Some analyses have suggested that there might be insufficient revenues for the Authority to compensate developing producing countries for actual or potential earnings foregone. See TD/B/449/Add.1 and TD/B/483.

[109] See A/AC.138/36, p. 67.

[110] See article 36, paragraph 40, alternative E of the draft convention appearing in the report of Sub-Committee I of the sea-bed Committee, the text of which is as follows: "to regulate the production, marketing and distribution of raw materials from the area and, where appropriate, to take, in consultation or in collaboration with the United Nations and its appropriate specialized agencies, measures to facilitate the stabilization of world prices of the raw materials obtained from the area, through *inter alia* reduction and suspension of production and international commodity agreements, whenever it deems that the production of such raw materials from the area may have adverse effects on the economies of exporters of similar raw materials from developing countries." Alternative D of the same text contains similar provisions. *Official Records of the General Assembly, Twenty-eighth Session, Supplement No. 21* and corrigenda 1 and 3, vol. II, p. 126.

[111] C. W. Friedmann, "Joint Exploration of Ocean Bed Resources: some Organizational Aspects", *Ocean Enterprises*, special report on a preliminary conference held in preparation for the *Pacem in Maribus* Convocation, 28 June-3 July 1970.

[112] L. C. Stevens, "Joint Ventures in the International Oil Industry", *Petroleum Review*, October 1973.

A more indirect way of participation[113] would be through the enterprise proposed by the 13-Power draft.[114] It is likely that the over-all objective of control over nodule exploitation might be accomplished by the regulatory powers of the International Sea-Bed Authority. Nevertheless, there will still be considerable scope for participation in the decision-making process within the individual nodule mining units to warrant the establishment of joint ventures between interested parties of advanced countries and the enterprise. A host of questions relating to financial arrangements, location of processing facilities, hiring of personnel, management and marketing practices can so drastically affect the profitability of individual mining ventures as to make an active and direct role desirable for the International Sea-Bed Authority in each individual venture. The participation of the enterprise in joint ventures, moreover, would provide the necessary feedback for the Authority to adjust the rules, standards and regulations of sea-bed mining to the real needs of both the industry and the international community at large.

5. *Revenue for the international machinery*

It has been suggested[115] that the revenue of the International Authority should neither amount to a hidden subsidy nor to a disincentive as compared to land mining operations. Any differential subsidy or disincentive would encourage inefficient allocation of world resources. It must be said, however, that this principle of "equivalent fiscal charge" is easier to conceive than to put into practice.

The tax burden on land mining operations varies dramatically from country to country and even from one mining operation to another, thus leaving open the question of what would be an equivalent fiscal charge. The adoption of the average tax charge in existence in the major mineral producing countries would not necessarily be more desirable than either the lowest or the highest existing fiscal charges. In fact, the fiscal charge of land-based mining ranges from a negative tax (subsidy) to very steep charges equivalent to over half of the market value of the metals produced.[116]

The equivalent fiscal charge principle alone cannot supply an operational method to determine the appropriate share of the International Authority in the revenues of the sea-bed mining industry. A suggestion often made is to establish the highest possible fiscal charge on nodule mining compatible with maintaining the necessary incentives to ensure a steady flow of investments in nodule mining. Though conflicting in the short run, these two objectives are in fact compatible in the long run. If enough incentives are given, the nodule industry will develop faster, thus increasing the revenue base of the Authority. The crux of the matter is then the quantification of a prospective level of return on investment that would encourage the large flow of funds necessary for the commissioning of nodule mining systems. A first approximation would be to survey the actual return on comparative investments in manufacturing and mining industries in the countries developing nodule mining technology.

For example, the average return on investment[117] for the whole manufacturing sector in the United States was 10.8 per cent in 1971 and 12.1 per cent in 1972. What is more relevant for the future nodule industry is that in the United States, the average return in metal mining (23 companies) was 10.5 per cent in 1971 and 10.4 per cent in 1972, while the average return in the non-ferrous metals industry (52 companies) was much lower: 5.0 per cent in 1971 and 7.2 per cent in 1972.[118] Considering the risks involved in a totally new technology for mining and processing and the novel institutional arrangement to be established for resource exploitation in the international area, it seems reasonable to expect that risk capital from advanced industrial countries would require a minimum prospective return on investment somewhat higher than these average rates of return. Since the rate of 15 per cent has been mentioned by industry officials, in informal discussions,[119] as their minimum target, this figure is used as a rough rule of thumb in this analysis.

(a) *Value of nodules versus value of processed minerals/metals*

A prerequisite for any estimate of the profit potential of the nodule industry is the determination of what stages of production should be considered in defining the international sea-bed mining industry. Should the value of nodules on board the mining ship (ore at the mine site) serve as the base for calculation, or the market value of the processed final products marketed by the industry? The method agreed for this calculation could affect quite dramatically the revenue potential for the International Authority. It can be roughly estimated that the nodules on board ship will be worth between 6 and 10 per cent of the value of the final products after the metallurgical processing is completed.[120]

On several occasions the representatives of countries developing sea-bed mining systems have indicated that they expect the nodule industry to generate substantial revenues for the international community. Moreover, the concept of the common heritage of mankind would seem to give precedence to the definition that would best benefit the international community as a whole. It could be expected that those countries wishing to set up nodule processing plants in their territory would be doing so on behalf of the international community. The host country would be trading off its usual share of net revenues or fiscal charge over the metallurgical processing stage for a number of real benefits. For instance, nodule processing will provide local employment and will induce the creation of a number of ancillary activities to supply some of the inputs of the industry and, even more important, to process further the metals/minerals produced. Aside from these important economic benefits, the security which comes from having a steady internal supply of minerals might be a sufficient reason for advanced industrial nations to forego their customary tax revenue from activities carried out within their borders.[121]

The following considerations on the revenue potential for the international machinery assume that the base for calculation will be the value of metals produced by the nodule in-

[113] For example, the granting of discount prices to subsidiaries or associated firms and the use of product distribution through third parties.

[114] See *Official Records of the General Assembly, Twenty-sixth Session, Supplement No. 21* and corrigenda 1 and 3, annex 1, sect. 8.

[115] D. B. Brooks and F. T. Christy, Jr., "Memorandum on Suggested Operational Guidelines for an International Regulatory Authority for the Sea-bed", *The United Nations and the Bed of the Sea (II)*, 21st report of the Commission to Study the Organization of Peace, New York, June 1970.

[116] See A/AC.138/73, pp. 18 and 19.

[117] Net worth (investment capital plus non-distributed profits).

[118] First National City Bank, *Monthly Economic Letter*, April 1973, pp. 6 and 7.

[119] Marne Dubs, Ninth Annual Conference of the Marine Technology Society, Washington, D.C., 10-12 September 1973.

[120] Mining costs of $US 6 per ton of nodule plus some $3 of profits for an approximate value of $9 per ton on board ship. The value of metals extracted from nodules might range from $90 to $170 per ton (depending on whether manganese is recovered or not).

[121] The waiver of taxes over certain economic activities is not so unique. Some advanced and developing countries grant tax-free status to manufacturing companies located within some "free port zones", when these activities are geared to the export market. The system of tax credit, however, has a direct parallel with the nodule industry. In most industrial countries, companies operating abroad are permitted to deduct from their tax bill all taxes paid to foreign governments. This procedure has been extensively used by the multinational petroleum and mining companies.

dustry. This approach, if generally agreed upon, would need to be considerably refined to take into account a number of specific problems that can be foreseen such as the definition of "final products". Subsequent stages of fabrication such as the production of alloys, plates, sheets, tubes, wires, etc., are not considered here. By the same token, the sale of some by-product chemical reagents such as chlorine[122] or the use of the tailings for the manufacture of construction materials or other uses will not be considered in the estimates of the revenue potential of the nodule industry.

The determination of metal prices for the purpose of computing the share of the International Authority will need to be closely scrutinized. For example, in some countries with domestic price controls, like the United States, copper prices may be considerably lower than in other markets, e.g. the London Metals Exchange. More serious is the possibility that intentional manipulation of prices could have the effect of reducing the take of the Authority. A common practice of multinational corporations to minimize taxes is to sell at a low price the commodity produced in a high tax country to an affiliate in a tax haven, that henceforth would proceed to market the product at prevailing prices.[123] This procedure could also be applied domestically if the party mining and processing nodules had interests in other industries or activities using the metals produced. Another situation that must be considered is that of countries with currency controls that would make it difficult to remit the share of the Authority abroad; this problem could be very serious if the currency is inconvertible and the country exercises strict control over its foreign trade.

(b) *The profit potential of the nodule industry—preliminary estimates of revenues and costs*

A preliminary investigation of the gross profit potential of the nodule industry can provide the necessary ground work for determination of the Authority's revenue. The difficulties involved in trying to estimate future revenues and costs of an industry when much of the pertinent information is proprietary cannot be overemphasized. Even in well-established industries a cost-benefit analysis for a new project must always be evaluated with care. Thus a prospective cost-benefit analysis for the nodule industry must be viewed as a first approximation to this crucial, if rather obscure, aspect of the future industry. To this end, a number of assumptions must be made to establish the basis for the estimates on costs and revenues.[124] Most of these assumptions have been derived from information made public by the nodule industry.

The estimate of gross revenues or sales is, conceptually, a straight-forward calculation. It can be made by multiplying the expected volume of production of each metal by their expected future prices. The estimated volume of production per million tons of dry nodules is presented in table 1.

Forecasts of future commodity prices are always of a conjectural nature. A considerable degree of uncertainty will be involved if the time span is over five years and a major new source of supply must be taken into account. Thus, some conservative assumptions will be made for metal prices during the first decade of the nodule industry. These prices are below current market prices of early 1974 which with the accelerating process of world-wide inflation will in all probability be exceeded in the following years. These price assumptions, conservative as they may be, would serve for a comparison with capital and production costs estimated on present basis, and provide a first approximation to the prospective financial return of the nodule industry.[125]

The assumed prices used in table 9 for calculations of estimated revenue of two possible sizes of nodule mining operations are all below present market prices. The greatest variations were in manganese metal price assumed as under half of current market price and cobalt assumed as two thirds of current price to allow for the expected drop in prices once these metals are recovered on a commercial scale.[126] The price of nickel is assumed as about 10 per cent below present levels and the price of copper (US $0.80 per pound), substantially below the high levels reached in recent months (up to US $1.10 per pound). Minor metals, including molybdenum (currently US $1.90 per pound), vanadium (US $1.50 per pound), silver and others are assumed to have an average price of US $1.50 per pound. This latter price assumption may turn out to be the most conservative of all, particularly in the case of nodules containing platinum, since this metal alone may in fact be worth more than the other metals.[127]

On the basis of these assumptions, the estimated gross revenue for a mining operation of 1 million tons per annum producing manganese metal would be approximately US $170 million. Only one firm so far (Deepsea Ventures, Inc.) has indicated that it intends to recover manganese in the form of metal. It seems that the other companies in the United States, Europe and Japan are not considering the recovery of manganese. If no manganese is recovered, the estimated revenue for a 3 million tons per annum operation would be US $268 million. These are the sizes of mining operations generally mentioned as being planned in the United States.[128]

Several attempts have been made in recent years to estimate capital requirements and mining and processing costs for different sizes of nodule ventures.[129] Many of the earlier estimates tended to be rather high. Uncertainties and unknowns were generally allowed for with large upward margins against errors. This caution is understandable given the novelty and

[122] Deepsea Ventures, Inc. has indicated that the resulting chlorine from their hydrochlorination process can be a great plus in the financial picture of their metallurgical process. See R. Kaufman and A. J. Rothstein, "Recent Developments in Deep Ocean Mining", *Sixth Annual Conference of the Marine Technology Society, 1970* (Preprints), Washington, D.C.

[123] See J. S. Arpan, *International Intercorporate Pricing*, New York, Praeger, 1971.

[124] See R. Branco, "The Tax Revenue Potential of Manganese Nodules", *Ocean Development and International Law Journal*, vol. 1, No. 2, 1973.

[125] These assumptions on prices must not be construed as projections or forecasts of metal prices in the 1980s but just as working assumptions for comparison with present cost estimates.

[126] See section II, on the probable impact of nodule mining.

[127] E/CN.11/L.343, annex III, para. 37.

[128] L. S. Ratiner, loc. cit. and A. J. Rothstein and R. Kaufman, op. cit.

[129] John Mero, *The Mineral Resources of the Sea*, New York, Elsevier Publishing, 1965, p. 313.

P. E. Sorensen and W. J. Mead, "A Cost-Benefit Analysis of Ocean Mineral Resource Development: The Case of Manganese Nodules", *American Journal of Agricultural Economics*, vol. 50, No. 5, December 1968, pp. 1611–1620.

A. Kaufman, "A survey of the Economics of Ocean Mining", paper prepared for the U.S.-Japan Marine Mining Panel Joint Meeting, Tokyo, 13 March-3 April 1970.

F. L. La Que, "Deep-Ocean Mining: Prospects and Anticipated Short-Term Benefits", *Ocean Enterprises*, occasional paper published by the Center for the Study of Democratic Institutions, June 1970, pp. 17–27.

G. L. Hubred, "New slant on the economy of manganese nodules", *Ocean Industry*, August 1970, pp. 26 and 27.

G. E. Bollow, "Economic Effects of Deep Ocean Mineral Exploitation", master thesis for the Naval Postgraduate School, 1971.

H. J. Meiser and E. Muller, "Manganese nodules—a further resource to cover the mineral requirements?", *Meerestechnik*, No. 5, October 1973, pp. 145–150.

John Mero, "Potential Economic Value of Ocean-Floor Manganese Nodule Deposits", *Ferromanganese Deposits of the Ocean Floor*, Washington, D.C., National Science Foundation, 1972.

G. Claus, "Theoretical and Experimental Investigations of Deep Ocean Mining Systems and Their Economic Evaluation", *Second International Ocean Development Conference, Tokyo, 5–7 October 1972*, pp. 1925–1955.

Table 9

ESTIMATED REVENUE OF TWO POSSIBLE SIZES OF NODULE MINING OPERATIONS

	1 million tons per annum		*3 million tons per annum*	
	Metal Production (thousand tons)	*Value of Production (US $ million)*	*Metal Production (thousand tons)*	*Value of Production (US $ million)*
Manganese[a]	230.0	80.5	—	—
Nickel[b]	15.0	49.5	45.0	148.5
Copper[c]	13.0	22.9	39.0	68.6
Cobalt[d]	2.0	8.8	6.0	26.4
Minor metals[e]	2.5	8.2	7.5	24.7
TOTAL	262.5	169.9	127.5	268.2

[a] Long-term price of manganese metal assumed as US $350 per ton (as against $0.33 per pound or US $730 per ton in December 1973) to take into account the impact on the rather small market for manganese metal.
[b] Price of US $1.50 per pound or US $3,300 per ton (US $1.62 in January 1974).
[c] Price of US $0.80 per pound or US $1,760 per ton (US $1.05 in December 1973).
[d] Price assumed as US $2.00 per pound or US $4,400 per ton (as against US $3.10 per pound in December 1973).
[e] Varying quantities of molybdenum (US $1.90 per pound in December 1973), vanadium (US $1.50 per pound in December 1973), zinc (US $0.80 per pound in December 1973), silver (US $45 per pound in December 1973) and others, all assumed at an average price of US $1.50 per pound or US $3,300 per ton. This assumption would be meaningless for nodules containing platinum.

complexity of nodule systems. For instance, nodule density, the topography of the ocean floor and the efficiency of the gathering apparatus (mining head) will influence mining costs as will the water depth and the efficiency of the system to lift the nodules from the ocean floor to the mine ship. The size of ore carriers and the round-trip distance between mine site and processing plant will determine the transportation cost.

But it is the processing cost that has probably caused the widest variation in total cost estimates. It is obvious that the metal content in nodules, plant capacity (daily throughout) and the specific circumstances of plant location (distance from port, environmental constraints, labour costs, cost of reagents and other inputs) will all influence the cost of processing. It seems, however, that the assumptions on the specific metallurgical processing system used for the estimates are the single most important reason for the high cost figures generally suggested. Estimates of processing cost based on pyrometallurgical treatment are around US $50 per ton of dry nodule,[130] and those on hydrochlorination at around US $30.[131]

The actual costs of mining, transporting and processing the nodules and marketing the metals produced will only be known after the first production unit starts operation. Even then, costs are likely to decrease as efficiency of operation improves and also as the industry develops more advanced systems. At the present time, any estimate of costs must be viewed with care. The task has been made somewhat easier by the recent disclosures of two American companies. Officials from Deepsea Ventures, Inc. published[132] a range of estimates of capital costs and total operating costs for several sizes of production units, which is reproduced in figure 7. They indicated that for their own organization an economic model was used that permitted them to estimate the cost of investment and operations with considerable assurance. For other sizes, however, the range of estimates provided in figure 7 was based mostly on the estimates of others adjusted within 50 per cent to 400 per cent depending on their evaluation of the reliability of the third party's figures. It can be inferred, therefore, that the actual estimates of costs for the type and size of operation planned by Deepsea Ventures would fall within the range shown in figure 7 for a 1 million tons per annum production unit. The range of estimates for other sizes are crude approximations of doubtful reliability.

The information provided by an official of Kennecott Copper, Inc.[133] is revealing. He suggested that the nodules could be gathered at the ocean floor and lifted on board ship for about US $6 per ton.[134] The transportation costs to shore would run between $3 and $6 per ton.[135] Metallurgical processing could be done for between $10 to $15 or between $12 to $18 per ton, depending on whether or not strict environmental regulations were enforced. He summarized that the average cost could be about $9 per ton of nodule delivered at the shore plant plus $13 for processing for a total of $22 per ton. He suggested that to be on the safe side a range of $20 to $30 per ton could be used.[136] Dubs also indicated that total investments to bring such a 3 million tons operation on stream would be between 250 to 280 million dollars. Since Dubs' figures apparently reflect the actual estimates of his company's proposed nodule system they could be used for cost-benefit estimates of a 3 million tons mining operation.

A first approximation to the gross profit potential of nodule mining, before the income of the Authority is established (operational net revenues) is indicated in table 10 which summarizes the estimates of gross revenues, operational costs and total investment. It is not very likely that the low estimate of return on total investment—as well as the high estimate—will actually be realized because its computation assumes the most pessimistic assumptions in every case: low gross revenue, high total operational costs and high total investment. This low estimate of return (43 per cent and 54 per cent respectively for

[130] H. J. Meiser and E. Muller, op. cit.

[131] R. Kaufman and A. J. Rothstein (1970), op. cit.

[132] A. J. Rothstein and R. Kaufman, "The Approaching Maturity of Deep Ocean Mining—The Pace Quickens", *Offshore Technology Conference, 1973* (Preprints), vol. I, pp. 323–344.

[133] Mr. Marne Dubs, Director of the Ocean Resources Department, gave these figures during the question and answer period, following the presentation of his paper "Metal markets, economics and ocean mining", at the Ninth Annual Conference of the Marine Technology Society, Washington, D.C., 10–12 September 1973.

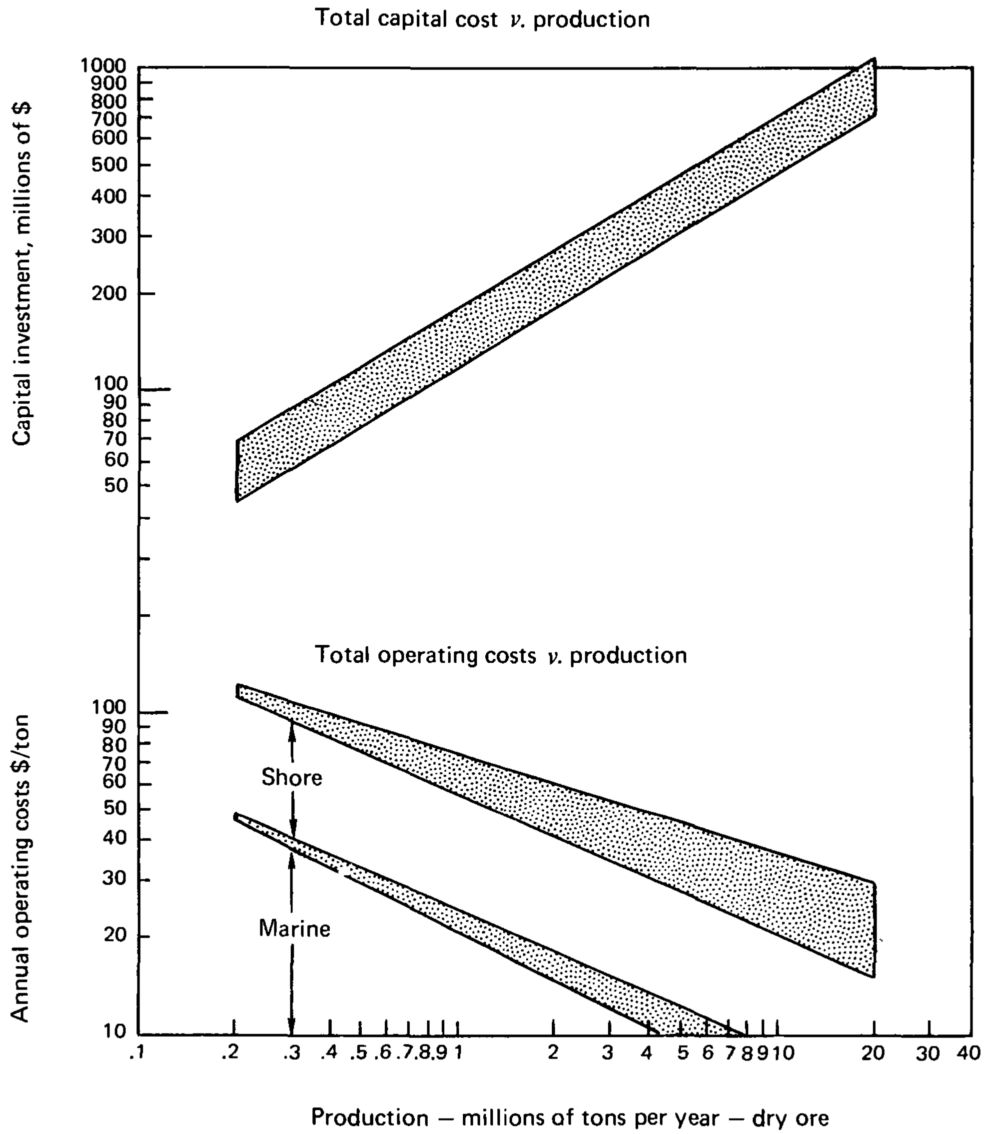
[134] This estimate of mining cost is in line with the estimates of G. Claus, op. cit. ($6.20 to $6.56 per ton) for different hydraulic lift systems.

[135] Other estimates of transportation costs are: $4 per ton (Mero), $4.80 per ton (Claus) and $6.30 per ton (Sorensen and Mead).

[136] These figures are noticeably lower than the range of $35 and $55 derived from figure 7 for an annual production of 3 million tons of nodule.

Figure 7

CAPITAL AND OPERATING COSTS VS. PRODUCTION
(*costs based on full stream production at outset*)



Source: A. J. Rothstein and R. Kaufman, "The Approaching Maturity of Deep Ocean Mining—The Pace Quickens", *Offshore Technology Conference, 1973* (Preprints), p. 340.

Table 10

ESTIMATED OPERATIONAL RESULTS OF TWO POSSIBLE SIZES OF NODULE MINING UNITS
(*millions of $US*)

	1 million tons per annum			*3 million tons per annum*		
	High	*Medium*	*Low*	*High*	*Medium*	*Low*
(*a*) Estimated gross revenue[a]	188	170	154	296	268	242
(*b*) Estimated total costs[b]	76	66	56	90	75	60
(*c*) Estimated net revenue[c]	132[c]	104	78[c]	236[c]	193	152[c]
(*d*) Estimated total investment[b]	180	150	120	280	265	250
(*e*) Return on total investment[d]	109%[d]	69%	43%[d]	94%[d]	73%	54%[d]

a Using the figures of table 9 as medium, the high and low estimates were computed as 10 per cent greater and 10 per cent lower than the medium.

b High and low from Rothstein-Kaufman (1 million tons) and Dubs (3 million tons); medium is the arithmetic average.

c High estimated net revenue (*c*) calculated as high (*a*) minus low (*b*); low (*c*) as: low (*a*) minus high (*b*).

d High return on total investment (*e*) is: high (*c*) divided by low (*d*); low (*e*) is: low (*c*) divided by high (*d*).

1 and 3 million tons operations), however, has the merit of sounding a cautious note for future policy making.[137]

In the future, after the best nodule deposits are exhausted, ore bodies with lower grades will probably be mined. By the same token, prices of some metals, in particular cobalt, manganese and nickel, might also fall as the volume of nodule recovery mounts. The impact of these developments on the profitability of the nodule industry will probably be less serious than it might be thought. The reason is that investment and operational costs are also likely to fall.[138]

(c) *The share of revenues of the International Authority*

The estimates of operational results computed above for the nodule industry provide the necessary basis for a consideration of the possible share of revenue for the Authority. The exact extent and form of this share will depend on the nature of the régime and the manner in which the exploitation takes place.

The share of the Authority, whether in the form of profit participation or taxation, should be effective in generating maximum revenues for the Authority. It should also induce the most efficient allocation of sea-bed resources among potential sea-bed miners. It is well known in economic geology that the best grade ore body of a region is several times more valuable than the "average" ore grade. The distribution and grade of nodule resources of the ocean floor, as on land, are very uneven. Some areas with high nodule concentration, high metal content, ideal ocean floor topographic conditions and proximity to processing plants would be considerably more attractive than the average nodule deposit. If allocation of mine sites is made by some arbitrary means (first-in, first-served basis; random distribution of ocean floor blocks to interested nations etc.) some of the best mine sites might be allocated to parties that may not even have the capability to mine the nodules. Moreover, the Authority would not receive any extra revenue with the allocation of the choice mine sites, even if they were to go to the most efficient producers.

Though the most efficient producer is only a theoretical concept, it serves, in fact, as a guideline in most schemes for allocation of mineral resources. The method used is to auction the right of exclusive exploitation to interested parties.[139] Under an auction system the exploitation rights for a given site would be awarded to the highest bidder. Refusal prices and other conditions to protect the public interest could also be imposed.

In summary, the determination of the revenue of the Authority should meet several objectives: (1) maximize revenues for the Authority; (2) assure the necessary financial incentives to attract capital and technology into the nodule industry; and (3) promote the allocation of choice mine sites to the most efficient producers. These objectives could be met by establishing the share of the Authority as made up of two component parts. The first component would be equal for all nodule mining ventures and would be established at a level that would assure the necessary financial incentives for the industry. The second component would be different for each venture and would be designed to derive that extra revenue that interested parties would be willing to pay for the right to exploit the choice mine sites.

(i) *The basic component of the Authority's share of revenues*

The basic component, common to all operations, could be determined in several ways. It could be based on the right of exclusive access to the resource, as, for instance, the payment of rental fees per square kilometre of area leased.[140] It could be based on production, such as a royalty over the value of output, a levy per ton of mineral recovered, or in a more crude form a fee per ton of nodules mined. It could also be based on net revenues (profits) such as a tax over profits or a direct sharing of profits in the case of joint-ventures with the Authority. These three approaches are not mutually exclusive. On the contrary, they are often combined in national legislations to reinforce each other in securing a fair share of revenue for the Government.

An income based on net revenues may assume quite distinct legal forms. In financial terms, however, a 50 per cent tax on profits is essentially the same as a partnership with equal sharing in the profits of the venture. This general approach has been traditionally favoured by fiscal experts and business groups because of its intrinsic flexibility. It permits the Government and the business entity to benefit equally in cases of exceptionally favourable market conditions resulting in high profits.

The shortcomings of a tax on, or participation in, the profits (operational results) of a business venture are mostly of an administrative nature. Computation of taxable profits can easily become a highly contentious affair often resulting in disputes between the fiscal authorities and the firm concerned.

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[137] These figures on the estimated return on total investment assume that depreciation allowances according to standard practice were included in the cost estimates given by the industry representatives mentioned. But even if that were not the case, and an additional allowance of, say, 10 per cent over total investment were made, the operational results would still be very attractive. For the 1 million ton operation they would range from a low of 33 per cent to a high of 99 per cent with a medium estimate of 53 per cent return. The 3 million ton operation would also fare very well with returns ranging from a low of 44 per cent to a high of 84 per cent with a medium estimated return of 65 per cent.

[138] It has been the experience of every major new industry that costs of production tend to fall sharply once the industry matures (i.e. plastics, colour television, mini-computers, etc.).

[139] The advantages of the auction system for nodule resources were described by two authorities in mineral economics:

> "The auction mechanism provides several advantages over a system that awards rights to the first claimant or over a system that awards rights on the basis of non-economic criteria. First, it helps to ensure that the most efficient producers will get the exploitation rights. This is because the exploiters with the lowest costs will be able to bid the greatest amount. Under a 'first-come, first-served' arrangement, there is no assurance that exploiters will be efficient. And under a system where non-economic criteria are used to allocate rights, this, by definition, would award rights to the less efficient. It would also tend to distribute wealth by awarding rights rather than by providing shares in royalties and auction revenues.
>
> "Second, the auction mechanism provides the least arbitrary means for choosing among competing claimants. Competition among claimants may not be great for the manganese nodules of the deep sea-bed for many years to come. But eventually, as the demand increases for such resources, the competition will become important.
>
> "Third, the auction mechanism approximates a fair value for the exploitation right much more effectively than any other system. The exploiter bids no more than he feels he can afford. This permits him to take into consideration the degree of risk attached to the operation, the value of the market, and other economic variables. It also builds in a large degree of flexibility and provides for an automatic response to the changes in conditions of risk, market, etc. It can, and should be combined with royalty payments so that the world community can share in production values."

D. B. Brooks and F. T. Christy, Jr., "Memorandum on Suggested Operational Guidelines for an International Regulatory Authority for the Sea-Bed", *The United Nations and the Bed of the Sea (II)*, 21st report of the Commission to Study the Organization of Peace, New York, June 1970, pp. 29 and 30.

[140] Concession taxes related to land area can be applied both to the exploration and to the exploitation stages. They can include deposits providing a minimum "guarantee" to the Government if the concession is not explored or exploited. These taxes seldom amount to an important share of the total take of the Government. They are generally designed to compensate the owner of the property that will be disturbed by the mining activities. They serve, however, the important function of discouraging speculation by concessionaries who are not interested in carrying out the exploration or commercial mining of the area. See J. N. Behrman, "Taxation of Extractive Industries in Latin America and the Impact on Foreign Investors", *Foreign Investment in the Petroleum and Mineral Industries*, Baltimore, the Johns Hopkins Press, 1971, p. 56.

Despite the extensive experience of advanced industrial countries in tax enforcement, it is known that a number of procedures can be and often are used to reduce the magnitude of taxable profits. The use of such procedures is particularly common where multinational corporations are involved and when some buying or selling takes place in more than one country.[141] These practices have been extensively described in the literature and much attention has been given in recent years to their control.[142]

If the share of the Authority is established as a tax on profits, exhaustive regulations will be required on methods to compute taxable profits. The novelty of an international machinery with fiscal powers would need to be studied closely. It is obvious that most of the potential points of discord in the computation of net revenues could be avoided if the Authority itself were a partner in the sea-bed mining venture and had an active role in management.

Taxes on production or sales have the opposite characteristics of those levied on profits. They are much simpler to administer as the tax guidelines are easier to determine, i.e., volume of production or value of sales. On the other hand, these taxes are not very flexible to changes in operational conditions. When prices reach very high levels the enterprise is able to reap much higher net profits than it would be possible with a tax on profits. When operational conditions are unfavourable due to fall in sales revenues or sharp increases in costs of production actual profits are sharply reduced or even wiped out; in such cases, the payment of royalties might constitute an excessive burden to the enterprise. For this reason royalties are generally set conservatively at levels compatible with the likely financial position of firms during unfavourable years.

Yet the question still remains: what could be the actual share of revenues of the Authority that would meet the requirement of providing the necessary incentive for the industry, namely guaranteeing at least a 15 per cent return on investment for nodule ventures? The determination of such shares—whether based on gross revenues or on net revenues—generally requires detailed studies on the likely operational results of the industry. The data available for the estimates of revenues and costs of the future nodule industry used in this report are clearly of a preliminary nature. Therefore, the figures presented must be understood as first approximations requiring further refinement.

From the figures in table 11 it could be tentatively concluded that a possible share of the Authority at 30 per cent of gross revenues (sales)[143] or 50 per cent of net revenues (profits) would still make nodule mining a rather attractive commercial proposition even considering the risks inherent in a new industry. The medium estimate of return on investment after payment of the Authority's share is quite similar for both methods: for the 1 million tons operation 35 per cent and for the 3 million tons size 43 per cent and 36 per cent. As expected, the range between high and low estimates of operational results is much wider for the 30 per cent share over gross revenues than for the 50 per cent share over net revenues, regardless of the size of operation. The limiting point is the low estimate of return (18 per cent) for the 1 million ton size with the share of the Authority set at 30 per cent of gross revenues. The 3 million ton operation would seem to fare considerably better: the low estimated return would be 28 per cent with payment of a 30 per cent share on gross revenues, and 27 per cent with a share of 50 per cent on net revenues.

The method of financing total investment will also affect the operational results of the equity capital invested in the nodule venture. Industrial and mining companies generally borrow a substantial proportion of their total capital requirements for a new venture. This proportion may be as high as 90 per cent in exceptional cases. It would seem reasonable to assume that firms from advanced countries would probably borrow at least 50 per cent of the total capital requirements for a nodule mining venture.[144] Borrowing will improve the return on equity as long as the rate of interest payable is less than the rate of return on total investment.[145]

The calculations of return on equity investment shown in table 12 are based on the assumption that the liability over borrowed capital would rest with the original investor. These computations show that the return on equity investment, even in the case of the low estimate, would seem quite attractive with either method of determining the Authority's share. Return on

[141] The report entitled, *Multinational Corporations in World Development* (United Nations publication, Sales No. E.73.II.A.11) summarizes the situation as follows in a section on profit management (pp. 34 and 35):

"Dividends and royalty payments are not the only means whereby multinational corporations withdraw profits from a foreign subsidiary. Profits can be recorded in other units of a global system, including holding companies located in tax havens, through control of the transfer prices for goods and services supplied by the parent company or exports to other affiliates.

"The importance of these controls in influencing the net profit before local taxes depends largely on the proportion of total purchases and sales tied to other affiliates . . . .

"Prices charged for tied imports have been shown in some instances to be far above prevailing "world" prices, and conversely those for exports have been below world prices. As already noted, overpricing, particularly for wholly-owned affiliates, has been used as an alternative to royalty payments. Considerable variation exists, however, in the amount of overpricing or underpricing and its overall frequency is not known."

[142] For an in-depth analysis of multinational practices to reduce tax liability in host countries, the reader is referred to: J. S. Arpan, *International Intercorporate Pricing,* New York, Praeger, 1971; United Nations document, "Establishing transfer prices in allocation of taxable income among countries" (ST/SG/AC.8/L.3) and J. Schulman, "Transfer pricing in multinational business", D.B.A. thesis, Harvard University, 1967.

[143] A share of 30 per cent of gross revenues may seem rather high at first sight. In many countries royalties of up to 20 per cent (Mexico and the United States) are payable over the value of mineral output. In the United States draft convention on the international sea-bed area it is proposed that miners should pay the Authority the equivalent of 5 to 40 per cent of the gross value at the site of oil and gas, and 2 to 20 per cent of the gross value at the site of other minerals (appendix A, No. 10.2). It must be recalled, however, that the "take" is made up of royalties plus concession fees, income taxes, and other charges.

[144] The practice of multinationals is quite interesting:

"The capital structure of a newly established subsidiary generally has a large proportion of locally raised debt if it is a joint venture, much less if it is wholly-owned. Studies of United States investment in Australia and Japan have shown that contributions of technology are likely to be capitalized in joint ventures, but not in wholly-owned subsidiaries. This difference may partly explain why wholly-owned subsidiaries have generally reported a higher return on book equity than joint ventures. Further differences in financial policy are evident, especially in the early years of existence: wholly-owned subsidiaries are provided with special support services at low or zero cost; royalty payments are temporarily forgiven; dividends are postponed. On the other hand, in later years, parent companies expect to be able to move funds between subsidiaries on demand."

See *Multinational Corporations in World Development* (United Nations publication, Sales No. E.73.II.A.11), p. 35.

[145] The liability for interest payment is also important if the share of the Authority is based on net revenues. The interest payment can be treated either as a liability of the nodule venture or of the parent company providing the equity capital and technology. In the former case, the Authority would effectively be subsidizing half of the cost of borrowing if the share of the Authority amounted to 50 per cent of net revenues. Conversely, it might be interpreted that in joint ventures the Authority would enter the partnership with the resources of the international community while the associated enterprise would provide all the capital and technology required. In that case, the liability for payment of interest and principal would lie with the original investor and not with the joint venture itself. This problem would not occur if the share of the Authority were based on gross revenues.

Table 11

ESTIMATED OPERATIONAL RESULTS OF TWO POSSIBLE SIZES OF NODULE MINING OPERATIONS AFTER PAYMENT OF TWO ALTERNATIVE SHARES OF REVENUES TO THE AUTHORITY
(in millions US dollars)

	1 million ton per annum			*3 million ton per annum*		
	High	*Medium*	*Low*	*High*	*Medium*	*Low*
Estimated net revenue *before* payment of Authority's share:	132	104	78	236	193	152
Possible shares of the Authority:						
30 per cent share over gross revenue (royalty)	56	51	46	89	80	72
50 per cent share of net revenue (profit split)	66	52	39	118	96	76
Estimated net revenue *after* payment of Authority's share:						
With a 30 per cent share over gross revenue	75	53	33	146	113	79
With a 50 per cent share of net revenue	66	52	39	118	96	76
Estimated return on total investment after payment of Authority's share: (percentage)						
With a 30 per cent share over gross revenue	63	35	18	58	43	28
With a 50 per cent share of net revenue	55	35	22	47	36	27

Source: Table 10.

Table 12

ESTIMATED RETURN ON EQUITY INVESTMENT (50 PER CENT OF TOTAL INVESTMENT) OF TWO POSSIBLE SIZES OF NODULE MINING OPERATIONS (ASSUMED INTEREST RATE ON BORROWED FUNDS = 10 PER CENT)
(in millions of US dollars)

	1 million tons			*3 million tons*		
	High	*Medium*	*Low*	*High*	*Medium*	*Low*
Net revenue after payment of Authority's share:						
As 30 per cent of gross revenue	75	53	33	146	113	79
As 50 per cent of net revenue	66	52	39	118	96	76
Interest payment = 10 per cent over half of total investment	6	8	9	12	13	14
Net revenue after interest payment:						
With 30 per cent share of gross revenue	69	45	24	134	100	65
With 50 per cent share of net revenue	60	44	30	106	83	62
Estimated return over equity (half of total investment as a percentage):						
With 30 per cent share of gross revenue	115	60	27	107	75	46
With 50 per cent share of net revenue	100	59	33	85	63	44

Source: Tables 10 and 11.

equity appears to be most attractive (over 44 per cent) for the larger size of operations (3 million tons of nodules per year).[146]

(ii) *Auction of mine sites*

A second component of the Authority's share of revenues in nodule mining could be derived from auctioning the mine sites. An auction system to be effective would have to take into account the rather small number of enterprises actively engaged in developing nodule systems. The numerous precedents in auctioning offshore blocks in the oil industry might be helpful in designing appropriate procedures for the nodule industry.

The first issue in a possible auction system would be the choice of sites which would be opened for bids. In the oil industry the appropriate agency of the government determines the specific blocks of its continental shelf to be offered in auction. It decides on the delimitation of the blocks and their exact location. This procedure might have serious disadvantages in the nodule industry, particularly in the initial years, since the international Authority would have limited knowledge of nodule distribution. Moreover, such procedure would unduly penalize the companies that have spent large sums prospecting the ocean floor for the most desirable potential mine sites. Instead, it might be preferable to permit the interested parties to indicate the specific locations on which they wish to bid. In that case, the Authority could set a deadline to receive notifications of one possible mine site from each interested party. On the

[146] It is assumed in these calculations that the nodule mining companies would not be subject to additional national corporate taxes on their profits. Since industrial countries provide for tax credits in their fiscal codes, the domestic tax liability of these companies might in fact be negative. The companies might be able to claim some deduction on their domestic taxes from other operations, equivalent to the difference between their payments to the Authority and the tax they would have paid if the nodule industry were entirely of a local nature. As is well known, mining companies in industrial countries generally benefit from special tax advantages (depletion allowance, accelerated depreciation, etc.), that tend to reduce their tax liability.

predetermined date, the Authority would publicize the specific locations of the ocean floor for which it would entertain bids a few months later.[147]

The obvious question, however, is whether there would be any real competition for mine sites. It might be argued that, since only a few (six to eight) enterprises or groups seem to be actively engaged in developing nodule systems, these groups might arrange among themselves not to bid on each other's sites. Two factors would minimize this danger. First, the number of companies or groups potentially interested in nodule mining is quite large. In fact, it might be said that the majority of large oil and mining companies in the world are potentially interested in sea-bed mining.[148] It seems reasonable to expect that once nodule mining is proven to be commercially viable many other firms will enter the industry.

The second factor that would enhance the chances of competitive bidding is the possibility that some form of control over the pace of nodule development might be adopted. If the Authority adopts a system of control similar to the one discussed above (III.3.4), a certain volume of nodule mining would be authorized each year. Using the figures presented in table 7 as an example, by 1976 the Authority might authorize projects to mine approximately 2.7 million tons of nodules. Assuming that 1976 would be the first year of provisional entry into force of the international régime, at that time it is likely that all the seven or eight most active groups would try to obtain authorization to go ahead with their programmes and at the same time assure the exclusive exploitation rights over their desired sites. Considering the likely sizes of operation, these groups might request authorization to mine an annual volume of 19 to 22 million tons of nodules, or approximately six to seven times as much tonnage as may be granted that year. The companies in that case would have to include in their bids—particularly in the first few years—a factor for priority over time[149] as well as priority over a specific mine site.

[147]The question of whether to establish a world-wide grid for potential sea-bed mining blocks is discussed below in section III.7 on conservation of nodule resources.

[148]This interest can be seen in the participation of 32 firms from six countries (United States of America, Canada, France, Germany (Federal Republic of), Australia and Japan) in the CLB system tests of 1972. These firms paid a minimum fee of $US 50,000 to participate in these tests. It seems likely that a number of other firms might enter the nodule industry by means of "purchased technology". The multinational groups established so far are primarily aimed at a co-operative development of technology. It can be expected that once a nodule system becomes operational, one or more members of that group might be tempted to operate alone. One additional factor in the possible future expansion of the industry is the programme of Howard Hughes. His nodule mining system, presently undergoing tests in the Pacific Ocean, may be available to other interested parties. In fact Summa Corporation has not yet finalized its plans for the commercial stage of nodule exploitation. A number of alternatives are under consideration: (*a*) to mine and process the nodules alone; (*b*) to set up a joint venture with a firm, or firms, experienced in metallurgy and marketing; (*c*) to mine nodules for sale to other parties; and (*d*) to build and sell complete nodule mining systems to interested parties.

[149]It might be countered that these seven or eight groups would attempt to arrange among themselves a time schedule as well as an agreement not to bid on each other's claims. The likelihood of such arrangements is not very great because of the importance of the time element in business and the difficulty to enforce such an agreement in the face of so many unknowns. For instance, company X that would be accorded priority by the other firms for the first year might disclose a mine site with such ideal conditions that one or more parties to the "gentlemen's agreement" would be tempted to repudiate the arrangement and try to obtain control of that site with a high bid. Moreover, the other several dozen potential nodule miners would also have a role to play in assuring the competitiveness of an auction system for sites. These latecomers could take a short-cut and instead of spending several million dollars over several years in exploration programmes, might simply spend equivalent sums as their bid prices for the choice sites that would be disclosed by the leaders in the industry.

The nature of bids would need to be determined if an auction system is adopted. Two basic possibilities could be contemplated, namely the full payment of a certain sum which would constitute the bid price (as in the oil industry) or the offer to make payments larger than those statutorily determined, over gross or net revenue, once production commences. Each method has advantages and disadvantages. A cash price for a site has the advantage of simplicity; the site would simply go to the highest bidder. The cash price has also the advantage of discouraging speculators from sitting on choice sites, though speculators can also be discouraged by the establishment of minimum work requirements (a schedule of minimum annual expenditures) and by surface rental fees. The disadvantage of the cash price is that it increases the financial burden of getting started in the nodule industry. As a result, the miner will attempt to raise the cut-off grade of the ore body and to speed up production schedules.[150] These procedures do not lead to good resources conservation practices.

Bids offering additional participation in gross or net revenues by the Authority would avoid some of the disadvantages of cash prices. On the other hand, they would be quite complex to evaluate. Decisions on "the best bid" for the Authority could lead to contention depending on the method of evaluation of bids. For instance a bid offering 4 per cent additional royalty might in fact be more attractive for the Authority than a bid offering 5 per cent depending on the prospective schedule of cash flow for both projects and the rate of discount used for the purpose of project evaluation.[151] Still another alternative is the combination of royalty and bonus in the auction system.[152]

In conclusion, it could be said that the revenue potential for the Authority from nodule exploitation is quite attractive. A prerequisite for the determination of the revenue of the Authority is an agreement on the type of régime to govern the exploitation of nodules. The formulation of an ideal, or a desirable revenue would only be possible after a decision is made on "who may exploit the area" and "in what form the exploitation may take place". Once this decision is made, further studies on the economics of nodule mining would be necessary to determine the most appropriate levels for each component of the revenue of the Authority.

6. *Preservation of the marine environment*

Despite the universal agreement on the need for measures to preserve the marine environment in all activities of exploration of the international area and exploitation of its resources, the translation of this principle into practice offers a number of difficulties. The problem centres on the definition of what constitutes an interference with the ecological balance of the marine environment. It is on the basis of such definition that operational standards for activities in the area could be established.

The amount of research on the deep sea environment is almost negligible compared to the multitude of programmes concerned with the ecological processes of the shallow coastal environment. But even in the latter case, scientists are far from unanimous in their opinions as to whether certain specific activities interfere significantly with the ecological balance of the marine environment. It is obvious, therefore, that at the moment there is a serious gap in the knowledge of the ecology of

[150]See A. P. H. Van Meurs, *Petroleum Economics and Offshore Mining Legislation*, Amsterdam, Elsevier Publishing Co., 1971, p. 87.

[151]See *Manual on Economic Development Projects* (United Nations Publication, Sales No. 58.II.G.5 and O.E.C.D., *Manual of Industrial Project Analysis in Developing Countries*, Paris, 1969.

[152]"It may be that because of the high levels of risk and uncertainty in much of the public domain land, the optimum leasing system might include a combination of royalty and bonus bidding" (J. W. Sprague and B. Julian, "An analysis of the impact of an all-competitive leasing system on onshore oil and gas leasing revenue", *Natural Resources Journal*, July 1970, pp. 515-531).

the deep oceans. Though some research on the environmental impact of nodule mining has been carried out in the United States,[153] and the United Nations has commissioned a study of this subject, the data existing at present would not be sufficient to establish detailed environmental standards.

Most of the environmental observations made so far were based on the intermittent operation of prototype lifting systems in relatively shallow waters of less than 1,000 metres depth. The ecological impact of the operation of a large mining system in 4,000 to 5,000 metres of water depth, and in some cases 800 miles from the nearest land, will probably only be assessed in its entirety when commercial operations have been under way for some time. Moreover, the nature of bottom sediments and benthic life is likely to vary from site to site. Ocean currents throughout the water column and water characteristics (temperature, salinity, etc.) might also be different depending on the location. Last but not least, the particular methods of mining and separation of sediments will have different impacts on the benthic and pelagic environments. For instance, the continuous line bucket system is designed to bring only the nodules to the surface. The hydraulic and airlift pumping systems, on the other hand, will transport large quantities of cold bottom water (rich in nutrients) as well as sediments to the warmer waters at the surface.[154]

[153] T. C. Malone, C. Garside and D. S. Roels, "Potential Environmental Impact of Manganese-Nodule Mining in the Deep Sea", *Offshore Technology Conference, 1973* (Preprints), vol. I, pp. 129-135; C. G. Welling, "Some Environmental Factors Associated with Deep Ocean Mining", *Eighth Annual Conference of the Marine Technology Society*, 1972; A. F. Amos, C. Garside, K. C. Haines and O. A. Roels, "Effects of Surface-Discharged Deep Sea Mining Effluent", *Journal of Marine Technology Society*, 1972, 6, No. 4, pp. 40-45.

[154] T. C. Malone, C. Garside and D. S. Roels, op. cit., p. 129.

Given these circumstances, it might be desirable to determine the appropriate standards for protecting the ecological balance in three stages. First, standards could be incorporated into the general principles of the régime for the preservation of this environment and the competence to establish and enforce standards. As a second line of defence, environmental impact statements could be required from all companies and groups requesting contracts or licences to mine nodules. Finally, the Authority could progressively develop detailed rules, standards and regulations, based on its accumulated experience.[155]

The above considerations refer primarily to deep sea-bed mining. It must be borne in mind, however, that at present approximately 95 per cent of the ocean pollution originates from vessels.[156] Pollutants are primarily introduced into the marine environment by collisions and other maritime casualties, loading and bunkering operations and operational discharges. The matter of standards and regulations for these activities will be considered by the Third United Nations Law of the Sea Conference, with particular reference to the work done by the Inter-Governmental Maritime Consultative Organization.

7. *Conservation of nodule resources*

The concern for conservation of sea-bed resources expressed in the Declaration of Principles reflects the fact that nodule

[155] For effective protection of the marine environment, as for other policy objectives, the Authority should be invested with sufficiently broad powers and flexibility to adjust its standards and regulations to its accumulated knowledge of the marine environment and to new circumstances with which it may be confronted in the future.

[156] See "Competence to establish standards for the control of vessel source pollution", (A/AC.138/SC.III/L.36).

Figure 8

SUMMARY PRESENTATION OF ISSUES AND ALTERNATIVES RELATING TO SEA-BED RESOURCE CONSERVATION

A. *Management of the international area*
- 1. Decisions relating to space (surface boundaries)
- (*a*) Over-all subdivision of the international area:
  - (i) On an *ad hoc* basis as requested by sea-bed miners
  - (ii) According to master grid
- (*b*) Size of individual blocks:
  - (i) As requested by miners
  - (ii) Equal size for all blocks
  - (iii) Variable sizes pre-determined by grid:
    - Blocks of one degree square as defined by meridians
    - Size determined by geological, morphological and other considerations
- 2. Decisions relating to time
- (*a*) Reservation of areas for future uses:
  - (i) Area returned to the Authority (three quarters of initial area authorized for exploitation)
  - (ii) Alternative bands with width of 2 degrees of longitude running from pole to pole
  - (iii) Discretionary decision by the Authority
- (*b*) Annual authorization of surface area, or nodule tonnage, for exploitation:
  - (i) No limits—as requested by interested parties
  - (ii) Controlled nodule development based on principle of complementarity with land-based production
- (*c*) Duration of exploration and exploitation permits—work requirements

B. *Regulation of mining operations*
- 1. No minimum recovery efficiency required
- 2. Control aimed at avoiding wasteful mining methods
- (*a*) Unmined areas of blocks:
  - (i) Unminable zones—topographic barriers
  - (ii) Areas with nodules below "cut-off" grade
- (*b*) "Sweep" efficiency:
  - (i) Limited manoeuvrability:
    - Continuous Line Bucket (CLB) system
    - "Vacuum cleaning" (hydraulic) and airlift systems
  - (ii) Extensive manoeuvrability—bottom crawling devices
- (*c*) Dredge efficiency

deposits are among the last mineral frontiers in our resource-hungry world. The concept of resource conservation, however, is not always clearly understood. In a nutshell, "the conservation of non-renewable resources is effected by rational, efficient use and long-term exploitation plans, and by the prevention of waste through inefficient production and treatment techniques or otherwise."[157]

The basic approach to resource conservation is to maximize the long-term utilization of a resource. To this end the individual operator may have to be discouraged from undertaking certain methods of resource exploitation that might be commercially attractive in the short-run. Conservation methods with respect to nodule resources would fall into two broad categories: over-all management of the international area and regulation of mining operations. The issues of resource conservation, with some alternative approaches for each case, are presented in summary form in figure 8.

It should be stressed that these issues are to a considerable extent interdependent. Thus, a given strategy of resource conservation would take account of each one of these areas. For example, a master grid for the international area with blocks of 50 km x 50 km (2,500 km^2) could be established; every two adjacent rows of blocks (100 km wide) would be available for exploitation and the adjoining two reserved for future use; each enterprise would be allocated one block for a certain number of years, subject to the metal production plan approved by the Authority. This hypothetical approach would resolve the over-all subdivision requirement for the international area and the size of individual blocks, while automatically reserving half of the best mine sites for future use. It would facilitate the control of nodule development so as to minimize the possible impact on developing countries exporters of minerals. It would prevent the speculative holding of large areas of top grade nodule deposits by a few operators, while at the same time, minimizing the need for detailed work requirements (the usual means of discouraging speculative holdings). Finally, it would provide an intrinsic regulation of minimum recovery efficiency.[158]

Management of the international area, from a resource conservation point of view, will require decisions with regard to space and to time. The spatial or geographical question has many similarities with the offshore oil industry. The two basic elements in the equation are the subdivision of the international area into blocks, or potential mine sites, and the size of these blocks. Two alternatives are possible with respect to the subdivision of the area. The first is simply to leave it to the interested parties (the nodule miners) to indicate the shape and specific location of desired blocks. This approach makes over-all resource management more difficult and may lead to some waste since the area left between the chosen blocks may be of such odd shapes and small size as to make its exploitation unattractive. This situation can be visualized in the hypothetical case A in figure 9, where a substantial buffer area might be left unused.

The other approach is to subdivide the international area in a rather homogeneous fashion as is generally done for the offshore oil industry. This would mean the establishment of a grid with parallel blocks of the same shape. The grid could be either of a global character with all blocks similarly defined by geographic co-ordinates, or of a more regional character, where the size of blocks would vary according to the geomorphic characteristics of the sea-floor, latitude, nodule density and grade, etc. In the hypothetical example of figure 9 B, the grid would be based on meridians of latitude and longitude. This rather simple and straightforward case would result in progressively smaller blocks with distance from the equator, as can be seen in table 13. The desirability of such a master grid would depend on considerations about the most appropriate block size.

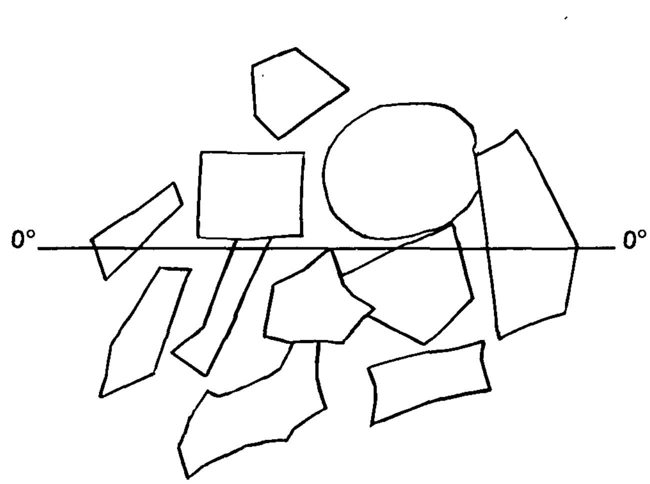
[157] *Natural Resources of Developing Countries: Investigation, Development and Rational Utilization* (United Nations Publication, Sales No. E.70.II.B.2), p. 38.

[158] For example, an enterprise wishing to mine 3 million tons of nodules per year could be notified that only after five years of mining activities would it be granted another block; if the nodule density at that site were known to be about 4 lb per square foot, or a total of about 50 million tons for the whole block, it means that after five years of exploitation some 15 million tons of nodules would be recovered, representing an implicit recovery efficiency of 30 per cent.

Figure 9

TWO HYPOTHETICAL CASES OF SUBDIVISION OF THE INTERNATIONAL AREA

A. International Area subdivided on an *ad hoc* basis with blocks shaped as requested by nodule miners



B. International Area subdivided with a global grid based on meridians of latitude and longitude

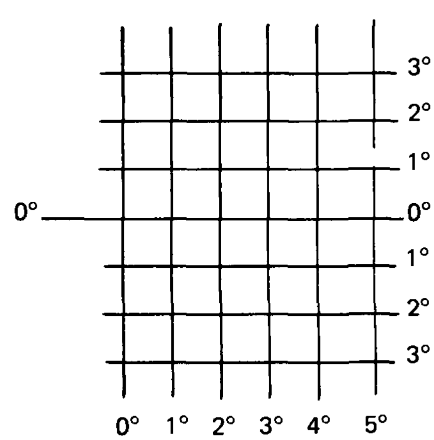


Table 13

AREA OF ONE-DEGREE SQUARE BLOCKS
(in square kilometres)

Latitude	*Area*	*Latitude*	*Area*	*Latitude*	*Area*
0°-1°	12,309	30°-31°	10,643	60°-61°	6,124
1°-2°	12,305	31°-32°	10,534	61°-62°	5,935
2°-3°	12,298	32°-33°	10,422	62°-63°	5,745
3°-4°	12,287	33°-34°	10,307	63°-64°	5,552
4°-5°	12,273	34°-35°	10,189	64°-65°	5,358
5°-6°	12,254	35°-36°	10,067	65°-66°	5,162
6°-7°	12,233	36°-37°	9,942	66°-67°	4,964
7°-8°	12,207	37°-38°	9,815	67°-68°	4,765
8°-9°	12,178	38°-39°	9,684	68°-69°	4,564
9°-10°	12,145	39°-40°	9,550	69°-70°	4,362
10°-11°	12,109	40°-41°	9,414	70°-71°	4,159
11°-12°	12,069	41°-42°	9,274	71°-72°	3,954
12°-13°	12,025	42°-43°	9,132	72°-73°	3,747
13°-14°	11,978	43°-44°	8,986	73°-74°	3,540
14°-15°	11,928	44°-45°	8,838	74°-75°	3,331
15°-16°	11,873	45°-46°	8,687	75°-76°	3,121
16°-17°	11,815	46°-47°	8,534	76°-77°	2,910
17°-18°	11,754	47°-48°	8,377	77°-78°	2,699
18°-19°	11,689	48°-49°	8,218	78°-79°	2,486
19°-20°	11,621	49°-50°	8,057	79°-80°	2,273
20°-21°	11,549	50°-51°	7,893	80°-81°	2,058
21°-22°	11,474	51°-52°	7,726	81°-82°	1,844
22°-23°	11,395	52°-53°	7,557	82°-83°	1,628
23°-24°	11,313	53°-54°	7,386	83°-84°	1,412
24°-25°	11,227	54°-55°	7,212	84°-85°	1,196
25°-26°	11,138	55°-56°	7,036	85°-86°	979
26°-27°	11,046	56°-57°	6,858	86°-87°	762
27°-28°	10,950	57°-58°	6,678	87°-88°	544
28°-29°	10,851	58°-59°	6,495	88°-89°	327
29°-30°	10,749	59°-60°	6,310	89°-90°	109

Source: Geographical Conversion Tables (Zurich, Amiran and Schick, 1961), pp. 219-221.

Several factors have to be taken into account in the determination of mine-site size for the nodule industry. The consideration that is generally advanced is that the mine size must be sufficient to provide the necessary nodule tonnage for the normal operation of the mining equipment and processing plant during their expected lifetime. It is reasonable to expect that in most industrial countries, these facilities would be depreciated in less than 10 years. Since nodule mining is a new industry at the beginning of its development, it can be expected that its rate of technological progress will make for a rapid obsolescence of plant and equipment. If the size of the mining blocks is to be determined so as to provide the necessary feedstock throughout the lifetime of the project, it seems that this period could be arbitrarily defined within the span of 10 to 20 years. The need of sufficiently large mine sites for this purpose is strongly questioned by one company developing nodule systems. International Nickel Co.[159] has proposed that each licensee be granted exclusive rights of access over an area of 2,500 square kilometres, with a buffer zone of at least 5 kilometres left between blocks to prevent encroachment. These smaller mine sites would prevent a speculative "land grab" by a few companies. Once the nodule deposits of one site have been depleted the miner would be granted another block, which could conceivably be one adjoining to the first one.

The problem of determining an "appropriate" block size is compounded by the fact that nodule density and grade change from site to site. Moreover, recovery efficiency of the different mining systems under development may vary considerably. Given these factors, three alternative approaches regarding mine size are possible: (*a*) variable sizes as requested by the sea-bed miner; (*b*) a standard size for all blocks regardless of locality or proposed production capacity; and (*c*) variable sizes predetermined by master grid.

An indication of what might be the claims of future miners as to the size required for their projects was given in a paper prepared by officials of two United States companies.[160] Using a comprehensive formula, the authors estimated that within the range of assumptions suggested for the variables in their formula, the tract area with an average density of 1.5 pounds per square foot, required for an annual production of 3 million tons of dry nodules over 20 years could range from 32,668 square kilometres to 127,043 square kilometres. While the proposed formula seems most useful, the assumptions used for the calculations would have to be critically examined as to their applicability to the real situation of nodule mining.[161] It seems reasonable to assume that nodule miners would want to obtain control over as large an area as possible of top grade sites.

The other aspect of management of the International Area for resource conservation relates to the time element. The issues involved are: (*a*) reservation of areas for future use; (*b*) annual authorization of surface area, or nodule volume, for exploitation and (*c*) the duration of exploration and exploitation permits. This last point is a common feature of all mining legislation and is generally associated with work requirements for the periods in question so as to prevent speculative holding of sites. The possibility of setting up a programme of controlled nodule development with maximum annual authorization of a certain

[159] INCO, "An Approach to International Regulation of the Recovery of Deep-Sea Ferromanganese Nodules", mimeographed, January 1973.

[160] J. E. Flipse, M. A. Dubs and R. J. Greenwald, "Preproduction Manganese Nodule Mining Activities and Requirements", in *Mineral Resources of the Deep Sea-Bed,* op. cit. in foot-note 13.

[161] It is interesting to note that the bill prepared by the American Mining Congress and proposing interim legislation for deep sea-bed resources, which is presently under consideration by the United States Congress, indicates that exclusive exploration rights should be granted over an area of 40,000 km^2. A provision is made that once exploitation starts, the miner would retain 1/4 of the area (10,000 km^2) returning the remainder 3/4 to the "international registry clearinghouse".

tonnage of nodules for exploitation would depend on the nature of the régime and future decisions of the Authority. This question is discussed at greater length in section III.3 above.

The reservation of areas for future use is a question having to do as much with equity as with resource conservation. It is generally agreed that in the absence of rules to the contrary a handful of firms from the most advanced countries could, in a few years, acquire rights over the best mine sites throughout the oceans. Later comers—developing countries as well as the small industrial countries—would have a very limited role to play, if any. This, of course, would apply if resource exploitation is carried out directly by the interested parties through licences. It has been suggested, therefore, that it would be in the interest of the world community at large to reserve part of the best nodule sites for future use.

This objective could be achieved in three different ways as illustrated in figure 10. One possibility would be to reserve three quarters of the initial area granted for exploration for future use; the nodule miner might then be requested to return this part to the Authority upon commencement of the exploitation stage. This approach is likely to guarantee quite attractive sites for future generations of miners since the quality of nodule deposits is not likely to vary greatly from that of the adjoining sites retained by the initial miner.

If the Authority establishes a master grid based on meridians, another possibility would be to hold for future use alternative bands with a width of 2° of longitude running from pole to pole. This method would automatically divide the ocean floor into adjoining areas which could be exploited in the first years and those that would be reserved for later use. For example, it is known that the most extensive and interesting deposits of nodules are in the North Pacific lying in an east-west band between 6°N and 20°N and extending from 110°W to 180°W.[162] If alternate bands of 2° longitude were drawn over this general area, it can be said that half of the best mine sites, in principle, would be available for exploitation while the other half would be held in abeyance for future use.

A third method would be a discretionary decision of the Authority regarding general areas which might be made available for exploitation, therefore holding the remainder of the International Sea-Bed Area for future use. This approach is the one generally adopted by coastal countries for offshore hydrocarbon resources. The difficulty in applying this approach to the management of deep sea-bed resources is that knowledge about the precise location of high grade nodule deposits is limited to the few companies that are actively engaged in nodule exploration programmes.

In a more strict sense, resource conservation is aimed at the actual regulation of mining operations. The objective is to avoid wasteful mining methods which tend to be adopted when a company holds the mineral right over a very large property. In these cases, the company attempts to maximize short-run profits by mining only the highest grade ores leaving behind ore which would be normally considered of commercial recovery grade. However, existing knowledge of nodule mining technology is insufficient for the establishment of detailed regulations. The Authority, however, could set up minimum targets for nodule recovery below which no exploitation activity would be permitted.

The desirability of setting up these minimum recovery targets is illustrated by the examples in the paper "Pre-production manganese nodule mining activities and requirements".[163] In this paper it is estimated that with existing technology, nodule recovery might be as low as 9 per cent to a maximum of 35 per cent of the total volume of nodules in place. The Authority might wish to consider whether it would be in the long-run interest of the international community to permit nodule mining operations which might leave behind 91 per cent

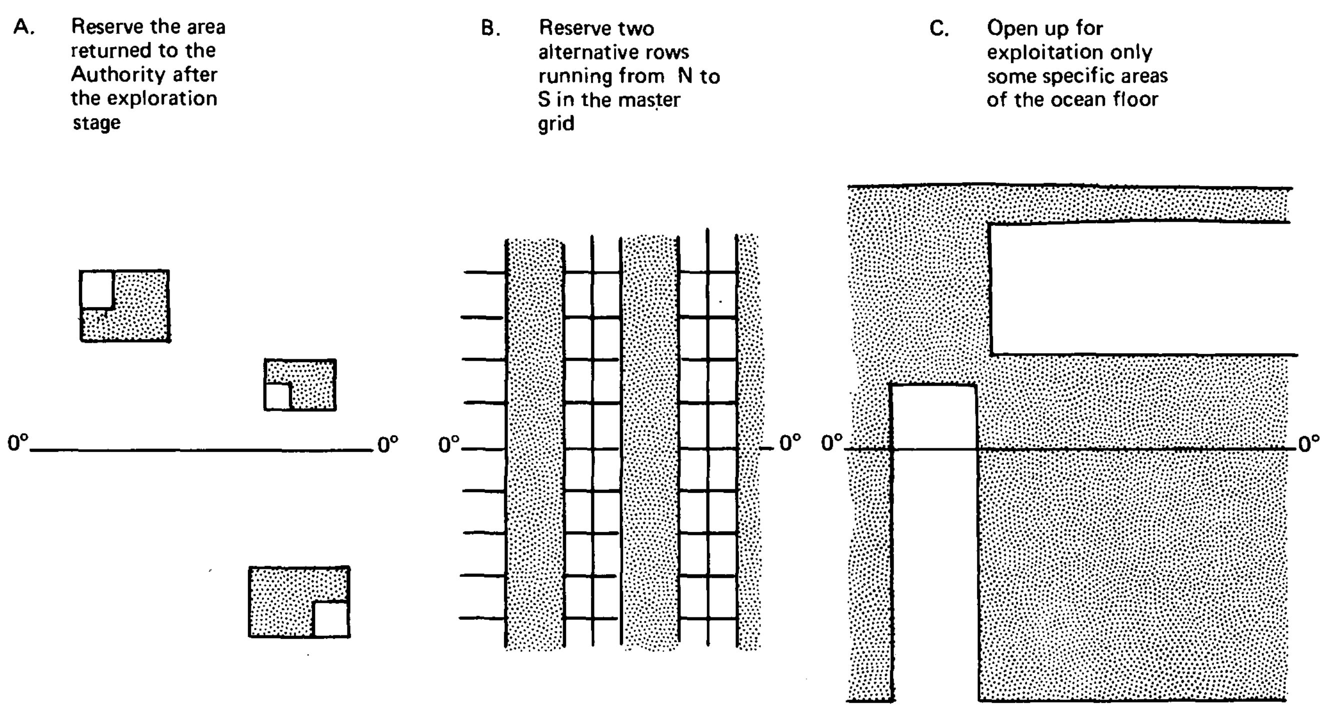
[162] D. R. Horn, B. M. Horn and M. N. Delach, "Ocean Manganese Nodules Metal Values and Mining Sites", Technical report No. 4, International Decade of Ocean Exploration, N.S.F., Washington, D.C., 1973.

[163] J. E. Flipse, M. A. Dubs and R. J. Greenwald, "Pre-production, Manganese Nodule Mining Activities and Requirements", *Mineral Resources of the Deep Seabed,* op. cit. in foot-note 13.

Figure 10

THREE POSSIBLE APPROACHES TO THE RESERVATION OF AREAS FOR FUTURE USE

(*The area shaded would be reserved for the future*)



of these important mineral resources. Recovery efficiency is a function of several factors, the most important of which are the percentage of total area that would remain unmined, the dredge efficiency and the sweep efficiency of the system.

The unmined area of a block depends on topographical barriers on the one hand and on nodule grade on the other. It is possible that part of an exploitation block might contain nodules below the cut-off grade in which case this area would not be worked over by the mining company. The paper suggests that 10 per cent of a mine site is likely to contain nodules below the cut-off grade.[164] It seems, however, that if the block size is not excessively large only a negligible proportion of the total area might contain nodules below the "cut-off" grade. The cut-off grade, of course, remains to be defined. As for the unmineable zones, which in the quoted industry paper are suggested to range between 15-25 per cent of the total area, the applicability of these figures would again depend on the size of the mine site. The larger the mine site—the paper considered mine sites as large as 750,000 square kilometres—the greater the likelihood of a significant proportion of the total area being covered with topographic barriers.

Dredge efficiency is the capability to collect the nodules lying within the sweep of the minehead. The industry paper uses three assumptions: 30 per cent, 50 per cent and 70 per cent. These assumptions probably reflect the capabilities of the mining systems under development by Deepsea Ventures and Kennecott. In the author's words: "At the present stage of development of the technology, it is unlikely that ocean miners will be able to approach a pick up efficiency of 100 per cent".[165]

The same could be said of the sweep efficiency. The industry paper works with assumptions of 45 per cent and 65 per cent of the total mine site. It can be visualized how difficult it will be to control the movement of a towed dredge head. This system will work like a giant vacuum cleaner with a suction head perhaps 15 metres wide (50 feet) dangling from the mine ship by about 5,000 metres of semi-flexible pipe. Given the currents throughout the water column, even with precise steering of the mine ship to a course exactly 15 metres parallel to the previous run, the mine head at the bottom could be sweeping a new row anywhere within a 150 metres path. One mining company, after several computer simulation exercises, was forced to conclude that the best procedure would be to simply sweep the mine site at random.

Given the stage of existing technology both dredge efficiency and sweep efficiency must be rather low. However, regulation of mining operations cannot be logically based on a level of technology which is some 5 to 10 years prior to actual commercial operations. It is obvious that considerable progress can be expected from the leaders of the industry, such as television monitoring of the mining operations, sophisticated guidance systems for the dredge head and other devices. It is also possible that mining systems with bottom crawling devices will become operational, thus increasing both pick up efficiency and sweep efficiency.

[164] *Ibid.*

[165] *Ibid.*, p. 655.

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Reports submitted by the United Nations Conference on Trade and Development

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NOTE BY THE SECRETARY-GENERAL OF THE UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

1. The secretariat of UNCTAD has prepared a number of reports, within its field of competence, on issues relevant to the business of the Third United Nations Conference on the Law of the Sea. The Trade and Development Board has requested that they be transmitted to that Conference, for consideration, and this note is submitted accordingly.

2. It should be recalled that the question of mineral production from the sea-bed first arose within UNCTAD as a result of General Assembly resolution 2750 A (XXV) of 17 December 1970, which requested the Secretary-General of the United Nations to co-operate with the United Nations Conference on Trade and Development and other bodies in order to:

"(*a*) Identify the problems arising from the production of certain minerals from the area beyond the limits of national jurisdiction and examine the impact they will have on the economic well-being of the developing countries, in particular on prices of mineral exports on the world market;

"(*b*) Study these problems in the light of the scale of possible exploitation of the sea-bed, taking into account the world demand for raw materials and the evolution of costs and prices;

"(*c*) Propose effective solutions for dealing with these problems."

3. In accordance with that resolution, the UNCTAD secretariat co-operated with the Department of Economic and Social Affairs of the United Nations Secretariat in the preparation of relevant studies, and reported on this co-operation to the Committee on Commodities at its sixth session. In the discussion of this subject at the Committee's sixth session, representatives of developing countries stated that they attached great importance to the subject-matter of General Assembly resolution 2750 A (XXV); that the co-operation envisaged in the resolution should be regarded as referring to UNCTAD at the inter-governmental as well as the secretariat level; that provision should be made for the Committee on Commodities to be informed of, and to discuss, developments in this field on a continuing basis; and that an opportunity should be provided for an examination of the matter at the third session of UNCTAD. Similar views were expressed at the eleventh session of the Trade and Development Board.

4. The UNCTAD secretariat initially carried out a preliminary over-all review of the main issues of international commodity policy arising from the potential production of minerals from the area of the sea-bed beyond the limits of national jurisdiction. The results of this review were incorporated in certain reports by the Secretary-General of the United Nations to the Committee on the Peaceful Uses of the Sea-Bed and the Ocean Floor beyond the Limits of National Jurisdiction appearing in documents A/AC.138/36 of 28 May 1971 and A/AC.138/73 of 12 May 1972[166] and were presented to the

[166] *Official Records of the General Assembly, Twenty-seventh Session, Supplement No. 21* and corrigendum, annex II, sect. 2.