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INDIA AND THE DEEP SEABED MINERALS
TECHNOLOGICAL CHALLENGES - ECONOMIC PROSPECTS

Report prepared for UNIDO

by

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Preface

The aim of this report is to focus on challenges facing Indian companies in deep seabed mining.

The report is divided into four chapters:

A brief presentation of the nodule deposits in the Central Indian Basin will be given in chapter 1: Ownership, size of deposits and formation will be dealt with.

The aim of chapter 2 is to give a brief evaluation of the status of the Indian nodule programme and the prospects for commercial exploitation. The aspects dealt with are background, today's situation, motives, time perspective for commercial exploitation, organizational challenges and possibilities for cooperation with other countries.

Chapter 3 describes the technology to be employed for exploration, mining, transport and processing of nodule deposits. Importance will be placed on identifying critical factors and conditions, and judging the need for improved or new technology in the various phases. Environmental aspects will also be dealt with. An evaluation will also be given of the economics of deep seabed mining.

The aim of chapter 4 is to place India's plans for commercial exploitation of nodule deposits in the Central Indian Basin in an international context. National programmes in Asia, Europe and North America will be presented and assessed. In addition to a description of on-going exploration, research and development work in the respective countries, an assessment will be given of the way in which activities are organized and financed, of the individual countries' motives for involvement, and of plans for commercial exploitation. The main purpose of the chapter is thus to assess the prospects for commercial exploitation of polymetallic nodules in general. We shall attempt to answer the following questions:

- When can commercial exploitation be expected to commence?
- Who will start, and why?
- How will first-generation projects be organized?

By request from UNIDO, particular emphasis has been attributed to chapter 3 and 4.

Jan Magne Markussen
Oslo, 27 June 1990

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CHAPTER 1

POLYMETALLIC NODULES IN THE CENTRAL INDIAN BASIN
RESOURCE BASE

Purpose

A brief presentation of the nodule deposits in the Central Indian Basin will be given here: Ownership, size of deposits and formation will be dealt with.

Registration of India as Pioneer Investor

India was registered as "Pioneer Investor" on 17 August 1987 by "the Preparatory Commission for the International Sea-Bed Authority and for the International Tribunal for the Law of the Sea" (PrepCom). India thus became the first country in the world to achieve status as Pioneer Investor in accordance with the 1982 United Nations Convention on the Law of the Sea, and was allocated exclusive rights for exploration and commercial exploitation of polymetallic nodules in an area of 150,000 square kilometers in the Central Indian Basin 1).

The Indian registration is interesting for several reasons. When the Convention was formulated, there were many who feared that only the rich and developed countries would be able to mine "the common heritage of mankind" as these deposits are called. India is by no means a typical developing country. Nevertheless, very few people outside India believed in 1982 that India would turn out to be the first country to achieve status as Pioneer Investor 2). A map showing the mine site or "Pioneer Area" allocated to India in the Central Indian Basin is presented on the next page.

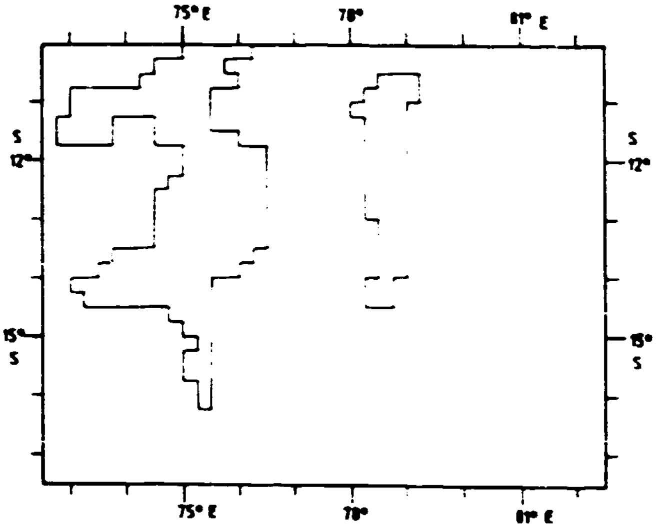
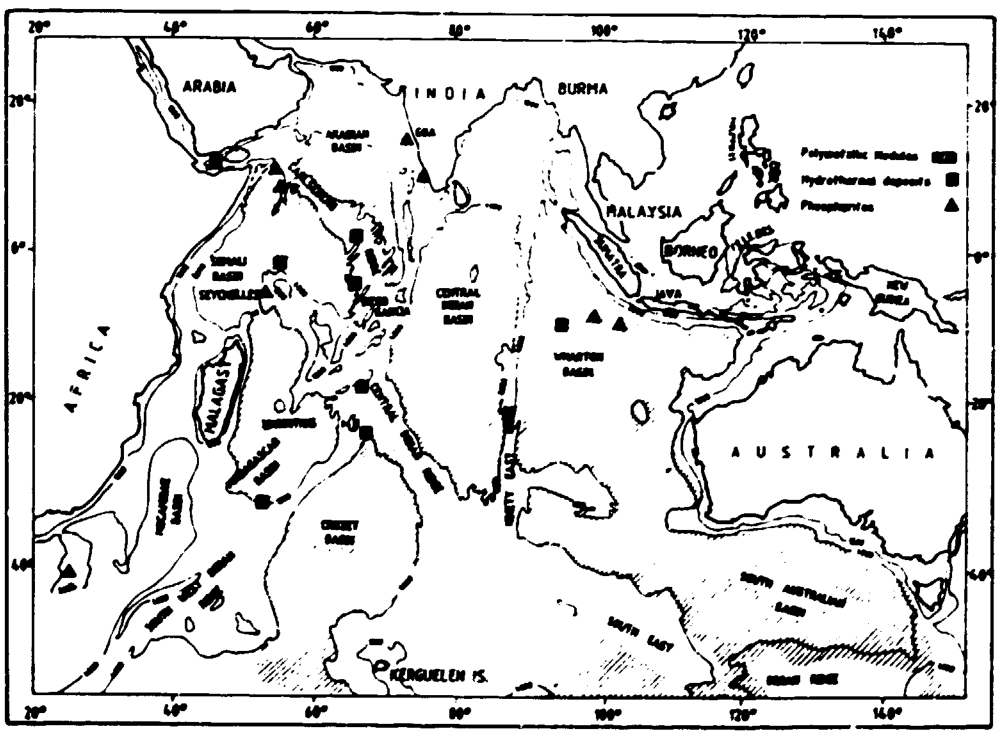


Figure 1: Map showing the Pioneer Area allocated to India 3).

Nodule Deposits in the Central Indian Basin

The Indian Ocean in general

Figure 2 shows distribution of deep sea minerals in various basins of the Indian Ocean 4):



It is assumed that about 10 million square kilometers of the Indian Ocean - to a smaller or larger degree - is covered with deposits of polymetallic nodules 5). There are nodules in all of the seabed regions, but density varies greatly within and between the different regions.

Central Indian Basin: Size of area, metal content and nodule density

Grades for potential economic deposits have been given in the range of 1.1-1.6% nickel, 0.9-1.2% copper, 0.2-0.3% cobalt and 25.0-30.0% manganese. Nodule density is indicated as 5-15 kg/m2 6)

The interesting nodule deposits of the Indian Ocean are situated in the Central Indian Basin in an area of 700,000 sq.km. between 10 degrees and 16 degrees southern latitude. Nickel and copper content is particularly high in a 300,000 sq.km. east west belt at 12-13 degrees south. Results from the Indian exploration programme show that the average content of nickel and copper in the nodule-rich belt at 12-13 degrees south is approximately 2,4% 7). Sea depth varies between 5,000 and 5,500 meters.

The high content of nickel and copper can be attributed to current conditions and presence of the mineral todorokite in the nodules 8).

The nodule-rich belt lies in the crossing between the eastgoing South Equatorial Countercurrent and the westgoing South Equatorial Current. When these two sea currents run together, cooler water of the equatorial undercurrent rises, leading to increased biological production in the surface water. There is thus an increased influx of biologically transported metals to the seabed.

The existence of todorokite is seen as a precondition for formation of commercially interesting nodule deposits, since this is the only mineral likely to contain high concentrations of nickel and copper.

The highest content of these metals is incidentally found where the seabed has sediment containing silica 9).

The nodule density in the area varies between 5 and 10 kg/m2 10).

Nodules in the Indian Ocean have an average diameter of 3-6 cm. They are very porous, containing water to the extent of one third to half their weight. Nodules are extremely fragile: they break easily and are crushed easily. They are formed by metals, coming both from seabed and seawater, covering a nucleus of sand, organic material, particles from other nodules, etc.

Comparison with Clarion-Clipperton nodules.

Commercially interesting nodule deposits are located in the Central Indian Basin and in the Clarion-Clipperton area in the Pacific between Hawaii and the US West Coast. Nickel and copper content is about the same in both areas. This is also largely true for manganese, whereas cobalt content is lower than in the Clarion-Clipperton area. Nodule density is also somewhat low, 5-10 kg/m2 as compared to 10 kg/m2. Nodule deposits in the Central Indian Basin appear sufficient for one or two first-generation nodule projects, whereas the corresponding figure for Clarion-Clipperton is ten. First-generation nodule projects are here defined as projects having an annual production capacity of 3 million tons of dry nodules over a period of 20-25 years 11).

Seabed conditions in the commercially interesting parts of the Central Indian Basin and the Clarion-Clipperton area are very similar. This can be of great importance for future identification of commercially interesting deposits. Increased knowledge of preconditions needed for formation of these deposits will naturally also facilitate the identification of such areas.

Notes - Chapter 1:

1) The former Secretary of Department of Ocean Development, Dr. S.Z. Qasim, describes the process like this: "In 1982, India was recognized by the United Nations Convention on the Law of the Sea as a Pioneer Investor in deep seabed mining. From then onwards, a massive effort was put in by India for the exploration of polymetallic nodules in the Central Indian Ocean, primarily to identify two mine sites (application areas) within the stipulated time fixed by the UN Preparatory Commission. The co-ordinates of the application-areas (2 areas of 150,000 sq. km. each and of equal commercial value) were determined by the end of 1983 and the application of India was filed with the Preparatory Commission in January 1984". The process of registration, however, was delayed because of overlapping claims in the Pacific between France, Japan, the Soviet Union and four industry groups. "After prolonged discussions, a basis for resolving the overlapping claims was found in August 1986. Since India's case was free from overlap, the Preparatory Commission accepted the details provided by India and registered India's application on 17 August 1987".

   The description is from: S.Z. Qasim and R.R. Nair (Ed.): "From the First Nodule to the First Mine Site - An Account of the Polymetallic Nodules Project", Department of Ocean Development, National Institute of Oceanography, New Delhi and Goa, May 1988, 51 pp.

2) Cf. chapter 4.

3) The map is from M. Sudhakar: "Ore Grade Manganese Nodules from the Central Indian Basin: An Evaluation", Marine Mining, Vol. 8, No. 2, 1989, pp. 210- 214.

4) The map is from: V.K. Banakar and V.N. Kodagali: "Nodules of the Central Indian Ocean Basin". Article published in S.Z. Qasim and R.R. Nair (1988) (cf. note 1)

5) H.N. Siddiquie, D.R. Das Gupta, N.R. Sengupta, P.C. Shrivastava and T. Mallik: "Manganese-Iron Nodules from the Central Indian Ocean", Indian Journal of Marine Sciences, Vol. 7, December 1978, pp. 239-240.

6) United Nations: "Analysis of Exploration and Mining Technology for Manganese Nodules", Graham and Trotman/United Nations, London/New York, 1984, 140 p.

   In this connection, it may be mentioned that polymetallic nodules contain some 30 metals, among which nickel, copper, cobalt, manganese, molybdenium, vanadium and titanium are considered to be of economic interest.

7) Personal communication with former Secretary of Department of

Ocean Development, Dr. S.Z. Qasim in 1985.

Sudhakar (1989) (cf. note 3) states that nodules in an area of the Central Indian Basin are characterized by high Mn/Fe ratios (mean 3.77), high Ni + Cu content (mean 2.41 percent) and high abundance (mean 7.48 kg/m2).

8) D.S. Cronan and S.A. Moorby: "Ore Grade Nodules from the Central Indian Ocean", Imperial College, London, 1982, 7 p.

9) Sudhakar (1989) (cf. note 3) states that "the results indicate that the nodules from siliceous sediments approximate the diagenetic end members of the series, as described in the Pacific, and are similar in composition to the north equatorial Pacific ore grade nodules. Siliceous sediments in CIB offer the possible sites for first generation mining".

Sudhakar presents the following table of concentration of nodules from two sediment provinces in the Central Indian Basin:

Concentration Maxima, Minima, and Mean of Manganese Nodules from Two Sediment Provinces in CIB

Parameter	Minimum	Maximum	Mean	S.D. ± of variation (%)	Coefficient
Mn	18.07[a] (13.15)[b]	33.58 (28.63)	26.05 (22.25)	3.52 (3.30)	13.51 (14.83)
Fe	4.94 (5.57)	13.62 (18.70)	7.73 (10.72)	2.67 (2.71)	34.54 (25.28)
Co	0.09 (0.12)	0.33 (0.43)	0.14 (0.21)	0.05 (0.06)	35.71 (28.57)
Ni	0.64 (0.44)	1.58 (1.54)	1.22 (0.92)	0.28 (0.22)	22.95 (23.91)
Cu	0.44 (0.27)	1.86 (1.27)	1.19 (0.685)	0.38 (0.25)	31.93 (36.50)
Grade (% Ni + Cu)	1.11 (0.71)	3.40 (2.66)	2.41 (1.61)	0.65 (0.45)	26.97 (27.95)
Mn/Fe	1.35 (1.01)	6.09 (5.14)	3.77 (2.24)	1.27 (0.80)	33.69 (35.71)
Cu/Ni	0.66 (0.48)	1.21 (1.23)	0.96 (0.73)	0.14 (0.15)	14.58 (20.55)
Abundance (kg/m²)	0.85 (0.72)	15.66 (13.69)	7.48 (4.68)	3.59 (3.25)	48.0 (69.44)

[a] Values above parenthesis are for Area S nodules; n = 45.

[b] Values within parenthesis are for Area R nodules; n = 44

10) Personal communication with Dr. S.Z. Qasim in 1985.

11) Jan Magne Markussen: "Polymetallic nodule deposits in the Indian Ocean", Newsletter no.2-1986, The Fridtjof Nansen Institute, pp. 12-31

CHAPTER 2

THE INDIAN NODULE PROGRAMME
STATUS AND PROSPECTS

Purpose

The aim of this chapter is to give a brief evaluation of the status of the Indian nodule programme and the prospects for commercial exploitation. The aspects dealt with are background, today's situation, motives, time perspective for commercial exploitation, organizational challenges and possibilities for cooperation with other countries.

2.1 Status of the programme

Background

Exploration for nodule deposits in the Central Indian Basin started in earnest in 1982. India's interest for deep seabed minerals dates back, however, to the mid 60s when Geological Survey of India (GSI) carried out the first preliminary studies. In 1979, scientists from National Institute of Oceanography (NIO) and GSI published a comprehensive analysis of the metal content of nodules in various parts of the Indian Ocean, the co-variation of different metals, rate of sedimentation, etc. 1). The analysis was mainly based on data which the Indian scientists had received from colleagues abroad. In the following two years foreign reports were also published, concluding that the Central Indian Basin probably contained economically interesting nodule deposits. The Indian research vessel "Gaveshani" of NIO carried out the first successful cruise for polymetallic nodules in 1981 in the Arabian Sea.

Department of Ocean Development (DOD) was set up in July the same year and DOD in consultation with other organisations identified "exploration of polymetallic nodules" as a major thrust area 2).

By 1982, the nodule deposits in the Pacific Ocean were explored far more thoroughly than deposits in the Indian Ocean. There were several reasons for that. Firstly, industrial groups and western research institutions realized relatively early that deposits in the Clarion-Clipperton area in the Pacific satisfied requirements for first-generation projects. Exploration work was therefore concentrated to this area. Secondly, exploration activities based in the United States have better access to the Pacific Ocean than to the Indian Ocean. Thirdly, many of the nations in the Pacific Region are characterized by advanced technology and a high level of economic development. The same does not apply for many of the nations in or around the Indian Ocean. More than half of the nations belonging to what is called the Third World are found in this area. The World Bank defines 30 of the 36 nations in the region as developing countries 3).

Today's situation

India has carried out a very comprehensive exploration programme in the Central Indian Basin; techno-economic analyses have been made; moreover India has progressed far in developing and testing methods for nodule processing.

The exploration programme has been led by NIO. Five ships have been used - two Indian vessels "Sagar Kanya" and "Gaveshani", a chartered Norwegian vessel "Skandi Surveyor" and two chartered British vessels. Most of the exploration activities have been carried out in the Central Indian Basin. Some exploration work has also been done in the Somali Basin and the Arabian Sea.

By the Summer of 1984 it was evident that India had succeeded in identifying commercially interesting nodule deposits in the Central Indian Basin. "Sagar Kanya" and Skandi Surveyor" have carried out the main work in this area. The work has included spot sampling by boomerang grabs; spot photography of the seabed; single beam echo sounding for bathymetry: and collection of bulk sampling by dredging for metallurgical testing. Two companies - Engineers India Limited (EIL) and Metallurgical & Engineering Consultants (India) Limited (MECON) - have also participated in the survey and exploration phase.

No comprehensive research and development efforts have been carried out so far on mining and transportation of nodules.

India has, as mentioned, developed and tested several methods for processing of nodules. NML-Jamshedpur, RRL-Bhubaneswar, Hindustan Zink Limited (HZL) and Hindustan Copper Limited (HCL) have been involved in this work. EIL has identified five potential processing methods suggested by these R&D centres:

Method:	R&D Center:
- Roast reduction ammoniac leach	(NML)
- SO roast leach	(RRL-B)
- Acid pressure leach without reductant	(RRL-B)
- Ammonia SO leach	(RRL-B)
- Acid pretreatment leach - pressure leach	(HZL)

India has not yet made any significant study on the environmental aspect of deep seabed mining 4).

India is, undoubtedly, well underway with the nodule programme. A great deal of further development and testing remain, however, before commercial mining can commence (the technological challenges facing India in deep seabed mining are described in chapter 3).

Supply considerations.

Supply considerations is the main motive for India's involvement in deep seabed mining.

Singh (1989) compares the projected cumulative world metal demands and the estimated global land resources. The comparison is presented below (in million tonnes):

Metal	Cumulative demand up to 2010	Global land Resources (in situ)	Ratio of global resources to cumulative demand
Manganese	398	2000	5.02
Cobalt	1.3	1.5	1.15
Nickel	29	54	1.86
Copper	406	460	1.13

Singh concludes that "it is clear that if a suitable factor is applied to convert in-situ resources to "recovered values", the available resources will reach a critical stage by (the year) 2010 unless additional resources are added up".

Singh also evaluates possible contribution from polymetallic nodules to projected Indian demands (cf. next page). (A project with an annual production of 3 million tonnes of nodules is considered). According to Singh's calculations, "cobalt production from a nodule project will be more than five times the likely annual consumption rate in the year 2010, while the nickel production will almost match the Indian demand. In the case of copper, production will contribute only about 10% of the current production from land resources. Import of copper will therefore have to continue even after it is produced from the nodule" 5).

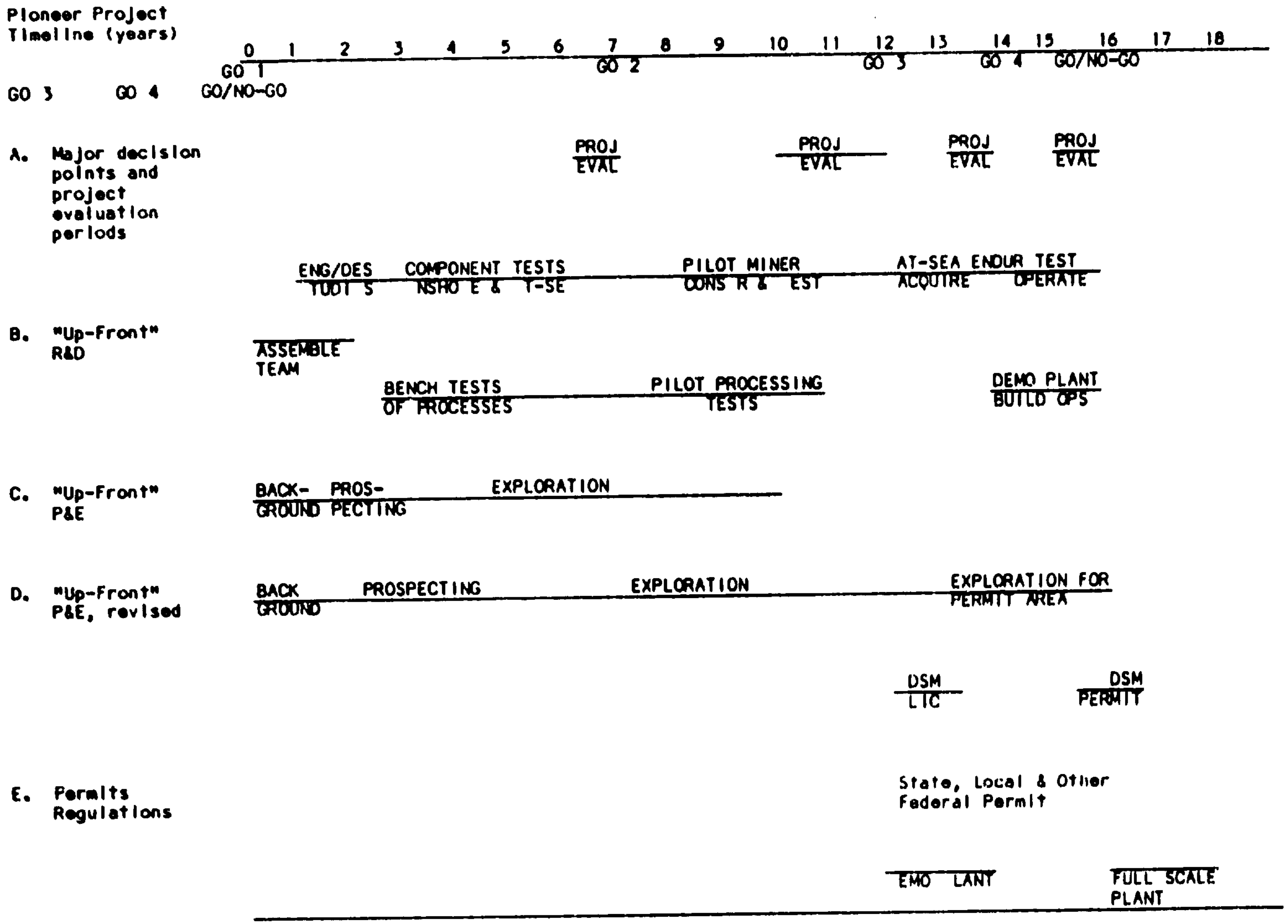
Metal	Current Production (kilo tonnes)	Expected consumption rate in 2010 (kilo tonnes)	Likely production of metals from 3 MTPA nodules plant (kilo tonnes)
Cobalt	-	0.6	3.2
Nickel	-	32.0	30.6
Copper	70	285.8	25.5

2.2 Prospects for commercial mining

Time perspectives

Generally it will take approximately 8 to 10 years from the time a country or company completes preliminary testing of mining, transport and processing technology, until a total concept has been developed ready to be applied on a commercial scale. The technology has first to be tested on a small scale, the deposits have to be explored in detail and the operation must be minutely planned for optimal utilization of the equipment 6).

Massachusetts Institute of Technology (1983) gives a description of assumed events in a pioneer venture and the possible timing of these events 7):



Organizational challenges

India has, as mentioned, carried out a comprehensive exploration programme; techno-economic analyses have been made; and India has progressed far in developing and testing of methods for nodule processing. Until the present, activities have been at the research and report stage. With the exception of EIL and MECON therefore, those involved in the Indian nodule project until now have primarily been research institutes.

India is now facing a new stage of development - preparations for test mining and commercial mining. This phase will require a new type of competence, and there will be a need to make organizational changes. It is of vital importance to introduce organizations with prior experience in planning and execution of major projects. India's own industry and shipping ought therefore to play a greater part in future developments of the programme. Future plans should use the experiences gained in the operation of for instance ONGC.

The research environments will retain also in future their central position in the programme. New actors will enter the research side as a result of the new orientation in the programme. The Central Mechanical Engineering Research Institute is an instance of a new institute now actively involved in the programmme.

The nodule programme is a national project. It is of importance that further development of the project will be characterized by close cooperation between India's authorities, industry, shipping and research. The necessity has arisen to found a commission or entity to take care of the coordinating responsibility for further development.

The great challenge will now be to formulate clear objectives for the project, in the short as well as the long term, decide the means to be employed in order to ensure fulfillment of the objectives, and establish an effective organization capable of taking care of the coordinating responsibility for the project.

Cooperation with other nations

Finally, let us briefly consider the need for, desirability of and potential for, cooperation with other nations.

Re: The need for cooperation

The reason organizations cooperate is to benefit from mutual knowledge and competence. The benefits derived will depend largely on three factors: timing, organization and cooperative partner.

Exploration and development of technology for exploitation of deep seabed minerals are characterized by great technological challenges. With 11 years' experience of matters concerning deep seabed mining, I am of the opinion that no organization or country can be 100% on its own in this field. There is so to speak no world champion in the sense that a single company or nation leads in all areas. As we will see in Chapter 4, developments in this area are moving in the direction of steadily increasing international cooperation.

India has also cooperated with foreign companies and countries in her nodule programme. When the necessity has arisen, India has purchased foreign technology and know-how and chartered foreign vessels. India has however at all times been in full control of the cooperation. Generally speaking, Indian supplies have been given preference when this has been possible. This policy has proved to be a wise one while the project has been under construction.

In the next phase of the project too, India will be dependent on competence from abroad. While India has an excellent point of departure in the areas of exploration and processing, she will be partly dependent on other countries when it comes to technology for mining and transport.

Re: Desirability of cooperation

In this context it will be natural to assess the desirability of increased international cooperation. In Chapter 4 the cost factor is employed as an argument for stronger international cooperation. Programmes that are purely national tend to have to 'reinvent the wheel' and thus prove very costly.

However, the re-invention of the wheel is not necessarily a bad policy in every case. The building up of basic competence is essential if a country is at all times to ensure the maintenance of own national control of the project. This strategy was successfully followed by Norway amongst others in connection with exploitation of national petroleum and gas reserves. India has followed a similar policy in that area.

Re: Potential for cooperation

Many countries and companies show an active interest in establishing closer cooperation with India in the area of deep seabed mining. The reasons for this are several:

In addition to the obvious fact that India represents a market, a number of countries and companies would like to build up competence in collaboration with India. The actual exploitation on a commercial scale of deep seabed minerals will probably begin in earnest around the year 2005. India has the potential of being among the first countries to exploit the nodule deposits commercially. Countries and companies collaborating with India will therefore be able to develop competence that will provide a competitive advantage when commercial production starts up in earnest.

Since India commenced its nodule program relatively early, the country is in a situation where it can pick and choose between possible collaborators. This ought to enable them to procure prime technology at a favourable price. The situation would have been completely different should India have postponed commencing her project until after production in the Pacific had started. In that case the Indians would probably have had to pay a much higher price than the case is in the actual event.

The nodule programme will place India in the club of industrially advanced countries mastering deep sea technology, and also give synergetic effects for other Indian programmes involving advanced technology. Indian companies will be in a position to benefit from the spinoff effects of the program.

Even though there may be disagreement as to the actual scope of co-operation with foreign countries, I think that a majority of Indians will no doubt be of the opinion that such a cooperation will be wise as well as necessary. However, strong national basic competence will be an essential precondition for ensuring that cooperation with other countries succeeds. Timing, organization and choice of collaborating partners will therefore be of decisive importance.

Notes - Chapter 2

1) H.N. Siddiquie, D.R. Das Gupta, N.R. Sengupta, P.C. Shrivastava and T. Mallik: "Manganese-Iron Nodules from the Central Indian Ocean", Indian Journal of Marine Sciences, Vol. 7, December 1978, pp. 239-240.

2) Department of Ocean Development and Confederation of Engineering Industry: "Proceedings from Workshop on Opportunities in Deep Seabed Mining", 16th September 1989, New Delhi, pp. 1-3.

3) Jan Magne Markussen: "Polymetallic nodule deposits in the Indian Ocean", Newsletter no.2-1986, The Fridtjof Nansen Institute, pp. 12-31

4) This section is based on Department of Ocean Development and Confederation of Engineering Industry (1989) (cf. note 2); S.Z. Qasim and R.R. Nair Eds.:"From the First Nodule to the First Mine Site - An Account of the Polymetallic Nodules Project", Department of Ocean Development, New Delhi, 1988, 51 pp.; J.M. Markussen and S. Sen: "India and the Seabed Minerals - What Now?", Fridtjof Nansen Institute, International Challenges Vol. 8, No. 1-1988,

5) T.R.P. Singh: "Metals in Polymetallic Nodules and Their Market Projections", 12 pp., published in Department of Ocean Development and Confederation of Engineering Industry (1989) (cf. note 2).

6) J.M. Markussen: "Commercial Exploitation of Polymetallic Nodules - When, Why, Who and How", Forthcoming article in Materials and Society (a Pergamon journal), New York, 1990, 24 pp.

7) J.D. Nyhart et al.: "A Pioneer Deep Ocean Mining Venture"; Massachussetts Institute of Technology, Boston, 1983, 255 pp.

CHAPTER 3

EXPLOITATION OF NODULE DEPOSITS TECHNOLOGICAL CHALLENGES

This chapter describes the technology to be employed for exploration, mining, transport and processing of nodule deposits. Importance will be placed on identifying critical factors and conditions, and judging the need for improved or new technology in the various phases. Environmental aspects will also be dealt with. An evaluation will also be given of the economics of deep seabed mining.

3.1 TECHNOLOGICAL CHALLENGES

Is the technology of today the technology of tomorrow?

The basic technology for exploration, mining, transport and processing is known. Today's technological concepts for exploration, mining, transport and processing of deep seabed minerals are a result of comprehensive research and development programmes. Today's technology has, however, two major characteristics:

- Assumptions regarding reliability and efficiency of today's concepts of mining and processing are based on theoretical analyses and testing on a minor scale.

- The technical concepts of today are a result of research and development activities in deep seabed mining; not least they are a result of general research and development in other fields. Todays's concepts show that seabed mining engineers have known how to apply to their own area the elements of available conventional technology and know-how in the offshore oil sector, shipping and land-based metal production. The question arises: Have these engineers managed to free themselves from conventional lines of thought and think afresh in order to develop technology precisely fitted for the purpose? This represents the principal challenge for the engineers in the years to come.

In the future, the focus will naturally be on improvement and development of technology for effective and reliable total systems. The driving forces behind this development will be private companies as well as governments. Importantly, it is no longer only the needs of the advanced industrialized countries that are taken care of. The developing countries are well represented here and may well prove a vital driving force in further developments in this field.

Further technical development will be a result of the interplay between the traditional forces of 'Technology Push' and 'Market Pull', in that benefit will be derived from the general technological development and from development particularly for deep seabed mining. The Market Pull part will of course increase in importance the nearer we approach commercial exploitation. In addition there are driving forces of a more socio-economic and political nature, often known as 'Pull of Society' factors 1).

How far removed will tomorrow's technology be from that of today? Even though the basic technology for exploration, mining, transport and processing is known, there is every reason to expect radical changes in many areas. For example, present exploration technology is both time-consuming and costly. Moreover, any nation or company which manages to develop environmentally acceptable and cost-efficient concepts that result in greater integration of the mining and processing system, thus making at-sea processing possible, will make a breakthrough both in technological and in financial terms.

Readers guide

The next five sections of this chapter contain brief presentations of the technology to be employed for exploration, mining, transport and processing of nodule deposits. The focus is on identifying critical factors and conditions, and judging the need for improved or new technology in the various phases 2).

A "Work Breakdown Structure" (WBS) for a nodule mining project is presented in Appendix A, with the main phases split up into subphases. Exploration, mining, transportation, shore terminal and process plant are all divided into five levels. In addition there is a section on project support divided into four levels. The Work Breakdown Structure should be studied parallel with the text.

Let us then turn to the presentation of technology.

Technological challenges - exploration.

The selection of a mine-site for nodule mining operations may be conducted in two phases: prospecting (pre-survey) and exploration (detail-survey). During the prospecting phase, a mine-site is delineated on the basis of ore abundance, ore grade, soil characteristics, topography, etc. Hull mounted equipment is used to allow high speed surveying. The second phase - exploration - comes prior to and during commercial operations. In this phase, a second round of seabed mapping is conducted, which is similar to, but more intensive than that of the first phase.

Prospecting (Pre-Survey)

The prospecting phase consists of a programme of resource assessment in a large area of the ocean. The purpose is to obtain an overview of the occurrence of polymetallic nodules, using a minimum of expensive ship time. Here, continuous seismic profiling and echo sounding will provide stratigraphic and bathymetric information, while "free-fall" type grab samplers, fitted with still cameras, will provide samples and photographs for statistical analyses. In prospecting, the aim is to identify potential mine-site(s) of commercial quality 3).

Exploration (Detail-Survey)

The aim of the exploration phase is to map in detail the potential mine-site selected by the prospecting phase. For exploration, the vessel will be outfitted with more specialized instruments and handling equipment. In addition to hull mounted instrumentation, a deep towed instrument carrying platform will be deployed to provide accurate data of seabed topograhy and soil composition.

The further evaluation of the mining area includes:

- Oceanographic and environmental studies.
- Detailed studies of ocean floor topography.
- Variations in nodule coverage and composition.
- Geological and geotechnical investigations.

Among the especially interesting conditions, I may mention:

Re.: Ocean environment mapping.

Special instruments are in use for meteorological and oceanographic data collection:

- current and wave records

- wave data buoys
- weather stations
- other equipment for hydrographic data collection, data transmission and real time monitoring and analysis of data.

Re.: Seabed surveying and nodule sampling/investigation

This phase entails, inter alia, deep towing of acoustical instrument packages and sediment sampling. The system will include both deep-towed side-scan sonar and sub-bottom profiler and box corer and "free-fall" type grab samplers.

Re.: Resource mapping

Resource Mapping is carried out by towed high resolution side-scan sonars, towed multibeam echo sounders, seabed sampling and observation by TV-camera from remotely operated vehicles. It is important to know at all times where the sensors are with respect to the surface vessel and with reference to geodetic coordinates. Hydro-acoustic systems are used to provide position reference of the subsea sensors during their operation, and to document the distance (altitude) above seabed and combine this with depth sensors.

Re.: Sampling of sediments.

Several types of devices can be used to obtain such samples:

- Grab type samplers. Free-fall grab sampling has been applied extensively to nodule exploration.
- Corers, long hollow cylinders, are used to penetrate the ocean bottom and encase a sample of the sediment penetrated.
- Dredges are elongated boxes, pipes or bags which are dragged slowly across the sea floor.
- Box corers are thin walled, bottomless metal boxes which are driven vertically into the sea floor. After penetration, a heavy blade or spade rotates downwards, enclosing the bottom of the box. The box is raised and the sample (core) retrieved.

These sampling methods allow for more detailed investigation of the nodules and the soil characteristics of the mine-site.

Special conditions related to the Central Indian Basin:

Re.: Survey vessel equipment - satellite navigation.

Both Omega and satellite navigation can be used in the Central Indian Basin today. The Omega system provides continous coverage with an accuracy of 4,000 meters and with 95 per cent repeatability.

By using Transit satellite navigation the obtained accuracy will be within 200 meters and repeatability 95 per cent. However, at these latitudes satellite passes are less frequent than what is required to ensure sufficient updating of survey positions.

GPS satellite navigation will increase accuracy to less than 100 meters, but coverage is limited to 6 hours a day. By using differential GPS, an accuracy within 10 meters can be obtained. Coverage will, however, still be a limitation. To obtain this accuracy we presuppose that landbased reference stations will be erected in the Maldives and in the Chagos Archipelago for linking signals.

By the end of 1991/early 1992 the GPS system will have been developed to provide 24-hour coverage. This will be significant to the survey operation, unless the authorities decide to limit the use of the system due to naval considerations.

Re.: Seafloor transponder chain for positioning of deeptowed sensors

Acoustic positioning and navigation of underwater equipment is needed during all phases of deep-sea surveying - from seafloor topography and resources mapping, throughout all aspects of the mining operation:

- Deployment of seabed transponders to mark the actual area of interest
- Survey vessel navigation in the area.
- Positioning of deep-towed instrumentation to collect geophysical data.

A similar seabed navigation chain will be required when pilot mining operations commence:

- Mining vessel navigation in the area.
- Deployment of deep-sea mining equipment.
- Positioning of the seafloor mining head/bottom unit inside the areas marked by the seabed transponder array defining the local mining area.
- Relative positioning of the bottom unit with respect to collector/pump station and riser connecting seafloor equipment with mining vessel.
- Measurement of riser vertical position and inclination using transponders and inclination sensors. Heading sensors may be required if rotation is anticipated.
- Positioning of mining vessel.
- Retrieval of deepsea mining equipment to surface.
- Re-entry of mining site.
- Location of "lost" mining equipment.

Re.: Equipment for seafloor investigation.

Designers of mining equipment will need data on seafloor soil composition, especially with respect to the sheer strength of the soil. The final design will depend largely on the geotechnical parameters of the seafloor soil.

The future technology for exploration of deep seabed minerals.

The deep seabed covers an area twice the size of the land area. As of today, only a very small portion of the total deep seabed has been surveyed for deposits of deep seabed minerals. Exploration for deep seabed minerals is both time-consuming and costly, due to the need for a lot of equipment of many types.

Next-generation technology in this area will probably be characterized by a high degree of integration and with many areas of utilization. By "high degree of integration" is meant multifunction equipment. When it comes to exploration of e.g. nodules, the equipment should be capable of registering topography, density and metal content. "Many areas of utilization" means that it will be desirable to develop equipment well-suited for exploring various forms of deep-sea minerals. The equipment might conceivably also be used for exploration of shallow water deposits, for other offshore purposes and to carry out measurement tasks for environmental purposes.

The Fridtjof Nansen Institute and the Norwegian company Simrad Subsea AS plan to carry out a feasibility study of the above mentioned "Next-Generation Exploration Technology-Concept" in 1991. Technical feasibility, market potential and possibilities for international R&D cooperation will be analyzed. The two organizations would welcome reactions from India regarding possible cooperation 4).

Technological challenges - mining

Mining Concepts

In principle there are three different types of mining systems:

- Hydraulic and pneumatic mining systems.
- Remote controlled mining shuttle system.
- Continous line bucket system.

Re.: Hydraulic and pneumatic mining systems.

Around 1980, three industry groups performed integrated tests of these systems in the Clarion-Clipperton area in the Pacific (cf. Chapter Four). The systems were tested at water depths around 6,000 meters. The testing must be described as very successful.

The mining of nodules with these systems will require steel pipes with a total length of approximately 6,000 m. The pipe must have a diameter of approximately 30 cm., and be equipped with pumps at regular intervals. The mining vessel will have characteristics resembling those of a drilling ship, with a moon-pool and gimbals for wave compensation in the riser pipe, and equipment for deployment and retrieval of the bottom unit and the pipestring. The mining vessel must be equipped with a dynamic positioning system, with side thrusters fore and aft. This system will receive position data from satellite navigation systems and acoustic reference systems for steering the bottom unit. The bottom unit will contain a mechanical device for nodule collection. This unit must be capable of collecting nodules lying on the surface, as well as those buried in the upper layers of sediment. The nodules will then be washed and crushed before being fed into a buffer storage unit. This unit, combined with the possibility of varying the velocity and direction of the bottom unit, will increase system efficiency.

Re.: Remote controlled mining shuttle concept.

This system will be based on a set of mining shuttles in continuous movement between the surface vessel and the seabed. A shuttle, with e.g. 1,500 tonnes of water displacement, will dive from the surface with the required ballast. Arriving on the seabed, it will discard part of its ballast and land on the soft sediment. From the landing point, the shuttle will be propelled by Archimedes screws or a belt system, and harvest the nodules with mud separation and tank storage. During this operation, ballast will be gradually dumped in order to adjust buoyancy. When the shuttle is filled, remaining ballast will be discharged, providing sufficient buoyancy for the return to the surface. Ten to twenty shuttles will operate around a surface platform, which could be a very large (500,000 to 700,000 tonnes) vessel, open at the stern with an internal harbour to handle the shuttles. When surfacing, the shuttles will be recovered by two smaller ships (1000 tonnes), using remote-controlled vehicles guiding the shuttles to the mother ship. After unloading of nodules, refueling and reloading of ballast, the shuttle will be launched through a moon-pool.

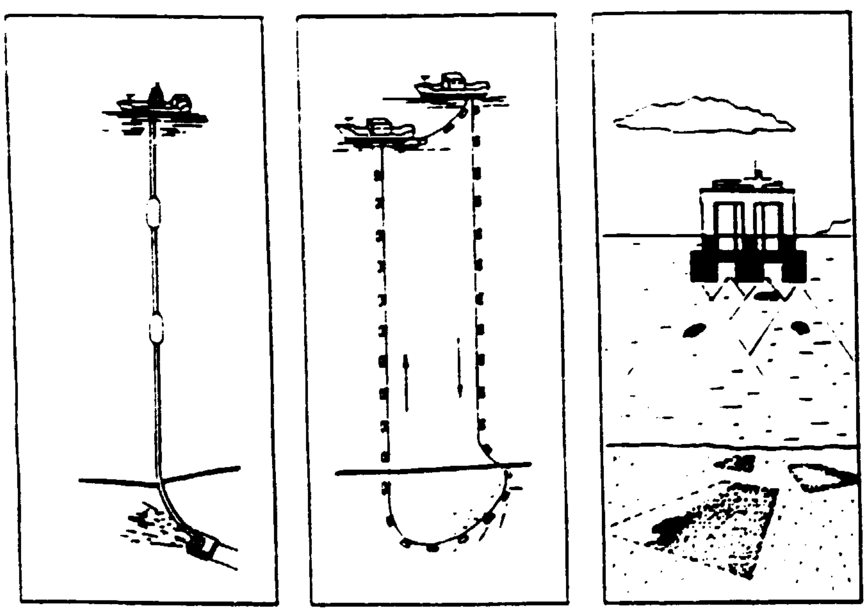
French organizations made comprehensive studies of the shuttle mining concept between 1980 and 1984. At the end of the R&D-period, they concluded that the concept was technically feasible, but not economically viable. The French programme was thereafter reoriented to the pumping system. The shuttle concept is interesting, as it provides greater flexibility than the traditional pumping concept, and should be regarded as a possible future generation system.

The third concept - the continous line bucket system - is cheap in operation, but has extremely low efficiency. The system is not regarded as commercially interesting mining system. The three different mining systems are illustrated in Figure 1.

Figure 1:

Mining systems

- Pumping
- CLB
- Shuttle



Presentation of a mining system for polymetallic nodules.

In this report, the focus will be on the hydraulic mining system with an annual production capacity of 3 million tonnes of dry nodules.

This mining system can be divided into six subsectors:

- The mining vessel, including navigation, control and dynamic positioning system.
- Handling and stowage equipment.
- Dredge pipe and bottom hose, including pumping system.
- Bottom unit/collector.
- Acoustic reference and navigation system.
- Ore handling system.

Re.: Mining vessel.

The mining vessel has a surface support function for the actual mining operation on the ocean floor. The vessel must be equipped with necessary equipment for handling of the bottom unit, navigation systems, a dynamic positioning system and support facilities for the crew. Buffer storage capacity for mined nodules may be incorporated, to enable continued mining when no transport vessel is present and as a contingency against any delay in transport arrangements. Finally the mining vessel must be equipped with a system for transferring nodules from the miner to transport vessels at sea. The types of ships suitable for use as mining vessels are limited, choice being mainly dependent on the lifting system. Possible vessel types are: monohull vessels like today's drill ships, multihull vessels or semi-submersible platforms.

Typical vessel characteristics would be:

- LBP	240 meters
- Beam	44 "
- Hull depth	17 "
- Draft	12.8 "

- Loaded displacement	106,000 metric tonnes
- Cargo deadweight	76,000 " "
- Mining equipment	11,200 " "
- Light ship displacement	19,300 " "
- Shaft horsepower	21,000 diesel electric
- Sea speed	14 knots

With an assumed annual production capacity of 3 million tonnes of nodules, two such vessels would be required.

The mining vessels could, as mentioned, be configured in a manner similar to conventional deep-water oil drilling ships. The ships must provide space for the pipestring and pump system, and for the pipe handling system and the heave compensation platform. The vessels must have storage capacity, so that mining can proceed in the absence of the ore carriers, or if sea conditions prohibit transfer. A "moon-pool" of, e.g. 12 x 15 meters must be provided, as well as accommodation for ship and mining crew (80 persons).

Main propulsion, as well as manoeuvring, mining, ballasting and ore transfer power will be supplied by multiple diesel-engine driven high voltage AC generators. Each mining ship will be equipped with dynamic positioning systems, including two main propellers and thrusters fore and aft 5). The navigation and communication system will include satellite, gyrocompass, acoustic systems, etc.

Re.: Handling and stowage equipment.

Handling and stowage equipment for the mining equipment on board the mining ship will include a 25 ton, 20 m. outreach bridge on a pedestal crane for launching and retrieval of the collector. Also included will be winches and racks for handling the hose used to connect the collector to the dredge pipe, handling in-line dredge pumps, dredge pipe rack, pipe transfer system, upper and lower derrick, gimbal platform, pipe lowering/lift system, and the heave compensation system.

Re.: Dredge pipe, bottom hose and pumping system.

The capability of the system to raise nodules depends on various factors. The most important of these are the following: Upward velocity in the pipe must be sufficient to keep the nodules in motion. The volumetric concentration of nodules and silt in the water must be acceptable to the pump when running, and must not cause blockage when the pumps are stopped and the mixture gradually drains down the pipe, to be replaced by seawater. Volumetric concentration will be usually about 10%, but some sources have indicated that a higher value seems feasible. Pipe diameter is dictated by production requirements, handling possibilities, drag values, and the limits of stress caused by all applied forces, including the mass of the pipe itself. In general, the pipe has to be protected from stresses caused by ship oscillation, so the top end must be secured by gimbals.

Pipe system design and dynamics are complicated, and considerable effort has been devoted to research and development. Work has mainly been concerned with the dynamic behaviour of an elastic pipe, and includes studies on tension, torsion, bending stresses, fatigue resistance, vibration and control of the system.

As mentioned, two different lifting systems may be employed: the pneumatic system (air-lift) and the hydraulic system (in-line pumps). Pipestring designs for the air-lift or in-line pump systems are broadly similar. In the case of the air-lift system, compressed air is fed down the pipestring through an attached air supply pipe. This compressed air is injected into the pipeline at intervals, producing a pumping action, due to the increased buoyancy of the slurry.

In the in-line pump system, pumps deployed along the length of the pipestring provide an impetus for nodule uplift.

The highest wear-and-tear factor for the pumps would result from the transport of uncrushed nodules, averaging 3-5 cm in diameter, and the impact of these on the pump blades. In this respect, the lowest and most inaccessible pump in the system would be the one most affected. Nodules will, however, probably be washed and crushed at the seabottom, thus reducing the wear factor considerably. The other major problem associated with electrical pumps is the electrical control and switching of the pumps.

One advantage of in-line pumps over the air-lift system is that the former system is considered to be at least 40-50% less energy intensive. Another major advantage is that far greater control can be attained over internal pipe flow, and thereby possibilities for reducing internal wear and some of the vibration.

Typical characteristics of the dredge pipe could be as follows:

- Length	5,500 m.
- Size	30.5 cm (12") inner diam. (constant)
- Couplings	Clamp type
- Material	High strength weldable steel
- Thickness	12.7 mm (1/2") minimum with stepped increases
- Pipe weight	approx. 1,045 metric tonnes
- Pipe weight with joints	approx. 1,300 metric tonnes

Each section of the pipe will have a length of approx. 30 meters. The soft connection between the dredge pipe and the collector is provided by an approx. 350 m. long crush-resistant high tensile hose, with an inner diameter of 30.5 cm (12"). The hose is supported above the bottom by buoyant fairing, and provides a cable-way for the cables going to the collector.

The pump system selected could consist of three multi-stage, motor-driven, mixed flow pumps, located in the upper two thirds of the dredge pipestring. They must then be configured to pass through the dredge pipe handling system on the gimbal platform.

Re.: Bottom unit/collector.

The collector unit must be designed for maximum efficiency in scooping up nodules from the seabed. In order to mine nodules efficiently from the seabed, the collector unit should have the following capabilities:

- Collect a high percentage of the desired size of nodules in a specified area.
- Reject nodules which are too large, and minimize retrieval of undesired elements.
- Move along the seafloor with low drag.
- Forward velocity should be kept at a level at which a minimum of sand and silt are disturbed and sucked into the transfer pipe (2-3 knots).
- Possess the ability to collect repeatedly and retain nodules in a hostile environment on the ocean floor.
- Possess the ability to encounter repeatedly and negotiate adverse topographical features (cliffs, vertical walls) and/or obstacles on the ocean floor.
- Represent easy production, at a corresponding relatively low cost.

Numerous possible designs and design configurations have been suggested for the nodule collector. The choice of the optimal width of the dredge head may prove difficult. The width of the collector unit needs to be small, so as to guarantee maximum pick-up contact with a possibly undulating seabed. This in turn dictates that forward pick-up velocity should be high, so as to compensate for width limitations, and this again entails an increased hydrodynamic drag from both dredge head and pipestring.
A typical collector would be approximately 20 m. wide.

Re.: Acoustic reference and navigation system.

The sweep efficiency of the mining system, i.e. the share of the mining area covered by the collector, will largely depend on the capabilities of the positioning system. Deflection of the 5,500 m long dredge pipe may be considerable, and position requirements could be fulfilled using a local acoustic reference system on the seabed. This system is based on hydro-acoustic interaction between an array of transponders, with accurate position relative to each other on the seabed, and an interrogating transceiver unit. The operational range depends on accuracy, the transmission properties of the sea, frequency, etc.

During the mining operation, various underwater navigation tasks have to be performed 6):

- Acoustic positioning of the nodule collector with respect to a predeployed acoustic transponder array, defining the local mining area.
- Relative acoustic positioning of the nodule collector with respect to a subsea pumping station and pipeline connecting subsea equipment and surface vessel.
- Measurement of pipeline vertical position and inclination, using acoustic transponders and inclination sensors. Heading sensors may be required if rotation is anticipated.
- Positioning of the surface vessel with respect to subsea transponder array, subsea pumping station and nodule collector. Position data will be input to the vessel's dynamic positioning system.

Re.: Ore handling equipment.

An ore handling system is required for the nodules from the moment they appear on the surface and until they are transferred to the ore transport ship.

This arrangement will include a hose and a pipe system to accommodate relative ship/gimbal platform movement while transferring the slurry to a separator, from where the water is returned to the sea. The nodules could then be deposited on a conveyor system, which would distribute them to the specially designed ship holds. For transfer to the transport ship, the nodules are removed from the ship holds by reclaimers which deliver them to the stern of the mining ship, where they enter a slurry system, which transfers the nodules to the ore transporter. A hose to transfer fuel from the transport ship to the mining vessel is included in the system.

Technological challenges - transport

After being collected on the ocean floor, and transported to the mining vessel, nodules must be shipped to the processing plant onshore.

Because of the specific gravity of the nodules, which is close to 2, the vessels for transporting the nodules from mine-site to the process plant onshore are similar to ore carriers or bulk carriers. Ore carriers are deadweight limited vessels, usually limited in size by the draft restriction of the port in question. The marine transport system includes all systems required to carry the nodules from the mineship to port.

The main difference between nodules and other bulk cargoes is that nodules are loaded at sea, in a harsh environment.

Transport of nodules from the mine-site to the processing plant is a critical operation. The whole transport system requires careful logistic planning to determine the number, size and main characteristics of the ships, and the amount of store materials required at mine-site, in port and at the plant.

The actual ship type and necessary equipment needed for cargo handling can to some extent be regarded as standard well-known technology. However, special equipment necessary for at-sea transfer of nodules, navigation and instrumentation required to keep the ships close together during transfer must be developed.

Several methods for transfer of nodules are possible. The mining vessel may have no storage capacity, thus requiring the permanent presence of a transport vessel. The mining vessel may have some storage capacity, and the transfer operation may then take place independently from mining, at least over shorter periods. Transfer rate must then never lag behind the rate of mining.

Fuel, water and supplies must also be transported from shore to the mining ship at site.

Typical characteristics of transport ships would be:

Length (B.P.)	230 meters
Beam	37 "
Depth	18.7 "
Draft	12.7 "
DWT	67,000 metric tonnes
Shaft horsepower	18,700 HP
Speed (loaded)	14.3 knots
Crew	32 persons

Assuming an annual production capacity of 3 million tonnes of nodules, four such ships will be required, two transport ships for each mining vessel.

Special conditions:

Re.: Nodules Transport

General assumptions, uncertainties and input from other areas have to be evaluated:

- volumes
- cargo consistency
- operating conditions
- weather statistics
- significant wave height
- wind
- temperature
- seasonal monsoon
- operation days
- weather
- maintenance/breakdown of equipment and vessels
- logistic
- round trip calculations (days)

Re.: Transfer to transport vessel

The necessity of transferring nodule ore and other items at sea gives rise to multi-faceted engineering and operational problems. The approach must address the following functions, among others:

- buffer storage capacity
- configuration between vessels at site
- availability of vessels positioning systems
- vessels propulsion system
- actual transfer system

Two key operational parameters are the availability of the mining ship and the availability of the transfer system to the mining system. The mining vessel must have high mining-site availability, because of the inverse relation between availability and required production capacity of the mining system - the higher the availability of the mining system, the smaller its production capacity requirement.

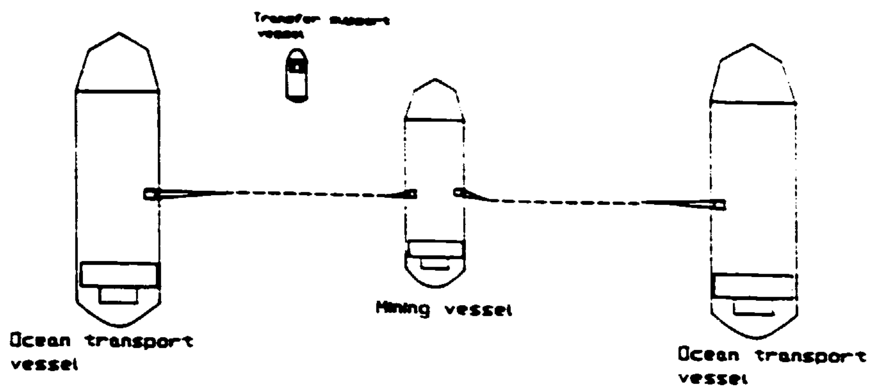
A unique feature of an ocean mining system is that it cannot remain stationary during transfer. Necessary vessel speed adds a force to the transfer system which must be taken into account during design.

The configuration between mining vessel and the transport vessel during transfer is an important input parameter for selecting preferred and feasible transfer systems. The matrix below illustrates possible configurations and transfer possibilities.

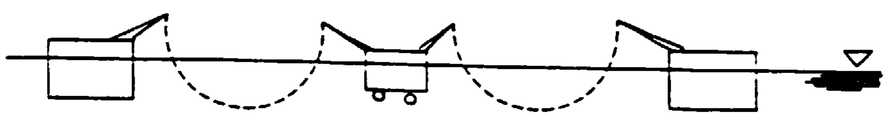
The matrix defines the various options with the more feasible options with an X. We see that a slurry transfer mode can be adapted to any mining/transport ship configuration, while alongside configuration allows broadest choice of nodule ore transfer but is very limited with respect to weather conditions.

Mining/transport ship configuration in transfer.	Transfer mode Slurry	Pneumatic	Conveyor
Mining ship tows/ in front of transport	X	-	X
Transport tows/ in front of mining ship	X	-	-
Moving on parallell coarses	X	X	-
Alongside	X	X	X

EXAMPLE AT SIDE BY SIDE CONFIGURATION DURING TRANSFER AT SITE



BIRD EYE VIEW



SIDE VIEW

Comments to the example:

This solution prevents one dangerous situation: impact between transport vessel and mining vessel. There is yet another advantage: it is easy to make a solution with hoses on both sides of the mining vessel. This enables one seagoing vessel to be connected on each side, thus avoiding transfer interruptions. A fore/aft layout could also be possible, but this may yield a dangerous situation if blockout on bulk carrier should happen. A fore/aft solution will also complicate the shifting from one ship to another.

Re.: Personnel transport

The considerable distances from mainland airports to the mine-site together with time factor requirements/considerations with respect to personnel transport to/from mine site, highlight the need to consider using an existing airport nearby.

Technological challenges - processing

Nodules can be processed using either a pyrometallurgical or a hydrometallurgical extraction process, or a combination of the two.

The processing plant must be located in an area that can provide the necessary electrical power, manpower, railway, road and air transportation, etc. It should also be built as close to the ore discharge facility as is economically, environmentally and politically feasible.

The processing sector includes all facilities connected to the processing plant, and may be sub-divided as follows:

- Ore marine terminal
- Onshore transportation system
- Processing plant
- Waste disposal system

During a first-generation project, nodule processing will take place on land, for environmental reasons. During later-generation projects however, it is assumed that this process will be done partly or wholly at the mine-site, at sea.

Re.: Ore marine terminal.

The ore terminal will require a facility of approx. 60.000 - 80.000 sq.m. The facility will require an abundant water supply, for use as slurry medium for transport of the nodules.

The quays must be equipped with cranes for handling the pipe systems used when unloading the nodules, in addition to the cranes required for loading and unloading equipment. The port must be dredged to accommodate vessels up to 80,000 DWT.

As the terminal will also function as supply base for the mining vessels, it must include storage facilities and offices for administration as well.

Re.: Onshore transportation system.

This system will include slurry transport of nodules from ore terminal to processing plant, and transport of waste material from processing plant to waste disposal site.

The port-to-plant slurry system will consist of land (a belt approximately 15 m. wide), a port pumping station, a surface slurry pipeline and a slurry water return line, with the necessary pumps. Seawater pumped from the harbour will be the slurry medium.

The waste material transport system will resemble that for nodule transport. The particles transported, however, will be considerably smaller, and a facility for decanting the sludge will be required. The water used as slurry medium will be re-circulated.

Re.: Processing plant

The metal content can be extracted through alternative processes: either pyrometallurgical or hydrometallurgical, or a combination of both.

The two basic approaches have many variations, complicating the choice of process. Smelting processes (pyrometallurgical) present limited options. Solvent extraction processes, on the other hand, can be split into three different leaching processes: sulphuric acid leaching, hypochloride acid leaching and ammonia leaching. The sulphuric acid leaching process is relatively expensive, as the solvent used cannot be recycled.

Straightforward pyrometallurgical techniques render extraction of manganese easy, whereas hydrometallurgical in general do not. Manganese would remain in the waste sludge, but it would be available there for processing at a later date 7).

Re.: Waste disposal system.

The waste from the metal extraction process contains partly toxic material, and can therefore not be dumped back into the sea. One alternative suggested is that the waste be stored in watertight ponds on shore.

In order to separate most of the liquid from the waste, a relatively arid area of approx. 1 sq.km. will be required, where a large decanting pond is constructed. If we assume annual production capacity to be 3 million tonnes of dry nodules, over a period of 20-25 years, a total of 20 large ponds, each measuring approx. 400,000 sq.m., will be required for waste storage.

Processing at sea.

According to the technological concepts of today the nodules will be washed and crushed on the seabed and raised 5.500 metres to the surface as slurry. The nodules will then be shipped to port and thence to the processing plant where the metals will be extracted. Much indicates that this concept will be employed for first generation projects. However, it is a major problem that we utilize only 2-3% or 20-25% of the nodules if we wish to extract three (nickel, cobalt and copper) or four (manganese) metals. The processing technology of today, which involves smelting and/or adding chemicals, makes processing at sea impossible due to environmental considerations. There can be no doubt that the nation or company which manages to develop environmentally acceptable and cost efficient concepts that result in greater integration of the mining and processing system, and thus makes at-sea processing possible, will, as mentioned, breakthrough both technologically and economically.

Technological challenges - special reports prepared for India.

The Fridtjof Nansen Institute published two reports in 1989 dealing exclusively on technological challenges facing the Indian nodule program:

> Markussen, Lothe, Arvesen, Faråsengen, Storaas, Fuglum and Rognså: "Technological Challenges Facing the Indian Nodule Program", The Fridtjof Nansen Institute, May 1989, 192 p.
>
> The report provides an overview of the problem areas - or as we call them - challenges India faces in the areas of further exploration, mining, transport and processing of the nodule deposits in the Central Indian Basin.

Vigerust: "Mining of Polymetallic Nodules in the Central Indian Basin - Technology and Reliability", The Fridtjof Nansen Institute, December 1989, 100 p. plus appendix.

The aim of the report is to present a mining system for nodules based on state of the art technology and to identify components and external operational conditions which will be critical to the mining operation. The identification is made by computer simulation.

These reports are available on request to Indian companies and organisations 8).

3.2 ENVIRONMENTAL ASPECTS

Environmental consequences.

The operations carried out in the exploration phase of the project will only to a small extent have negative environmental effects. Operation of machinery and generators on board the exploration vessels produce exhaust gases and noise (and vibration). Towing of the submerged equipment module could have a disturbing effect on fish and marine mammals at the various depths. Seabed flora and fauna will also be affected by activities on the seabed such as sample-taking of minerals and seabed material. None of these effects can, however, be characterized as significant.

Several of the mining operations will have an effect on the surroundings, though the concept choice as regards the respective equipment components will be of significance as to the actual degree of affectedness. However, two of the operations will, regardless of concept choice, be bound to affect the surroundings. In the first place, the bottom unit will physically remove seabed material, and it will also whirl up particle material into the bottom layer of the actual seawater. The other operation is release of waste water at sea. The release will affect the environment since the water will have a different temperature, particle content and chemical characteristics.

Among the operations connected with the transport phase, it is the pumping out of waste water from the transport vessel that will have the most marked effect on the surroundings.

At-sea processing of polymetallic nodules with the processing methods developed today, would lead to severe damage of the environment. Land-based processing of the nodules will cause the same environmental consequences as land-based mining.

Regulations - Environmental impact study programmes.

Deep-sea mining is characterized by vast areas (the deep seabed is twice the size of the total land area), huge metal deposits (the total cobalt reserve in the nodule deposits in the Clarion Clipperton area in the Pacific is twice the size of the total land-based reserves), and the fact that commercial production has yet to commence. In this area therefore we have a singular opportunity to incorporate preventive measures into developments, and thus render unnecessary the usual environmental firefighting operations.

The present rules and regulations adopted to protect the environment against the consequences of deep-sea mining are, however, very vaguely formulated. This applies to the UN Law of the Sea Convention as well as to the respective national legislation of the individual countries. Limited knowledge of the environmentel aspects of such activities prevailing at the time the rules and regulations were drawn up is one important reason, this in turn being due to a lesser developed environmental consciousness than is the case today.

Environmental impact study programmes have been initiated in several countries the last one and a half year. France, Germany, Japan, Norway, the Soviet-Union and the United States all have programmes on environmental aspects of deep seabed mining. It may also be mentioned that the Fridtjof Nansens Institute is carrying out an environmental study for the United Nations. The report will be ready in December 1990 and will be used in the United Nations' work on formulating regulations for protection of the environment in connection with the future commercial exploitation of deep seabed minerals 9).

3.3 ECONOMIC ASPECTS

The MIT cost model.

The MIT model (Massachussetts Institute of Technology) is the most comprehensive cost model that has been developed so far 10). The model contains a cost estimation section and a financial analysis section. The former divides the capital and operating cost estimates (in Millions USD, annual production 3 million tons of nodules, full production begins and runs for about 20-25 years) as indicated below:

	Capital Costs	Annual Operating Costs
1: Preparatory Prospecting and Exploration and Research and Development	Capitalized 30.00	Expensed 142.00
Total		172.00

	Capital Costs	Annual Operating Costs
2: Mining	306.24	65.58
3: Transport	200.88	22.20
4: Ore Discharge Terminal	22.87	3.19
5: Onshore Transportation	36.65	7.68
6: Processing	449.10	99.60
7: Waste Disposal	15.28	3.90
8: Marine Support	1.80	4.88
9: General and Administrative	88.20	4.00
10: Continuing Preparations	.0	6.00
Total	1,121.02	217.03

The second major section of the model is the financial analysis section. In this section, the estimated costs and revenues are integrated with various taxation and regulatory assumptions to calculate the financial return of the project. The real-term, non-inflated internal rate of return for the baseline set of assumptions, with U.S. taxation and assuming 50% debt funding, is 9,21%

The need for a new cost model.

There is much talk of the 'profitability' of deep seabed mining. Many people seem to regard profitability as a clearly defined concept. This is of course not the case. In the first place there is a world of difference between what is a paying proposition in the market and what might be profitable from a socio-economic viewpoint. In the second place, these are factors that will vary from company to company and from country to country.

It has long been difficult to say anything certain about the profitability of the deep seabed mining projects. The main reason is the lack of a cost model based on realistic conditions.

Many models have been developed attempting to analyse these conditions. The MIT model (Massachusetts Institute of Technology) from 1983, which is based on a model from 1978, is however still the most comprehensive. Many of the premises this model is based on have lost their currency. Let me give some examples of conditions that have changed in later years:

- A heavy state subsidization of exploration and technological development has taken place in Europe and Asia since 1981. The Japanese as well as the French exploration and development program is for instance 100% financed by the state. This will also alter the economy of the projects.
- The market price for several of the nodule metals has shown a marked improvement in 1988-1989. The average prices for

nickel, copper and cobolt have been higher in this period than the assumptions of the MIT-model.

- The oil-price fell in 1986 and has remained at a relatively low level. Few market analysts expect the oil price to increase to its traditional levels. A lower oil price will of course have consequences for the costs of deep seabed mining.
- We know more about the technological demands now of course than we did 10 years ago and the technological developments have been going on steadily the whole time.

On this basis there is definitely a need for a new techno-economic model using altered and fresh premises - and to distinguish between different types of actors. The point is: What could be commercially feasible for one group could be totally unacceptable to another.

French Cost Model.

GEMONOD/IFREMER of France made a comprehensive study of the economics of nodule mining in 1988 and 1989. The results of the French study will probably be published at the end of this year or early next year.

The assumed annual production capacity of the French model is 1.5 million tonnes of dry nodules. Total investment cost amount to 940 million USD. The annual operating cost is 240 million USD. These amounts may be divided as follows:

	Investment Cost	Operating Cost
Mining	30%	20%
Transport	20%	15%
Processing	50%	65%

It is expected that full production will take place during a period of 21 years. The internal rate of return has been evaluated at 12%

regardless of the source of financing used. The investment pay-off period will be 6 years from the moment production has reached full capacity (Information given by GEMONOD to Markussen in August 1989).

The new French model seems very interesting. The model has been made in close cooperation with French industry and shipping. It should be noted, however, that the model does not take into account the effects of heavy state subsidization of development cost.

Notes - Chapter 3:

1) As mentioned in chapter 4, European and Asian governments have financed virtually the whole of the technical development since 1981, their motive being that of long-term supply considerations. Moreover, there is every reason to suppose that the technological developer will be obliged to pay attention to increasingly stringent environmental considerations in the years ahead. Growing global awareness of the need to protect the environment will without doubt lead to more precise regulations that will represent an important new example of 'Pull of Society'.

2) This chapter is primarily based on Markussen, Lothe, Arvesen, Faråsengen, Storaas, Fuglum and Rognsaa: "Technological Challenges Facing The Indian Nodule Programme", The Fridtjof Nansen Institute, May 1989, 192 pp.; and Jan Magne Markussen: "India and The Deep Seabed Minerals - 1988 Competence Report"; and J.D. Nyhart et al.: "A Pioneer Deep Ocean Mining Venture"; Massachussetts Institute of Technology, 1983, 255 pp.

3) Prospecting can be conducted in three stages. First, a rough grid search of a large area is made - e.g. an examination of a region measuring 840 miles by 480 miles, where samples are collected at 40 points. Next, a medium grid search is made, narrowing the sections for future surveying using free-fall grabs and still photographs, and possibly a dredge to collect bulk samples from promising sections. At this stage, a region measuring 420 miles by 300 miles could be covered, and samples could be taken at 48 points. The results from this stage are then used to specify the region to be examined in the third stage, which could comprise a detailed examination of an area approximately 210 miles by 130 miles, and could imply collecting samples at 235 points. This fine grid search is thus made to determine the area to be investigated during exploration stages.

4) Simrad Subsea AS has at the moment great commercial and technical success with their EM12 Multibeam Echo Sounder. The EM12 operates at 13 kHz, and provides precision swath mapping capability at full ocean depth (11,000 meters). The resulting maps offer quality and accuracy far beyond any map produced by conventional methods - and at a significantly lower overall cost. Three contracts for a total of NOK 80 Million have been signed with France, the UK and Spain the last six months. Simrad is now negotiating six more contracts.

5) Dynamic positioning of the mining vessels will be an absolute requirement for system operability. During deep ocean mining operations, the mining ship will have to track accurately

along a pre-determined course at a specified speed, whilst the collector unit traverses the mineral-rich area on the seabed. As mining operations progress over an extended period of time, a DP system will be required in order to attain the required degree of accuracy, safety and automatic control. The technology necessary for dynamic positioning of a deep ocean mining vessel is already well proven. DP systems are used extensively on drillships operating in remote locations and in deep waters. For vessels equipped with DP systems, a highly accurate automatic tracking mode has also been developed, in which the vessel sails accurately along a course and at a speed selected by the DP operator. The autotrack mode is the vessel control mode required for mining operations.

A complete DP system from Simrad Albatross for deep seabed mining operations is presented in Markussen, Nielsen, Hansen and Arvesen: "Indian Nodule Mining - Norwegian Technology, Products and Services", The Fridtjof Nansen Institute, 1986, 345 pp. Simrad Albatross AS, a company in the Norwegian Simrad Group, has a 80-90% share worldwide of the market for Dynamic Positioning Systems and Position Mooring Systems.

6) The Norwegian company Simrad Subsea AS has been involved in severel engineering studies of acoustic positioning and control systems for ocean mining. A complete system is evaluated in Markussen et al. (1986)(cf. note 5).

7) The pyrometallurgical process for extraction of nickel, cobalt, copper and manganese, developed by the Norwegian company Elkem AS, can be described like this:

The process starts with drying and prereduction with coal in a rotary kiln. The preheated and prereduced mix is charged into an electric smelting furnace. From the furnace, a slag containing all the manganese, and a metal containing copper, nickel, cobalt and iron can be tapped. From the manganese-rich slag, silicomanganese and or ferromanganese can be produced in a submerged arc furnace. The metal can be oxidized to remove iron in a slag, thus leaving a metal containing mainly copper, nickel and cobalt. From this final metal, copper, nickel and cobalt can be extracted along a hydrometallurgical route.

The handling of the polymetallic nodules can thus be described as follows:

- Raw nodules are unloaded and transported to plant site by belt conveyors.
- Washing of raw nodules with fresh water to remove alkalies and chlorides.
- Intermediate storage before drying of nodules and storage under cover of dried nodules.
- Handling of dried nodules and coal through rotary kiln for preheating the charge to discharge bin.

- Direct feeding from discharge bin of the preheated charge to an Elkem furnace of the closed type for production of metal alloy and slag.
- Metal alloy from the furnace to be treated with oxygen in a converter for removal of carbon.
- Hydrometallurgical treatment of the metal alloy for separation of Cu, Ni, Co and Mn.
- Slag from the furnace together with quartz and coke to be fed to an Elkem furnace of the closed type for production of silicomanganese (SiMn) and slag to be discarded.

8) The reports may be ordered from:

Ocean Mining Programme
The Fridtjof Nansen Institute
P.O. Box 326
N-1324 Lysaker, Norway

Telephone 47 2 53 89 12
Telefax 47 2 12 50 47
Telex 79 965 nanse n

9) The study of "Environmental Consequences of Deep-Sea Mining - Problem Areas and Regulations" is split up into three parts. Part 1 gives a brief assessment of the need for unambiguous environmental regulations in light of the advancements that have taken place in deep-sea mining. Part 2 will identify the problem areas - i.e. the environmental consequences of deep-sea mining are described. Part 3 gives an assessment of the rules and regulations. An overview of international and national legislation is to be found here; an analysis is made of the regulatory techniques employed in the legislation, the effects of the legislation are described and implementation by authorities is evaluated. Finally a brief sketch of new legislation is presented.

The environmental study, that the Fridtjof Nansen Institute is now carrying out, will be used in the United Nations' work on formulating regulations for protection of the environment in connection with the future commercial exploitation of deep seabed minerals. The main target groups for this report will thus be the United Nations Office for Ocean Affairs and Law of the Sea, the national delegations to the Preparatory Commission, and the governments they represent.

10) Nyhart et al.: "A Pioneer Deep Ocean Mining Venture", Massachusetts Institute of Technology, Cambridge, MA, February 1984, 255 pp.

An similar analysis was also made at the Fridtjof Nansen Institute in 1982: Ånund Haktorson: "Commercial Exploitation of Manganese Nodules - Costs, Revenues, Profitability and Risks", The Fridtjof Nansen Institute, June 1982, 152 pp.

CHAPTER 4:

THE INDIAN NODULE PROGRAMME IN AN INTERNATIONAL PERSPECTIVE - PROSPECTS FOR COMMERCIAL EXPLOITATION.

Purpose.

The aim of this final chapter is to place India's plans for commercial exploitation of nodule deposits in the Central Indian Basin in an international context. National programmes in Asia, Europe and North America will be presented and assessed. In addition to a description of on-going exploration, research and development work in the respective countries, an assessment will be given of the way in which activities are organized and financed, of the individual countries' motives for involvement, and of plans for commercial exploitation. The main purpose of the chapter is thus to assess the prospects for commercial exploitation of polymetallic nodules in general. We shall attempt to answer the following questions:

- When can commercial exploitation be expected to commence?
- Who will start, and why?
- How will first-generation projects be organized?

Preconditions

Commercial exploitation of nodules will depend on the interplay between economic, political, technical, legal and environmental factors. These factors will therefore be regarded as interdependent. I will also distinguish between different types of actors, and examine the groups one by one. The reason for this is the considerable disparities between the interested parties in terms of motivation, financing and organization 1).

4.1. DEEP SEABED MINING FROM THE MID -70s UNTIL THE PRESENT: DEVELOPMENT TRENDS.

Three distinct periods

Preparations for commercial exploitation of nodules began in earnest with the formation of four internationally composed industrial groups (consortia) in 1973-76. Three separate periods can be distinguished:

1973-76 to 1980-81: Private companies with profit motives.

The first period commencing with the formation of the industrial groups and bringing us to 1980-81, is characterized by private industry's high expectation for profit, and investing in deep seabed mining. Expectations as to profitability were considerable at the time the companies were formed. The publication in the early 70s of reports giving an exaggerated impression of the scope of the resources, while underestimating the technological and economic aspects, was partly to blame for this. Each of the four industrial groups invested between 100 and 250 million dollars in exploration and development of technology for mining, transport and processing 2).

1980-81: New actors enter the arena.

Around 1980 the four consortia drastically reduced the scale of their development programmes. At that time metal prices were very low as a result of the decline in growth of the world economy. In addition, the consortia were also thoroughly dissatisfied with developments in the UN Law of the Sea negotiations.

In my view, economic considerations carried far more weight than political ones in determining this 'wait and see' attitude. If the companies' analyses around 1980 had concluded that these projects would prove commercially viable in a 5 to 10 year perspective, it would not be unreasonable to assume that national legislation would have been passed to enable such development.

1981 - to date: State programmes with long-term supply motives.

Nations and governments with not only the will but also the ability to think in a long-term perspective, and with either supply and/or political motives behind their engagement, were the new type of actors that came on stage around 1981. Since then, state programmes have dominated developments in this field.

France, India, Japan and the Soviet Union launched comprehensive exploration and development programs around 1981. China and South Korea followed some years later; they have carried out preliminary exploration and techno-economic analyses. In addition, the Federal Republic of Germany has its own research and development programme, and Norwegian and Finnish industry have also initiated R&D-programmes.

Four pronounced trends

If we look at developments from the time industry groups were formed and up to the present, we can observe some pronounced trends:

Geographically: Europe and Asia have increased their involvement, while the level of activity in North America has declined drastically.

Organizationally: In active countries there is often cooperation at the national level among the research community, industry and government authorities.

Ideologically: As to the question of private consortia versus state programmes, there are different motives for involvement and different attitudes towards state subsidization.

North-South: Some developing countries have a stronger position than perhaps could be expected. For instance, who would have believed in 1982 that India would turn out to be the first country to achieve status of Pioneer Investor pursuant to the UN Convention on the Law of the Sea?

The ultimate question is, of course, whether these trends will endure and even intensify in the future. Will for instance government-organized and government-funded projects dominate the commercial exploitation of nodule deposits? To answer this, we shall have to examine the various groups and try to predict probable developments within each one.

4.2. POSSIBLE DEVELOPMENTS WITHIN THE VARIOUS GROUPS OF ACTORS

Groups of actors

For the purposes of this analysis, we distinguish between these three groups of actors or participants:

- Developing countries and the United Nations

  Three subgroups:
  - The "superpowers" of the Third World: India and China.
  - Other developing countries.
  - The United Nations.

- National programmes in industrialized countries

- Private companies

  Three subgroups:
  - Internationally composed industrial groups.
  - Active participation in national programmes.
  - Independent suppliers to national programmes.

Possible developments within the respective groups

Re.: Developing countries and the United Nations

India has carried out a comprehensive exploration programme in the Central Indian Basin. Techno-economic feasiblity analyses have been made; and India has also progressed far in developing and testing methods for nodule processing. India is now, as mentioned in chapter two, facing a new stage of development - preparations for test mining and commercial exploitation of the deposits. Some re-organization is therefore likely to take place, involving for instance greater participation of Indian industry and shipping in future programme development. Supply considerations underlie India's involvement here.

China has conducted initial exploration in the Pacific Ocean and has carried out preliminary techno-economic analyses. China may well become increasingly involved in the coming years. There is for example reason to expect that China will apply for a mine site in accordance with the UN Convention in the course of the next one to two years. One reason could be the wish to acquire "a fair share" of "the common heritage of mankind". Another reason may be the China-India rivalry, spurring China to match India's claims.

India and China are undoubtedly the superpowers of the Third World. For both of them deepsea engagement will be a part of their high tech drive to avoid missing the industrial revolution for the second time. What then about the other developing countries?

The great majority of developing countries have no realistic possibilities of participating independently in deep seabed mining. Any participation will have to be through the UN, and establishing of the Enterprise under the UN Convention on the Law of the Sea. I personally feel rather sceptical as to the rationality of establishing a separate UN-based company to carry out commercial production parallel with other first-generation projects funded by governments or private companies. The Enterprise ought rather in my opinion to aim at establishing cooperation with other companies and groups, so as to build up techno-economic competence 3).

The establishment of regional cooperation may represent another long-term opportunity for developing countries to become involved in this area 4).

Re.: National programmes in industrialized countries

Long-term supply security is a main motive behind the various governments' involvement in deep seabed mining. Moreover, exploitation of deep seabed minerals can represent an important growth area for industry, shipping and research in these countries. By financing exploration and development of technology the respective governments are helping companies to build up competence.

There is reason to believe that government involvement in Europe as well as Asia in deep seabed mining will be sustained until commercialization of the projects takes place. However, governments are also likely to encourage stronger involvement from the private sector in for instance financing.

There is also reason to believe that individual countries will be interested in a greater degree of international cooperation in the years to come. France, the Soviet Union and South Korea have all initiated cooperation with other countries, and Japan also seems interested. The cost of for instance the French and the Japanese deep seabed programmes would undoubtedly have been lower if cooperation had been arranged from the outset.

It is primarily countries in Europe and Asia that have initiated national deep-sea mining programmes since 1981. The United States has been somewhat passive - except for the exploration of polymetallic crust deposits off Hawaii and sulphide resources off the US West Coast, for several reasons. In the USA, private enterprise predominates while Europe and Asia have traditions of stronger national engagement, with closer cooperation between industry, research and governmental authorities. It would also seem that the USA has had, at best, a somewhat hazy national ocean policy since 1981. Ocean policies appear to be formulated at the regional level, for instance for the State of Hawaii, rather than for the nation as a whole.

The Canadians have concentrated their efforts on exploring the sulfide deposits off the Canadian west coast.

We should also mention that the heavy state subsidization that has taken place in Europe and Asia since 1981, is altering the economy of deep-sea projects for private companies. The investment cost will be reduced, while the profitablity will increase.

Re.: <u>Privat companies.</u>

<u>Private companies group 1: the international industrial groups.</u>

The four internationally composed industrial groups adopted, as mentioned, a non-commital or "wait and see" attitude in 1980-81. However, we must also keep in mind the following two factors:

- The groups carried out a comprehensive exploration and technology development programme up to 1980-81, providing them with a very sound technological basis for future commercial exploitation.

- A political-legal basis for future commercial exploitation exists. The problem with overlapping claims in the Clarion-Clipperton area in the Pacific has been settled and mine sites have been allocated to the groups in accordance with US legislation.

Reactivation of the industrial groups will depend primarily on developments in the metal markets. During late 1988 and 1989, metal prices were high. However, the situation remains highly unstable. Nickel and copper prices for instance are expected to fall in 1990, as expanding production overtakes demand. The price fall in 1990 must be regarded as a natural reaction to the high average price sustained during late 1988 and 1989.

It will be interesting to observe to what extent prices will stabilize in 1992-93 - and whether at a level that can make deep-sea mining attractive to private sector 5).

If nodule metal prices should stabilize at a level that would allow mining companies an acceptable return on investment, there is reason to expect a reactivation of the industrial groups. This was confirmed by the leader of one of the groups (personal communication, June 1989).

In this case, there is likely to be some change in ownership. Moreover, the industrial groups will probably be interested in firmer international cooperation: indeed, there are indications that such a cooperation can be a reality in the next four to six years. This point is discussed later in the chapter.

Private companies group 2: Active participation in national programmes

The Japanese project was established in 1981. The first three years were spent building up basic competence, and the research community was primarily involved. This competence was subsquently handed over to Japanese companies. Since then companies like Mitsubishi Heavy Industries, Ishikawajima-Harima Heavy Industries Co. Ltd. and Mitsui Engineering and Shipbuilding Co. Ltd. have been responsible for further development and testing of the Japanese mining concept. In India there will probably be increasing company involvement in the deepsea project, while French industry is active in France's national programme.

Typical of the private companies participating in the Japanese and French deepsea projects is that development of technology and competence is nearly 100% government funded. The French have invested more than 700 million francs in their programme to date. Government subsidization reduces the cost of the "entrance ticket" -

the price that companies have to pay to enter the market thereby easing the "economy" of the projects from the companies viewpoint.

Private companies group 3:
Independent suppliers to national programmes

Norwegian companies have supplied equipment and services to India, France and the United States 6). Finnish companies have carried out consultancy work and development of technology in deep seabed mining for the Soviet Union. The Norwegian and Finnish companies are examples of what can be called independent suppliers. When the time approaches for commencing commercial exploitation the number of "independent suppliers" will increase.

The majority of the present actors in deep seabed mining are typically engaged in every phase of such a project. This is a matter of vertical integration where the countries and consortia are already involved, or wish to become involved in, everything from exploration to marketing of the finished metals. In addition to these actors, we will increasingly see suppliers specializing in certain parts of the technology - companies we could call "niche-suppliers".

4.3. PROSPECTS FOR COMMERCIAL EXPLOITATION OF NODULE DEPOSITS

Time perspectives

Commercially interesting nodule deposits have been identified in the Central Indian Basin and in the Clarion-Clipperton area of the Pacific. While the nodule deposits in the Central Indian Basin are sufficient for one - or maximum two - first generation commercial projects, the Clarion-Clipperton area contains enough nodules for at least ten full-scale projects. The aim of this section is to look at the time perspectives for commercial exploitation of the nodule deposits in the Clarion-Clipperton area of the Pacific.

Three countries (France, Japan, the Soviet Union) and four international industry groups registered in the United States (Ocean Minerals Company, Ocean Management Incorporated, Ocean Mining Associates and Kennecott Consortium) have been granted mine sites in the Clarion-Clipperton area in accordance with the UN Convention on the Law of the Sea, and with US legislation, respectively. It is expected that China - and possibly also South Korea - will apply for mine sites in this area within the next two years.

Japan has formulated plans for test mining. The intention is to carry out preliminary testing of mining technology in the Clarion Clipperton area around 1995, at which time Japan will decide on the further schedule for the project.

There have been discussions for some time now between Japan, France and West Germany on a possible cooperation in deep sea mining. This might well lead to a major international nodule cooperation project in the Clarion-Clipperton area. Such a major international cooperation project could become a reality after the Japanese have finished their initial testing programme.

Reactivation of the industrial groups will depend primarily on developments in the metal markets. Should prices for nodule metals stabilize at a level that would enable the mining companies to earn profits for the next three years, there is reason to expect a reactivation of the industry groups. They could then also be interested in joining a possible cooperation project. This will be discussed below.

Generally, it will take approximately 8 to 10 years from the time a country or company completes preliminary testing of mining, transport and processing technology until a total concept has been developed ready to be applied on a commercial scale. Thus it is reasonable to expect exploitation to commence sometime between the year 2000 and 2005.

Organizational changes - international cooperation.

The next five years may prove highly interesting. Test mining will take place. Private companies could take a renewed interest in this sector because they may once more find the projects economically attractive.

Great organizational changes could well follow. Purely national initiatives could be largely replaced by international cooperation - where states as well as private interests participate. Many factors indicate the advisability of such cooperation:

- Purely national initiatives mean costly development programmes.

- There are significant similarities between the basic technology planned for use by the national programmes and the international groups during commercial exploitation.

- Within the national programs there is an increasing willingness to cooperate with others.

- It is worth recalling that the exploration and technological developments undertaken by the international groups were characterized by cooperation between American, European and Japanese companies.

Political and Legal Aspects.

Summing up, I believe there are good possibilities that the next five years will be marked by great changes within the field of deep ocean mining - both technologically, economically and with respect to the organizing of the activities. On this background, one can foresee great political and legal challenges, especially within two fields:

- It is a matter of considerable urgency to establish a set of rules and regulations that can prevent environmental damage and secure a sustainable development in this field.

- The United States, West Germany and Great Britain have chosen not to sign the United Nations Law of the Convention of 1982 because they disagree on some of the rules intended to regulate the future exploitation of the deep sea minerals. In my view, an initiative should be taken to get these countries to enter into the cooperation on ocean law again, and thereby create the foundation for a commonly accepted Convention on the law of the sea.

Notes - Chapter 4:

1) This chapter is based on a forthcoming book by Jan Magne Markussen: "Polymetallic Nodules - Prospects for Commercial Exploitation" (to be published in 1991).

2) The shareholders of the four industrial groups - Ocean Minerals Company, Ocean Management Incorporated, Ocean Mining Associates and Kennecott Consortium - are high technology, mining and oil companies from North America, Europe and Japan. The owner companies had various motives for their involvement. Some discerned potentials for further development of their technology. Others saw deepsea minerals as a source of supply for important metals. The main objective was naturally financial profit.

   Each of the four consortia invested between $ 100 and 250 million in exploration and development of technology for mining, transport and processing. By 1981 the industrial groups had identified commercially interesting resources in the Clarion Clipperton area in the Pacific, and had carried out successful small-scale tests of mining and processing technology.

   It should be mentioned that the governments of for instance Japan, West Germany and Britain subsidized part of the investments made by companies from these countries. The French Government also financed a considerable part of the approx. 200 million francs that were invested in the French group AFERNOD (Association Francaise pour l'Etude et la Recherche des Nodules).

   The development of deep seabed mining from 1973-76 up to 1981 is discussed in Jan Magne Markussen: "Status and Perspectives for Exploitation of Polymetallic Nodules", Fridtjof Nansen Institute, December 1983, 229 pp.

3) The "Enterprise" is in principle planned to be established and organized to carry on commercial exploitation on the same basis as other commercial companies. To this I have some comments. The Enterprise will experience no problems in gaining access to the necessary technology. Technology will, however, have its price; and great technological and economic uncertainty will surround first-generation commercial projects. I consider it unrealistic to expect a particularly high internal rate of return for these projects. This makes me rather sceptical as to the rationality of establishing a separate UN-based company to carry on commercial production parallel with other first-generation projects funded by governments or private companies. The alternative is, in my view, to try to work together with other companies and groups in order to build up techno-economic competence gradually.

The Enterprise could then at a later date decide whether to commence its own production or continue to collaborate with others. If the Enterprise should want to go ahead on its own, the parallel system of the UN Convention on the Law of the Sea will secure excellent mine sites for the Enterprise. One method of achieving this initial collaboration could be for the Enterprise to buy shares in other companies/industrial groups. Another alternative could be the allotment of B-share capital to the Enterprise as part of the concession terms. By acquiring B-share capital, the Enterprise will gain increased knowledge and thereby build up its own competence, with the industrial groups still retaining control of the company. This would naturally necessitate some alterations in the text of the convention.

4) This is not likely to materialize during first-generation projects, for financial and technical reasons. However, for later-generation projects this may prove a possible alternative. It is for instance conceivable that the IOMAC-cooperation may be developed in that direction. IOMAC (Indian Ocean Marine Affairs Conference) is a regional collaboration between countries in and around the Indian Ocean, with its secretariat in Colombo, Sri Lanka.

5) The expected reduction in the base metal prices is commented on in Financial Times, 24 November 1989. According to the latest report from the Economist Intelligence Unit, the decline in copper prices next year will occur mainly due to an expected 200,000 tonne surplus of refined copper supplies over demand, up from near zero this year. The unit's latest report *) on industrial raw materials forecasts a price for copper of 95 cents per lb in 1990, 24% down from the expected 1989 average. Nickel is expected to be under $4 per lb, against $6 per lb this year.

The copper surplus will allow some rebuilding of severely depleted stocks. The Report also points out that at 95 cents/lb "most producers will still find copper production a highly profitable business".

The vulnerability of the nickel market to its dependence on stainless steel is likely to show next year, according to the report, which estimates a market surplus of around 55,000 tonnes next year, up from 10,000 tonnes this year. However, the apparent overproduction is not expected to depress prices severely. "Because stocks have been reduced to levels bordering on the unworkable over the last two years, the surplus will allow stock recovery to continue", says the Report. Hence "a gradual decline and stabilisation of spot market prices is most probable over the forthcoming year".

*) World Commodity Outlook 1990 - Industrial Raw Materials, Economist Intelligence Unit, London.

6) Some 30 Norwegian companies and organizations have joined forces to offer products and services for exploration, mining, transport and processing. The Norwegian group was also joined by Swedish companies and organizations in January 1988. (Cf. Lars Lothe, Ed.: "Deep Seabed Mining - Norway and Sweden - 1988 Competence Report", Fridtjof Nansen Institute, August 1988, 244 pp.)

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APPENDIX

WORK BREAKDOWN STRUCTURE

In this appendix the main phases of the nodule programme are split into subphases:

- General
- Exploration
- Mining
- Transportation
- Shore terminal
- Process plant
- Project support

The WBS is based on J.M. Markussen et al.: "Technological Challenges Facing the Indian Nodule Programme", Fridtjof Nansen Institute, Oslo 1989, 192 pp.

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — **WBS SHEET no. 1**

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/exploration)	1.1 Pre-survey	1.1.1 Survey vessel	Cont. sheet 7
		1.1.2 Survey vessel equipment	Cont. sheet 7
		1.1.3 Survey vessel personnel	Cont. sheet 8
		1.1.4 Survey data processing, interpretation and reporting	Cont. sheet 8
	1.2 Detail survey	1.2.1 Survey vessel	Cont. sheet 10
		1.2.2 Survey vessel equipment	Cont. sheet 10
		1.2.3 Survey vessel personnel	Cont. sheet 11
		1.2.4 Survey data processing, interpretation and reporting	Cont. sheet 11
	1.3 Other surveys	1.3.1 Survey to support mining operation and nodule transport	Cont. sheet 12
		1.3.2 Survey to support investigations for possible harbour site	Cont. sheet 12
		1.3.3 Survey for deployment and retrival of oceanographic buoys	Cont. sheet 12
		1.3.4 Any surveys requested by project if required to ensure project ac implementation	Cont. sheet 12

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 2

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
2. MINING PROJECT	2.1 State of the art in ocean mining	2.1.1 Available technology	Cont. sheet 13
		2.1.2 Necessary Research and development	Cont. sheet 13
	2.2 Bottom unit	2.2.1 Bottom unit engineering	Cont. sheet 13
		2.2.2 Bottom unit procurement and construction	Cont. sheet 14
	2.3 Nodule riser	2.3.1 Engineering nodule riser	Cont. sheet 15
		2.3.2 Nodule riser procurement construction	Cont. sheet 17
	2.4 Mining vessel	2.4.1 Mining vessel engineering	Cont. sheet 17
		2.4.2 Mining vessel procurement and construction	Cont. sheet 19

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET NO. 3

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
3. TRANSPORTATION	3.1 Transportation design premises and task	3.1.1 Nodule transport	Cont. sheet 21
	3.2 Transport of spares and provisions	3.2.1 Input parameters provisions	Cont. sheet 23
		3.2.2 Spares and provisions transport system	Cont. sheet 23
		3.2.3 Spares and provisions transport at site	Cont. sheet 23
	3.3 Transport of personnel	3.3.1 Input parameters personnel transport	Cont. sheet 24
		3.3.2 Personnel transport system to site	Cont. sheet 24
		3.3.3 Personnel transport system at site	Cont. sheet 24
	3.4 Transport of waste from onshore processing	3.4.1	Cont. sheet 24
	3.5 Technical/economical evaluation of transport systems	3.5.1	Cont. sheet 24

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 4

LEVEL 1 — LEVEL 2 — LEVEL 3 — LEVEL 4

- **4. SHORE TERMINAL**
  - 4.1 Pre-investigations
    - 4.1.1 Onland survey — Cont. sheet 25
    - 4.1.2 Near shore survey — Cont. sheet 25
    - 4.1.3 Seaward access route survey — Cont. sheet 25
    - 4.1.4 Geotechnical survey — Cont. sheet 25
    - 4.1.5 Environmental survey — Cont. sheet 26
    - 4.1.5 Logistic planning — Cont. sheet 26
  - 4.2 Ore-discharge terminal
    - 4.2.1 Safety — Cont. sheet 26
    - 4.2.2 Harbour basin — Cont. sheet 26
    - 4.2.3 Berths — Cont. sheet 26
    - 4.2.4 Berthing operation — Cont. sheet 27
    - 4.2.5 Discharge procedures — Cont. sheet 27
    - 4.2.6 Storage — Cont. sheet 27
  - 4.3 Supply base
    - 4.3.1 Safety — Cont. sheet 27
    - 4.3.2 Harbour basin — Cont. sheet 27
    - 4.3.3 Berths — Cont. sheet 27
    - 4.3.4 Berthing operation — Cont. sheet 28
    - 4.3.5 Discharge procedures — Cont. sheet 28
    - 4.3.6 Temporary storage — Cont. sheet 28
  - 4.4 Reagent discharge terminal
    - 4.4.1 Safety — Cont. sheet 28
    - 4.4.2 Harbour basin — Cont. sheet 28
    - 4.4.3 Berths — Cont. sheet 28
    - 4.4.4 Berthing operation — Cont. sheet 29
    - 4.4.5 Loading/unloading procedures — Cont. sheet 29
    - 4.4.6 Temporary storage — Cont. sheet 29
  - 4.5 Export/multipurpose terminal
    - 4.5.1 Safety — Cont. sheet 29
    - 4.5.2 Harbour basin — Cont. sheet 29
    - 4.5.3 Berths — Cont. sheet 29
    - 4.5.4 Berthing operation — Cont. sheet 30
    - 4.5.5 Loading/unloading procedures — Cont. sheet 30
    - 4.5.6 Transit storage area

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — **WBS SHEET no. 5**

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
5. PROCESS PLANT	5.1 Pre investigations	5.1.1 Onland survey	Cont. sheet 31
		5.1.2 Geotechnical survey	Cont. sheet 31
		5.1.3 Power supply	Cont. sheet 31
		5.1.4 Infrastructure planning	Cont. sheet 31
	5.2 Onshore transportation system	5.2.1 Nodule transport	Cont. sheet 31
		5.2.2 Reagents transport	Cont. sheet 31
		5.2.3 Metal transport	Cont. sheet 31
		5.2.4 Waste transport	Cont. sheet 32
	5.3 Process plant	5.3.1 Site preparation	Cont. sheet 32
		5.3.2 Buildings	Cont. sheet 32
		5.3.3 Process equipment	Cont. sheet 32
		5.3.4 Other equipment	Cont. sheet 32
		5.3.5 Storage	Cont. sheet 32
		5.3.6 Other facilities	Cont. sheet 32
	5.4 Waste disposal system	5.4.1 Site survey	Cont. sheet 32
		5.4.2 Site preparation	Cont. sheet 32
		5.4.3 Deposit system	Cont. sheet 32
		5.4.4 Water treatment	Cont. sheet 32

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 6

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
6. PROJECT SUPPORT	6.1 Management	6.1.1 Prospecting and exploration administration	Cont. sheet 33
		6.1.2 Mining operation administration	Cont. sheet 33
		6.1.3 Transport vessel administration	Cont. sheet 33
		6.1.4 Shore terminal administration	Cont. sheet 33
		6.1.5 Process plant administration	Cont. sheet 33
		6.1.6 Authorities relations	Cont. sheet 33
		6.1.7 Construction management	Cont. sheet 33
	6.2 Contract administration	6.2.1 Prequalifications	Cont. sheet 34
		6.2.2 Tender invitations	Cont. sheet 34
		6.2.3 Tender evaluations	Cont. sheet 34
		6.2.4 Purchasing	Cont. sheet 34
	6.3 Planning and control	6.3.1 Cost control	Cont. sheet 35
		6.3.2 Progress reports	Cont. sheet 35
		6.3.3 Project planning	Cont. sheet 35
		6.3.3 Document control	Cont. sheet 35

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

1.1 Pre-survey*

- 1.1.1 Survey vessel *
  - 1.1.1.1 Availability of present survey vessels
    - 1.1.1.1.1 Refit/conversion
      - 1.1.1.1.1.1
    - 1.1.1.1.2 Agents/domestic network
      - 1.1.1.1.2.1
    - 1.1.1.1.3 Local suppliers and support
      - 1.1.1.1.3.1
    - 1.1.1.1.4 Organization/infrastructure quality assurance and safety
      - 1.1.1.1.4.1
    - 1.1.1.1.5 Finance/contracting
      - 1.1.1.1.5.1
  - 1.1.1.2 New build of survey vessel
    - 1.1.1.2.1
- 1.1.2 Survey vessel equipment
  - 1.1.2.1 Ship instrumentation
    - 1.1.2.1.1 Standard instruments
      - 1.1.2.1.1.1
    - 1.1.2.1.2 Radio communication
      - 1.1.2.1.2.1
    - 1.1.2.1.3 Navigation and positioning
      - 1.1.2.1.3.1
    - 1.1.2.1.4 Deck machinery
      - 1.1.2.1.4.1
    - 1.1.2.1.5 Deck space and laboratory facilities
      - 1.1.2.1.5.1
  - 1.1.2.2 Survey navigation and positioning equipment*
    - 1.1.2.2.1 Repeator output from log and gyro
      - 1.1.2.2.1.1
    - 1.1.2.2.2 Satellite navigation* (transit and GPS)
      - 1.1.2.2.2.1
    - 1.1.2.2.3 Hydroacoustic positioning* reference system
      - 1.1.2.2.3.1
    - 1.1.2.2.4 Bottom transponders for re-entry purposes
      - 1.1.2.2.4.1
    - 1.1.2.2.5 Navigation computer and software for online processing
      - 1.1.2.2.5.1
  - 1.1.2.3 Geophysical equipment for providing data on bathymetry and seafloor topography and composition
    - 1.1.2.3.1 Sub bottom sediment profiler
      - 1.1.2.3.1.1
    - 1.1.2.3.2 General purpose deep water echo sounder
      - 1.1.2.3.2.1
    - 1.1.2.3.3 Multibeam echo sounder with integrated side scan sonar
      - 1.1.2.3.3.1
    - 1.1.2.3.4 Computer facilities
      - 1.1.2.3.4.1
    - 1.1.2.3.5 Others
      - 1.1.2.3.5.1

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — **WBS SHEET no. 8**

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6

1.1 Pre-survey

From sheet no. 7

- 1.1.2.4 Equipment for seafloor* soil investigation
  - 1.1.2.4.1 Various grab samplers
    - 1.1.2.4.1.1
  - 1.1.2.4.2 Various core samplers
    - 1.1.2.4.2.1
  - 1.1.2.4.3 Various dredge samplers
    - 1.1.2.4.3.1
  - 1.1.2.4.4 Vibration samplers/in-situ testing
    - 1.1.2.4.4.1
  - 1.1.2.4.5 Underwater camera and video
    - 1.1.2.4.5.1
  - 1.1.2.4.6 Accessories, wirerope, blocks, meterwheels, etc.
    - 1.1.2.4.6.1
- 1.1.2.5 Equipment for gathering* of meteorological, environmental and oceanographic data
  - 1.1.2.5.1 Multipurpose oceanograpic buoys
    - 1.1.2.5.1.1
  - 1.1.2.5.2 Wave riders, current meters, tide gauges
    - 1.1.2.5.2.1
  - 1.1.2.5.3 Specific requirement for measurement of sound velocity
    - 1.1.2.5.3.1
  - 1.1.2.5.4 Recording of wind, air, temperature and pressure
    - 1.1.2.5.4.1

1.1.3 Survey vessel personnel

- 1.1.3.1 Ship's crew
  - 1.1.3.1.1
- 1.1.3.2 Survey crew
  - 1.1.3.2.1
- 1.1.3.3 Scientific personnel
  - 1.1.3.3.1
- 1.1.3.4 Personnel for QA & safety
  - 1.1.3.4.1
- 1.1.3.5 Client's representation
  - 1.1.3.5.1
- 1.1.3.6 Work permits/crew changes
  - 1.1.3.6.1
- 1.1.3.7 Recruitment and training of personnel
  - 1.1.3.7.1

1.1.4 Survey data processing, interpretation and reporting

- 1.1.4.1 Preprocessing
  - 1.1.4.1.1 Survey programmes
    - 1.1.4.1.1.1
  - 1.1.4.1.2 Track charts
    - 1.1.4.1.2.1
  - 1.1.4.1.3 Special maps
    - 1.1.4.1.3.1

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

1.1 Pre-survey

From sheet no. 8

- 1.1.4.2 Onboard processing and interpretation
  - 1.1.4.2.1 Data collecting formats — 1.1.4.2.1.1
  - 1.1.4.2.2 Map standards, scales, legends etc. — 1.1.4.2.2.1
  - 1.1.4.2.3 Data reduction, storage and retrival — 1.1.4.2.3.1
  - 1.1.4.2.4 Processing of navigation data — 1.1.4.2.4.1
  - 1.1.4.2.5 Processing of geophysical data — 1.1.4.2.5.1
  - 1.1.4.2.6 Processing of geological data — 1.1.4.2.6.1
  - 1.1.4.2.7 Reporting — 1.1.4.2.7.1
- 1.1.4.3 Onshore processing and interpretation
  - 1.1.4.3.1 Personnel — 1.1.4.3.1.1
  - 1.1.4.3.2 Office facilities and accommodation — 1.1.4.3.2.1
  - 1.1.4.3.3 Computer capacity — 1.1.4.3.3.1
  - 1.1.4.3.4 Post-survey processing of data and interpretation — 1.1.4.3.4.1
  - 1.1.4.3.5 Physical storage of data — 1.1.4.3.5.1
- 1.1.4.4 Presentation of results and reporting
  - 1.1.4.4.1 Internal reports — 1.1.4.4.1.1
  - 1.1.4.4.2 Field progress reports — 1.1.4.4.2.1
  - 1.1.4.4.3 Reports on equipment performance — 1.1.4.4.3.1
  - 1.1.4.4.4 Report on personnel management — 1.1.4.4.4.1
  - 1.1.4.4.5 Reports to clients — 1.1.4.4.5.1
  - 1.1.4.4.6 Scientific reports — 1.1.4.4.6.1
  - 1.1.4.4.7 Project reports — 1.1.4.4.7.1
  - 1.1.4.4.8 Feedback reports to project planning unit and survey unit — 1.1.4.4.8.1

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

1.2 Detail survey*

- 1.2.1 Survey vessel*
  - 1.2.1.1 Availability of present survey vessels
    - 1.2.1.1.1 Refit/conversion
      - 1.2.1.1.1.1
    - 1.2.1.1.2 Agents/domestic network
      - 1.2.1.1.2.1
    - 1.2.1.1.3 Local suppliers and support
      - 1.2.1.1.3.1
    - 1.2.1.1.4 Organization/infrastructure quality assurance and safety
      - 1.2.1.1.4.1
    - 1.2.1.1.5 Finance/contracting
      - 1.2.1.1.5.1
  - 1.2.1.2 New build of survey vessel
    - 1.2.1.2.1
- 1.2.2 Survey vessel equipment
  - 1.2.2.1 Ship instrumentation
    - 1.2.2.1.1 Standard instruments
      - 1.2.2.1.1.1
    - 1.2.2.1.2 Radio communication
      - 1.2.2.1.2.1
    - 1.2.2.1.3 Navigation and positioning
      - 1.2.2.1.3.1
    - 1.2.2.1.4 Deck machinery
      - 1.2.2.1.4.1
    - 1.2.2.1.5 Deck space and laboratory facilities
      - 1.2.2.1.5.1
  - 1.2.2.2 Survey navigation and positioning equipment
    - 1.2.2.2.1 Repeator output from log and gyro
      - 1.2.2.2.1.1
    - 1.2.2.2.2 Satellite navigation (transit and GPS)
      - 1.2.2.2.2.1
    - 1.2.2.2.3 Hydroacoustic positioning reference system
      - 1.2.2.2.3.1
    - 1.2.2.2.4 Bottom transponders for re-entry purposes
      - 1.2.2.2.4.1
    - 1.2.2.2.5 Seafloor transpoder chain for positioning deep towed sensors*
      - 1.2.2.2.5.1
    - 1.2.2.2.6 Navigation computer and software for online processing
      - 1.2.2.2.6.1
  - 1.2.2.3 Geophysical equipment for providing data on bathymetry and seafloor 'opograpy and composition
    - 1.2.2.3.1 Sub-bootom sedement profiler
      - 1.2.2.3.1.1
    - 1.2.2.3.2 General purpose deep-water echo sounder
      - 1.2.2.3.2.1
    - 1.2.2.3.3 Multibeam echo sounder with integrated side scan sonar
      - 1.2.2.3.3.1
    - 1.2.2.3.4 Towed instrument platform* with "instruments"
      - 1.2.2.3.4.1
    - 1.2.2.3.5 Computer facilities
      - 1.2.2.3.5.1
    - 1.2.2.3.6 Others
      - 1.2.2.3.6.1

Cont. sheet no. 11

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

1.2 Detail survey

From sheet no. 10

- 1.2.2.4 Equipment for seafloor soil investigation
  - 1.2.2.4.1 Various grab samplers
    - 1.2.2.4.1.1
  - 1.2.2.4.2 Various core samplers
    - 1.2.2.4.2.1
  - 1.2.2.4.3 Various dredge samplers
    - 1.2.2.4.3.1
  - 1.2.2.4.4 Vibration samplers/in-situ testing
    - 1.2.2.4.4.1
  - 1.2.2.4.5 Underwater camera and video
    - 1.2.2.4.5.1
  - 1.2.2.4.6 Accessories, wirerope, blocks, meterwheels, etc.
    - 1.2.2.4.6.1
- 1.2.2.5 Equipment for gathering of meteorological, environmental and oceanographic data
  - 1.2.2.5.1 Multipurpose oceanograpic buoys
    - 1.2.2.5.1.1
  - 1.2.2.5.2 Wave riders, current meters, tide gauges
    - 1.2.2.5.2.1
  - 1.2.2.5.3 Specific requirement for measurement of sound velocity
    - 1.2.2.5.3.1
  - 1.2.2.5.4 Recording of wind, air, temperature and pressure
    - 1.2.2.5.4.1

1.2.3 Survey vessel personnel

- 1.2.3.1 Ship's crew
  - 1.2.3.1.1
- 1.2.3.2 Survey crew
  - 1.2.3.2.1
- 1.2.3.3 Scientific personnel
  - 1.2.3.3.1
- 1.2.3.4 Personnel for QA & safety
  - 1.2.3.4.1
- 1.2.3.5 Client's representation
  - 1.2.3.5.1
- 1.2.3.6 Work permits/crew changes
  - 1.2.3.6.1
- 1.2.3.7 Recruitment and training of personnel
  - 1.2.3.7.1

1.2.4 Survey data processing, interpretation and reporting

- 1.2.4.1 Preprocessing
  - 1.2.4.1.1 Survey programmes
    - 1.2.4.1.1.1
  - 1.2.4.1.2 Track charts
    - 1.2.4.1.2.1
  - 1.2.4.1.3 Special maps
    - 1.2.4.1.3.1

1. POLYMETALLIC NODULE DATA ACQUISITION PLAN (Prospecting/Exploration)

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
1.2 Detail survey	From sheet no. 11		
	1.2.4.2 Onboard processing and interpretation	1.2.4.2.1 Data collecting formats	1.2.4.2.1.1
		1.2.4.2.2 Map standards, scales, legends etc.	1.2.4.2.2.1
		1.2.4.2.3 Data reduction, storage and retrival	1.2.4.2.3.1
		1.2.4.2.4 Processing of navigation data	1.2.4.2.4.1
		1.2.4.2.5 Processing of geophysical data	1.2.4.2.5.1
		1.2.4.2.6 Processing of geological data	1.2.4.2.6.1
		1.2.4.2.7 Reporting	1.2.4.2.7.1
	1.2.4.3 Onshore processing and interpretation	1.2.4.3.1 Personnel	1.2.4.3.1.1
		1.2.4.3.2 Office facilities and accommodation	1.2.4.3.2.1
		1.2.4.3.3 Computer capacity	1.2.4.3.3.1
		1.2.4.3.4 Post-survey processing of data and interpretation	1.2.4.3.4.1
		1.2.4.3.5 Physical storage of data	1.2.4.3.5.1
	1.2.4.4 Presentation of results and reporting	1.2.4.4.1 Internal reports	1.2.4.4.1.1
		1.2.4.4.2 Field progress reports	1.2.4.4.2.1
		1.2.4.4.3 Reports on equipment performance	1.2.4.4.3.1
		1.2.4.4.4 Report on personnel management	1.2.4.4.4.1
		1.2.4.4.5 Reports to clients	1.2.4.4.5.1
		1.2.4.4.6 Scientific reports	1.2.4.4.6.1
		1.2.4.4.7 Project reports	1.2.4.4.7.1
		1.2.4.4.8 Feedback reports to project planning unit and survey unit	1.2.4.4.8.1

1.3 Other surveys

1.3.1 Survey to report pilot mining operation and nodule transport

1.3.2 Survey to support investigations for possible harbour site

1.3.3 Survey for deployment and retri val of oceanographic buoys

1.3.4 Any surveys requisted by project if required to ensure project activity implementation

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

2. MINING PROJECT

LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | LEVEL 6

2.1 State of the art in ocean mining*

- 2.1.1 Available technology
  - 2.1.1.1
- 2.1.2 Necessary research* and development
  - 2.1.2.1

2.2 Bottom unit

- 2.2.1 Bottom unit engineering
  - 2.2.1.1 Design basis*
    - 2.2.1.1.1 Problem definition
      - 2.2.1.1.1.1
    - 2.2.1.1.2 Design criteria
      - 2.2.1.1.2.1
    - 2.2.1.1.3 Economical aspects
      - 2.2.1.1.3.1
  - 2.2.1.2 Structure design*
    - 2.2.1.2.1 Vehicle Frame
      - 2.2.1.2.1.1
    - 2.2.1.2.2 Jumper
      - 2.2.1.2.2.1
    - 2.2.1.2.3 Buffer storage
      - 2.2.1.2.3.1
    - 2.2.1.2.4 Attachments
      - 2.2.1.2.4.1
    - 2.2.1.2.5 Connections
      - 2.2.1.2.5.1
  - 2.2.1.3 Power system design*
    - 2.2.1.3.1 Power source
      - 2.2.1.3.1.1
    - 2.2.1.3.2 Transmission
      - 2.2.1.3.2.1
  - 2.2.1.4 Instrumentation system* design
    - 2.2.1.4.1 Instruments*
      - 2.2.1.4.1.1
    - 2.2.1.4.2 Signal transmission*
      - 2.2.1.4.2.1
  - 2.2.1.5 Mechanical system*
    - 2.2.1.5.1 Propulsion*
      - 2.2.1.5.1.1
    - 2.2.1.5.2 Steering/manoeuvering*
      - 2.2.1.5.2.1
    - 2.2.1.5.3 Nodule pic up*
      - 2.2.1.5.3.1
    - 2.2.1.5.4 Nodule treatment*
      - 2.2.1.5.4.1
    - 2.2.1.5.5 Nodule transfer*
      - 2.2.1.5.5.1
    - 2.2.1.5.6 Buffer storage unit*
      - 2.2.1.5.6.1
    - 2.2.1.5.7 Control*
      - 2.2.1.5.7.1

2. MINING OPERATION

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

2.2 Bottom unit

From sheet no. 13

- 2.2.1.6 Errosion and corrosion* protection
  - 2.2.1.6.1 Coating
    - 2.2.1.6.1.1
  - 2.2.1.6.2 Cathodic system
    - 2.2.1.6.2.1
- 2.2.1.7 RAM*
  - 2.2.1.7.1 Reliability*
    - 2.2.1.7.1.1
  - 2.2.1.7.2 Availability*
    - 2.2.1.7.2.1
  - 2.2.1.7.3 Maintainability*
    - 2.2.1.7.3.1
- 2.2.1.8 IMR*
  - 2.2.1.8.1 Inspection
    - 2.2.1.8.1.1
  - 2.2.1.8.2 Maintenance
    - 2.2.1.8.2.1
  - 2.2.1.8.3 Repair
    - 2.2.1.8.3.1
- 2.2.1.9 Emergency prepareness*
  - 2.2.1.9.1 Safety during engineering phase
    - 2.2.1.9.1.1
  - 2.2.1.9.2 Safety during testing and fabrication
    - 2.2.1.9.2.1
  - 2.2.1.9.3 Safety during operation
    - 2.2.1.9.3.1
  - 2.2.1.9.4 Emergency prepardness
    - 2.2.1.9.4.1
- 2.2.1.10 Test and commissioning* programme
  - 2.2.1.10.1 Factory acceptance test (FAT)
    - 2.2.1.10.1.1
  - 2.2.1.10.2 Factory integration test (FIT)
    - 2.2.1.10.2.1
  - 2.2.1.8.3 Production test
    - 2.2.1.10.3.1

2.2 Bottom unit

2.2.2 Bottom unit* procurement and construction

- 2.2.2.1 Structure
  - 2.2.2.1.1 Vehicle Frame
    - 2.2.2.1.1.1
  - 2.2.2.1.2 Jumper
    - 2.2.2.1.2.1
  - 2.2.2.1.3 Buffer storage
    - 2.2.2.1.3.1
  - 2.2.2.1.4 Attachments
    - 2.2.2.1.4.1
  - 2.2.2.1.5 Connections
    - 2.2.2.1.5.1
- 2.2.2.2 Power system
  - 2.2.2.2.1 Power source
    - 2.2.2.2.1.1
  - 2.2.2.2.2 Transmission
    - 2.2.2.2.2.1

Cont. sheet no. 15

2. MINING OPERATION

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

2.2 Bottom unit

From sheet no. 14

- 2.2.2.3 Instrumentation system
  - 2.2.2.3.1 Instruments
    - 2.2.2.3.1.1
  - 2.2.2.3.2 Singnal transmission
    - 2.2.2.3.2.1
- 2.2.2.4 Mechanical system
  - 2.2.2.4.1 Propulsion
    - 2.2.2.4.1.1
  - 2.2.2.4.2 Steering/manoeuering
    - 2.2.2.4.2.1
  - 2.2.2.4.3 Nodule pick up unit
    - 2.2.2.4.3.1
  - 2.2.2.4.4 Nodule treatment unit
    - 2.2.2.4.4.1
  - 2.2.2.4.5 Nodule transfer unit
    - 2.2.2.4.5.1
  - 2.2.2.4.6 Buffer storage unit
    - 2.2.2.4.6.1
- 2.2.2.5 Corrosion protection
  - 2.2.2.5.1 Coating
    - 2.2.2.5.1.1
  - 2.2.2.5.2 Cathodic system
    - 2.2.2.5.2.1
- 2.2.2.6 IMR equipment
  - 2.2.2.6.1 Inspection tools
    - 2.2.2.6.1.1
  - 2.2.2.6.2 Maintenance tools
    - 2.2.2.6.2.1
  - 2.2.2.6.3 Repair tools
    - 2.2.2.6.3.1
- 2.2.2.7 Test equipment
  - 2.2.2.7.1

2.3 Nodule riser

2.3.1 Engineering nodule riser

- 2.3.1.1 Design basis*
  - 2.3.1.1.1 Problem definition
    - 2.3.1.1.1.1
  - 2.3.1.1.2 Design criteria
    - 2.3.1.1.2.1
  - 2.3.1.1.3 Economical aspects
    - 2.3.1.1.3.1
- 2.3.1.2 Structure design*
  - 2.3.1.2.1 Riser sections
    - 2.3.1.2.1.1
  - 2.3.1.2.2 Riser connection
    - 2.3.1.2.2.1
  - 2.3.1.2.3 Riser termination
    - 2.3.1.2.3.1
  - 2.3.1.2.4 Riser attachments

2. MINING OPERATION

LEVEL 2

LEVEL 3

2.3 Nodule riser

From sheet no. 15

LEVEL 4	LEVEL 5	LEVEL 6
2.3.1.3 Power system design	2.3.1.3.1 Power source	2.3.1.3.1.1
	2.3.1.3.2 Transmission	2.3.1.3.2.1
2.3.1.4 Instrumentation system design	2.3.1.4.1 Instruments*	2.3.1.4.1.1
	2.3.1.4.2 Singnal transmission*	2.3.1.4.2.1
2.3.1.5 Mechanical system	2.3.1.5.1 Artificial lift	2.3.1.5.1.1
	2.3.1.5.2 Control system	2.3.1.5.2.1
2.3.1.6 Corrosion protection* design	2.3.1.6.1 Coating	2.3.1.6.1.1
	2.3.1.6.2 Cathodic system	2.3.1.6.2.1
2.3.1.7 RAM*	2.3.1.7.1 Reliability*	2.3.1.7.1.1
	2.3.1.7.2 Availability*	2.3.1.7.2.1
	2.3.1.7.3 Maintainability*	2.3.1.7.3.1
2.3.1.8 IMR*	2.3.1.8.1 Inspection	2.3.1.8.1.1
	2.3.1.8.2 Maintenance	2.3.1.8.2.1
	2.3.1.8.3 Repair	2.3.1.8.3.1
2.3.1.9 Emergency preparenesss*	2.3.1.9.1 Safety during the engineer phase	2.3.1.9.1.1
	2.3.1.9.2 Safety during testing and fabrication	2.3.1.9.2.1
	2.3.1.9.3 Safety during operation	2.3.1.9.3.1
	2.3.1.9.4 Emergency preparedness	2.3.1.9.4.1
2.2.1.10 Test equipment*	2.3.1.10.1 Facary acceptance test (FAT)	2.3.1.10.1.1
	2.2.1.10.2 Integration test (FIT)	2.2.1.10.2.1
	2.3.1.10.3 Production test	2.3.1.10.3.1

2. MINING OPERATION

LEVEL 2
LEVEL 3 | LEVEL 4 | LEVEL 5 | LEVEL 6

2.3 Nodule riser

- **2.3.2 Nodule riser* procurement and construction**
  - 2.3.2.1 Structure
    - 2.3.2.1.1 Riser sections
      - 2.3.2.1.1.1
    - 2.3.2.1.2 Riser connection
      - 2.3.2.1.2.1
    - 2.3.2.1.3 Riser termination
      - 2.3.2.1.3.1
    - 2.3.2.1.4 Riser attachments
      - 2.3.2.1.4.1
  - 2.3.2.2 Power system
    - 2.3.2.2.1 Power pack
      - 2.3.2.2.1.1
    - 2.3.2.2.2 Transmission
      - 2.3.2.2.2.1
  - 2.3.2.3 Instrumentation system
    - 2.3.2.3.1 Instruments
      - 2.3.2.3.1.1
    - 2.3.2.3.2 Singnal transmission
      - 2.3.2.3.2.1
  - 2.3.2.4 Mechanical system
    - 2.3.2.4.1 Artificial lift
      - 2.3.2.4.1.1
    - 2.3.2.4.2 Control system
      - 2.3.2.4.2.1
  - 2.3.2.5 Corrosion protection
    - 2.3.2.5.1 Coating
      - 2.3.2.5.1.1
    - 2.3.2.5.2 Cathodic system
      - 2.3.2.5.2.1
  - 2.3.2.6 IMR
    - 2.3.2.6.1 Inspection tools
      - 2.3.2.6.1.1
    - 2.3.2.6.2 Maintenance tools
      - 2.3.2.6.2.1
    - 2.3.2.6.3 Repair tools
      - 2.3.2.6.3.1
  - 2.3.2.7 Test equipment
    - 2.3.2.7.1

2.4 Mining vessel

- **2.4.1 Mining vessel engineering**
  - 2.4.1.1 Design basis*
    - 2.4.1.1.1 Problem definition
      - 2.4.1.1.1.1
    - 2.4.1.1.2 Design criteria
      - 2.4.1.1.2.1
    - 2.4.1.1.3 Economical aspects
      - 2.4.1.1.3.1

Cont. sheet no. 18

2. MINING OPERATION

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
2.4 Mining vessel			
From sheet no. 17			
	2.4.1.2 Vessel design	2.4.1.2.1 Main dimensions	2.4.1.2.1.1
		2.4.1.2.2 General arrangements	2.4.1.2.2.1
		2.4.1 2.3 Superstructure	2.4.1.2.3.1
		2.4.1.2.4 Turret/derrick	2.4.1.2.4.1
	2.4.1.3 Propulsion/power plant*	2.4.1.3.1 Main propulsion and thrusters	2.4.1.3.1.1
		2.4.1.3.2 Power plant	2.4.1.3.2.1
	2.3.1.4 Navigation,* instrumentation and positioning systems	2.3.1.4.1 Dynamic positioning	2.3.1.4.1.1
		2.3.1.4.2 Navigation	2.3.1.4.2.1
		2.3.1.4.3 Riser monitoring	2.3.1.4.3.1
		2.3.1.4.4 Bottom unit monitoring	2.3.1.4.4.1
		2.3.1.4.5 Storage monitoring	2.3.1.4.5.1
		2.3.1.4.6 Offloading monitoring	2.3.1.4.6.1
		2.3.1.4.7 General data transfer system	2.3.1.4.7.1
	2.4.1.5 Mechanical system* design	2.4.1.5.1 Supply handling	2.4.1.5.1.1
		2.4.1.5.2 Nodule handling	2.4.1.5.2.1
		2.4.1.5.3 Riser handling	2.4.1.5.3.1
		2.4.1.5.4 Bottom unit handling	2.4.1.5.4.1
		2.4.1.5.5 Nodule transfer system	2.4.1.5.5.1
		2.4.1.5.6 Heave compensation system	2.4.1.5.6.1
	2.4.1.6 Crew*	2.4.1.6.1 Ship crew	2.4.1.6.1.1
		2.4.1.6.2 Operation/mining crew	2.4.1.6.2.1
		2.4.1.6.3 Training and qualifications	2.4.1.6.3.1
	2.4.1.7 Corrosion protection* design	2.4.1.7.1 Coating	2.4.1.7.1.1
		2.4.1.7.2 Cathodic system	

2. MINING OPERATION

LEVEL 2
LEVEL 3   LEVEL 4   LEVEL 5   LEVEL 6

2.4 Mining vessel

From sheet no. 18

- 2.4.1.8 RAM*
  - 2.4.1.8.1 Reliability*
    - 2.4.1.8.1.1
  - 2.4.1.8.2 Availability*
    - 2.4.1.8.2.1
  - 2.4.1.8.3 Maintainability*
    - 2.4.1.8.3.1
- 2.4.1.9 IMR*
  - 2.4.1.9.1 Inspection
    - 2.4.1.9.1.1
  - 2.4.1.9.2 Maintenance
    - 2.4.1.9.2.1
  - 2.4.1.9.3 Repair
    - 2.4.1.9.3.1
- 2.4.1.10 Emergency prepareness*
  - 2.4.1.10.1 Safety during the engineer phase
    - 2.4.1.10.1.1
  - 2.4.1.10.2 Safety during testing and fabrication
    - 2.4.1 10.2.1
  - 2.4.1.10.3 Safety during operation
    - 2.4.1.10.3.1
  - 2.4.1.10.4 Emergency preparedness
    - 2.4.1.10.4.1
- 2.2.1.11 Test procedures*
  - 2.4.1.11.1 Facary acceptance test (FAT)
    - 2.4.1.11.1.1
  - 2.4.1.11.2 Integration test (FIT)
    - 2.4.1.11.2.1
  - 2.4.1.11.3 Production test
    - 2.4.1.11.3.1

2.4 Mining vessel

- 2.4.2 Mining vessel* procurement and construction
  - 2.4.2.1 Structure
    - 2.4.2.1.1 Main dimensions
      - 2.4.2.1.1.1
    - 2.4.2.1.2 General arrangements
      - 2.4.2.1.2.1
    - 2.4.2.1.3 Superstructure
      - 2.4.2.1.3.1
    - 2.4.2.1.4 Turret/derrick
      - 2.4.2.1.4.1
  - 2.4.2.2 Propulsion/power plant
    - 2.4.2.2.1 Main propulsion and thrusters
      - 2.4.2.2.1.1
    - 2.4.2.2.2 Power plant
      - 2.4.2.2.2.1

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WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 20

2. MINING OPERATION

LEVEL 2

LEVEL 3

2.4 Mining vessel

From sheet no. 19

LEVEL 4	LEVEL 5	LEVEL 6
2.4.2.3 Navigation, instrumentation and positioning systems	2.4.2.3.1 Dynamic positioning	2.4.2.3.1.1
	2.4.2.3.2 Navigation	2.4.2.3.2.1
	2.4.2.3.3 Riser monitoring	2.4.2.3.3.1
	2.4.2.3.4 Bottom unit monitoring	2.4.2.3.4.1
	2.4.2.3.5 Storage monitoring	2.4.2.3.5.1
	2.4.2.3.6 Offloading monitoring	2.4.2.3.6.1
	2.4.2.3.7 General data transfer system	2.4.2.3.7.1
2.4.2.4 Mechanical system	2.4.2.4.1 Supply handling	2.4.2.4.1.1
	2.4.2.4.2 Nodule handling	2.4.2.4.2.1
	2.4.2.4.3 Riser handling	2.4.2.4.3.1
	2.4.2.4.4 Bottom unit handling	2.4.2.4.4.1
	2.4.2.4.5 Nodule transfer system	2.4.2.4.5.1
2.4.2.5 Crew	2.4.2.5.1 Ship crew	2.4.2.5.1.1
	2.4.2.5.2 Operation/mining crew	2.4.2.5.2.1
2.4.2.6 Corrosion protection	2.4.2.6.1 Coating	2.4.2.6.1.1
	2.4.2.6.2 Cathodic system	2.4.2.6.2.1
2.4.2.7 IMR	2.4.2.7.1 Inspection tools	2.4.2.7.1.1
	2.4.2.7.2 Maintenance tools	2.4.2.7.2.1
	2.4.2.7.3 Repair	2.4.2.7.3.1
2.4.2.8 Test equipment	2.4.2.8.1	

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — WBS SHEET no. 21

3. TRANSPORTATION

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

3.1 Transport design premises and tasks

- 3.1.1 Nodule transport*
  - 3.1.1.1 Mining vessel* characteristics
    - 3.1.1.1.1 Max. operating condition
      - 3.1.1.1.1.1
    - 3.1.1.1.2 Vessel configuration during transfer
      - 3.1.1.1.2.1
    - 3.1.1.1.3 Dynamic behaviour
      - 3.1.1.1.3.1
    - 3.1.1.1.4 Maximum speed during transfer
      - 3.1.1.1.4.1
    - 3.1.1.1.5 Production volume
      - 3.1.1.1.5.1
    - 3.1.1.1.6 Layout transfer equipment
      - 3.1.1.1.6.1
    - 3.1.1.1.7 Power supply to transfer equipment
      - 3.1.1.1.7.1
    - 3.1.1.1.8 Positioning system
      - 3.1.1.1.8.1
    - 3.1.1.1.9 Training of personnel for transfer operation
      - 3.1.1.1.9.1
  - 3.1.1.2 Ocean transport vessel characteristics
    - 3.1.1.2.1 Evaluation of system
      - 3.1.1.2.1.1
    - 3.1.1.2.2 Max. operating condition
      - 3.1.1.2.2.1
    - 3.1.1.2.3 Speed
      - 3.1.1.2.3.1
    - 3.1.1.2.4 Power plant
      - 3.1.1.2.4.1
    - 3.1.1.2.5 Propulsion
      - 3.1.1.2.5.1
    - 3.1.1.2.6 Dynamic positioning system
      - 3.1.1.2.6.1
    - 3.1.1.2.7 Port restrictions
      - 3.1.1.2.7.1
  - 3.1.1.3 Transfer plant on* mining vessel
    - 3.1.1.3.1 Evaluation of transfer system
      - 3.1.1.3.1.1
    - 3.1.1.3.2 Buffer
      - 3.1.1.3.2.1
    - 3.1.1.3.3 Nodule treatment
      - 3.1.1.3.3.1
    - 3.1.1.3.4 Power requirement
      - 3.1.1.3.4.1

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — **WBS SHEET no. 22**

3. TRANSPORTATION

LEVEL 2
LEVEL 3 — **LEVEL 4** — **LEVEL 5** — **LEVEL 6**

3.1 Transport design premises and task

From sheet no. 21

- 3.1.1.4 Transfer to ocean* transport vessel (OTV)
  - 3.1.1.4.1 Evaluation of system
    - 3.1.1.4.1.1
  - 3.1.1.4.2 Cargo consistency
    - 3.1.1.4.2.1
  - 3.1.1.4.3 Connection system
    - 3.1.1.4.3.1
  - 3.1.1.4.4 Operation of transfer connecting system
    - 3.1.1.4.4.1
  - 3.1.1.4.5 Operating condition
    - 3.1.1.4.5.1
  - 3.1.1.4.6 Transfer vessel configuration
    - 3.1.1.4.6.1
  - 3.1.1.4.7 Reciving plant on OTV
    - 3.1.1.4.7.1
  - 3.1.1.4.8 Hook up system
    - 3.1.1.4.8.1
  - 3.1.1.4.9 Handling equipment
    - 3.1.1.4.9.1
  - 3.1.1.4.10 Transport/transfer support vessel
    - 3.1.1.4.10.1
  - 3.1.1.4.11 Operating procedures
    - 3.1.1.4.11.1
  - 3.1.1.4.12 Max. vessel speed during transfer operation
    - 3.1.1.4.12.1
  - 3.1.1.4.13 Traning of personnel
    - 3.1.1.4.13.1
- 3.1.1.5 OTV reciving system
  - 3.1.1.5.1 Connecting system
    - 3.1.1.5.1.1
  - 3.1.1.5.2 Cargo consistency
    - 3.1.1.5.2.1
  - 3.1.1.5.3 Capacity of reciving system
    - 3.1.1.5.3.1
- 3.1.1.6 OTV on board cargo* handling
  - 3.1.1.6.1 Operating condition (wheather/operation)
    - 3.1.1.6.1.1
  - 3.1.1.6.2 Storing
    - 3.1.1.6.2.1
  - 3.1.1.6.3 Nodule treatment
    - 3.1.1.6.3.1
  - 3.1.1.6.4 Cargo distribution on OTV
    - 3.1.1.6.4.1
  - 3.1.1.6.5 Cargo consistency
    - 3.1.1.6.5.1
  - 3.1.1.6.6 Setteling process
    - 3.1.1.6.6.1
  - 3.1.1.6.7 Cargo hold layout
    - 3.1.1.6.7.1

3. TRANSPORTATION

LEVEL 2 — LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

3.1 Transport design premises and task

From sheet no. 22

- 3.1.1.7 OTV discharge system
  - 3.1.1.7.1 Evaluation of system → 3.1.1.7.1.1
  - 3.1.1.7.2 Layout in port → 3.1.1.7.2.1
  - 3.1.1.7.3 Discharging capacities → 3.1.1.7.3.1
  - 3.1.1.7.4 Capacities on board → 3.1.1.7.4.1
- 3.1.1.8 Facilities on shore
  - 3.1.1.8.1 Areas available (settling plant) → 3.1.1.8.1.1
  - 3.1.1.8.2 Processing → 3.1.1.8.2.1
  - 3.1.1.8.3 Habour limitations → 3.1.1.8.3.1

3.2 Transport of spares and provisions

- 3.2.1 Input parameters provisions
  - 3.2.1.1 Supplies → 3.2.1.1.1
  - 3.2.1.2 Spares → 3.2.1.2.1
  - 3.2.1.3 Fuel oil/lub. oil → 3.2.1.3.1
  - 3.2.1.4 Waste from site → 3.2.1.4.1
- 3.2.2 Spares & provisions transport system
  - 3.2.2.1 Ocean transport vessel → 3.2.2.1.1
  - 3.2.2.2 Special vessel → 3.2.2.2.1
- 3.2.3 Spares & provisions transport at site
  - 3.2.3.1 Fuel supply → 3.2.3.1.1
  - 3.2.3.2 Provisions → 3.2.3.2.1

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 24

3. TRANSPORTATION

LEVEL 2 — LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

3.3 Transport of personnel*

- 3.3.1 Input parameters personnel transport
  - 3.3.1.1 Number of personnel
    - 3.3.1.1.1
  - 3.3.1.2 Scheduled transport
    - 3.3.1.2.1
  - 3.3.1.3 Unscheduled transport
    - 3.3.1.3.1
  - 3.3.1.4 Emergency
    - 3.3.1.4.1
- 3.3.2 Personnel transport system to site
  - 3.3.2.1 Ocean transport vessel
    - 3.3.2.1.1
  - 3.3.2.2 Helicopter
    - 3.3.2.2.1
  - 3.3.2.3 High speed vessel
    - 3.3.2.3.1
  - 3.3.2.4 Airplane
    - 3.3.2.4.1
- 3.3.3 Personnel transport system at site
  - 3.3.3.1 Support vessel
    - 3.3.3.1.1
  - 3.3.3.2 Helicopter
    - 3.3.3.2.1

3.4 Transport of waste from onshore processing*

3.5 Technical/economical evaluation of transport systems*

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — WBS SHEET no. 25

4. SHORE TERMINAL

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
4.1 Pre-investigations			
4.1.1 Onland survey	4.1.1.1 Mapping	4.1.1.1.1	
	4.1.1.2 Site investigation	4.1.1.2.1	
4.1.2 Near shore survey*	4.1.2.1 Mapping	4.1.2.1.1 Land	4.1.2.1.1.1
		4.1.2.1.2 Coastal zone	4.1.2.1.2.1
		4.1.2.1.3 Water depths	4.1.2.1.3.1
	4.1.2.2 Site selection*	4.1.2.2.1 Approach from sea	4.1.2.2.1.1
		4.1.2.2.2 Approach from land	4.1.2.2.2.1
		4.1.2.2.3 Climatic conditions	4.1.2.2.3.1
		4.1.2.2.4 Port construction possibilities	4.1.2.2.4.1
	4.1.2.3 Hydraulic models*	4.1.2.3.1 Numerical models	4.1.2.3.1.1
		4.1.2.3.2 Physical models	4.1.2.3.2.1
4.1.3 Seawards access* route survey	4.1.3.1 Mapping	4.1.3.1.1 Land contours	4.1.3.1.1.1
		4.1.3.1.2 Sea charting	4.1.3.1.2.1
	4.1.3.2 Access routing*	4.1.3.2.1 Offshore routing	4.1.3.2.1.1
		4.1.3.2.2 Coastal zone approach	4.1.3.2.2.1
		4.1.3.2.3 Entrance to harbour	4.1.3.2.3.1
	4.1.3.3 Anchorage*	4.1.3.3.1 Offshore anchorage	4.1.3.3.1.1
		4.1.3.3.2 Approach zone anchorage	4.1.3.3.2.1
4.1.4 Geotechnical survey*	4.1.4.1 Soil characteristics*	4.1.4.1.1 Dredging equipment	4.1.4.1.1.1
		4.1.4.1.2 Reclamation purposes	4.1.4.1.2.1

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — **WBS SHEET no. 26**

4. SHORE TERMINAL

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
4.1 Pre-investigations			
4.1.5 Environmental survey*	4.1.5.1 Tides*	4.1.5.1.1	
	4.1.5.2 Waves*	4.1.5.2.1 Brakwater layout and* stability	4.1.5.2.1.1
	4.1.5.3 Currents*	4.1.5.3.1	
	4.1.5.4 Winds*	4.1.5.4.1	
	4.1.5.5 Littoral drift*	4.1.5.5.1	
	4.1.5.6 Sedimentation*	4.1.5.6.1	
4.1.6 Logistic planning*	4.1.6.1 Ship characteristics	4.1.6.1.1	
	4.1.6.2 Navigational aids*	4.1.6.2.1	
	4.1.6.3 Radio communication	4.1.6.3.1	
	4.1.6.4 Traffic management*	4.1.6.4.1 Environmental aspects*	4.1.6.4.1.1
4.2 Ore-discharge terminal*			
4.2.1 Safety*	4.2.1.1 Specifications safety*	4.2.1.1.1	
	4.2.1.2 Design safety*	4.2.1.2.1	
	4.2.1.3 Construction safety*	4.2.1.3.1	
	4.2.1.4 Personnel safety*	4.2.1.4.1	
	4.2.1.5 Operational safety*	4.2.1.5.1	
4.2.2 Harbour basin	4.2.2.1 Approach lanes	4.2.2.1.1	
	4.2.2.2 Protective measures	4.2.2.2.1	
	4.2.2.3 Water depths	4.2.2.3.1	
	4.2.2.4 Manouering areas	4.2.2.4.1	
	4.2.2.5 Anchorage areas	4.2.2.5.1	
4.2.3 Berths	4.2.3.1 Berths structures*	4.2.2.1.1	
	4.2.3.2 Design loads*	4.2.2.2.1	
	4.2.3.3 Berth equipment*	4.2.2.3.1	
	4.2.3.4 [illegible]		

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT — WBS SHEET no. 27

4. SHORE TERMINAL

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
4.2 Ore-discharge terminal			
4.2.4 Berthing operations	4.2.4.1 Vessel traffic system*	4.2.2.1.1	
	4.2.4.2 Berthing and de-berthing*	4.2.2.2.1	
	4.2.4.3 Berthing aid system*	4.2.2.3.1	
	4.2.4.4 Availability of habour*	4.2.2.4.1	
4.2.5 Di charge* procedures	4.2.5.1 Ship equipment	4.2.5.1.1	
	4.2.5.2 Land based equipment*	4.2.5.2.1	
4.2.6 Storage*	4.2.6.1 Open areas	4.2.6.1.1	
	4.2.6.2 Sheltered areas	4.2.6.2.1	
4.3 Supply base*			
4.3.1 Safety	4.3.1.1 Specifications safety	4.3.1.1.1	
	4.3.1.2 Design safety	4.3.1.2.1	
	4.3.1.3 Construction safety	4.3.1.3.1	
	4.3.1.4 Personnel safety	4.3.1.4.1	
	4.3.1.5 Operational safety	4.3.1.5.1	
4.3.2 Harbour basin	4.3.2.1 Approach lanes	4.3.2.1.1	
	4.3.2.2 Protective measures	4.3.2.2.1	
	4.3.2.3 Access routing	4.3.2.3.1	
	4.3.2.4 Manouering areas	4.3.2.4.1	
	4.3.2.5 Anchoraje areas	4.3.2.5.1	
4.3.3 Berths	4.3.3.1 Berths structures	4.3.2.1.1	
	4.3.3.2 Design loads	4.3.2.2.1	
	4.3.3.3 Berth equipment	4.3.2.3.1	
	4.3.3.4 Erosion protection	4.3.2.4.1	

4. SHORE TERMINAL

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
4.3 Supply base*			
4.3.4 Berthing operations	4.3.4.1 Vessel traffic system	4.3.2.1.1	
	4.3.4.2 Berthing and de-berthing	4.3.2.2.1	
	4.3.4.3 Berthing aid system	4.3.2.3.1	
	4.3.4.4 Availability of habour	4.3.2.4.1	
4.3.5 Discharge procedures	4.3.5.1 Ship equipment	4.3.5.1.1	
	4.3.5.2 Land based equipment	4.3.5.2.1	
4.3.6 Temporary storage	4.3.6.1 Open areas	4.3.6.1.1	
	4.3.6.2 Sheltered areas	4.3.6.2.1	
4.4 Reagent discharge terminal*			
4.4.1 Safety	4.4.1.1 Specifications safety	4.4.1.1.1	
	4.4.1.2 Design safety	4.4.1.2.1	
	4.4.1.3 Construction safety	4.4.1.3.1	
	4.4.1.4 Personnel safety	4.4.1.4.1	
	4.4.1.5 Operational safety	4.4.1.5.1	
4.4.2 Harbour basin	4.4.2.1 Approach lanes	4.4.2.1.1	
	4.4.2.2 Protective measures	4.4.2.2.1	
	4.4.2.3 Access routing	4.4.2.3.1	
	4.4.2.4 Manouering areas	4.4.2.4.1	
	4.4.2.5 Anchorage areas	4.4.2.5.1	
4.4.3 Berths	4.4.3.1 Berths structures	4.4.2.1.1	
	4.4.3.2 Design loads	4.4.2.2.1	
	4.4.3.3 Berth equipment	4.4.2.3.1	
	4.4.3.4 Erosion protection	4.4.2.4.1	

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 29

4. SHORE TERMINAL

LEVEL 2 / LEVEL 3	LEVEL 4		LEVEL 5	LEVEL 6
4.4 Reagent discharge terminal*				
4.4.4 Berthing operations	4.4.4.1	Vessel traffic system	4.4.2.1.1	
	4.4.4.2	Berthing and de berthing	4.4.2.2.1	
	4.4.4.3	Berthing aid system	4.4.2.3.1	
	4.4.4.4	Availability of habour	4.4.2.4.1	
4.4.5 Loading/unloading procedures	4.4.5.1	Ship equipment	4.4.5.1.1	
	4.4.5.2	Land based equipment	4.4.5.2.1	
4.4.6 Temporary storage	4.4.6.1	Open areas	4.4.6.1.1	
	4.4.6.2	Sheltered areas	4.4.6 2.1	
4.5 Export/multipurpose terminal*				
4.5.1 Safety	4.5.1.1	Specifications safety	4.5.1.1.1	
	4.5.1.2	Design safety	4.5.1 2.1	
	4.5.1.3	Construction safety	4.5.1.3.1	
	4.5.1.4	Personnel safety	4.5.1.4.1	
	4.5.1.5	Operational safety	4.5.1.5.1	
4.5.2 Harbour basin	4.5.2.1	Approach lanes	4.5.2.1.1	
	4.5.2.2	Protective measures	4.5.2.2.1	
	4.5.2.3	Access routing	4.5.2.3.1	
	4.5.2.4	Manouering areas	4.5.2.4.1	
	4.5.2.5	Anchorage areas	4.5.2.5.1	
4.5.3 Berths	4.5.3.1	Berths structures	4.5.2.1.1	
	4.5.3.2	Design loads	4.5.2.2.1	
	4.5.3.3	Berth equipment	4.5.2.3.1	
	4.5.3.4	Erosion protection	4.5.2.4.1	

WORK BREAKDOWN STRUCTURE for an OCEAN MINING : **WBS SHEET no. 10**

4. SHORE TERMINAL

LEVEL 2

LEVEL 3 | **LEVEL 4** | **LEVEL 5** | **LEVEL 6**

4.5 Export/multipurpose terminal

LEVEL 3	LEVEL 4	LEVEL 5
4.5.4 Berthing operations	4.5.4.1 Vessel traffic system	4.5.2.1.1
	4.5.4.2 Berthing and de-berthing	4.5.2.2.1
	4.5.4.3 Berthing aid system	4.5.2.3.1
	4.5.4.4 Availability of habour	4.5.2.4.1
4.5.5 Loading/unloading procedures	4.5.5.1 Ship equipment	4.5.5.1.1
	4.5.5.2 Land based equipment	4.5.5.2.1
4.5.6 Transit storage area	4.5.6.1 Open areas	4.5.6.1.1
	4.5.6.2 Sheltered areas	4.5.6.2.1

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

5. PROCESS PLANT

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
5.1 Pre-investigations			
5.1.1 Onland survey	5.1.1.1 Mapping	5.1.1.1.1	
5.1.2 Geotechnical survey	5.1.2.1 Soil survey	5.1.2.1.1	
	5.1.2.2 Rock survey	5.1.2.2.1	
5.1.3 Power supply	5.1.3.1 Electrical	5.1.3.1.1	
	4.1.3.2 Gas	5.1.3.2.1	
5.1.4 Infrastructure planning	5.1.4.1 Transport systems	5.1.4.1.1 Roads	5.1.4.1.1.1
		5.1.4.1.2 Rail	5.1.4.1.2.1
		5.1.4.1.3 Pipelines	5.1.4.1.3.1
	5.1.4.2 Buildings	5.1.4.2.1 Accommodation/office	5.1.4.2.1.1
		5.1.4.2.2 Factory buildings	5.1.4.2.2.1
		5.1.4.2.3 Storage buildings	5.1.4.2.3.1
	5.1.4.3 Water supply	5.1.4.3.1 Cooling water	5.1.4.3.1.1
		5.1.4.3.2 Consumable water	5.1.4.3.2.1
5.2 Onshore transportation system			
5.2.1 Nodule transport	5.2.1.1.1Roads	5.2.1.1.1	
	5.2.1.2 Rail	5.2.1.2.1	
	5.2.1.3 Pipelines	5.2.1.3.1	
5.2.2 Reagents transport	5.2.2.1 Roads	5.2.2.1.1	
	5.2.2.2 Rail	5.2.2.2.1	
	5.2.2.3 Pipelines	5.2.2.3.1	
5.2.3 Metal transport	5.2.3.1 Roads	5.2.3.1.1	
	5.2.3.2 Rail	5.2.3.2.1	

5. PROCESS PLANT

LEVEL 2 / LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
5.2 Onshore transportation system			
5.2.4 Waste transport	5.2.4.1 Roads	5.2.4.1.1	
	5.2.4.2 Rail	5.2.4.2.1	
	5.2.4.3 Pipelines	5.2.4.3.1	
5.3 Process plant			
5.3.1 Site preparation	5.3.1.1 Soil	5.3.1.1.1	
	5.3.1.2 Rock	5.3.1.2.1	
5.3.2 Buldings	5.3.2.1 Accommodation/office	5.3.2.1.1	
	5.3.2.2 Factory buildings	5.3.2.2.1	
	5.3.2.3 Storage buildings	5.3.2.3.1	
5.3.3 Process equipment	5.3.3.1 Nodule process	5.3.3.1.1	
	5.3.3.2 Waste treatment	5.3.3.2.1	
5.3.4 Other equipment	5.3.4.1		
5.3.5 Storage	5.3.5.1 Nodule storage	5.3.5.1.1	
	5.3.5.2 Reagent storage	5.3.5.2.1	
	5.3.5.3 Metal storage	5.3.5.3.1	
5.3.6 Other facilities	5.3.6.1		
5.4 Waste disposal system			
5.4.1 Site survey	5.4.1.1 Waste basin	5.4.1.1.1	
	5.4.1.2 Access roads	5.4.1.2.1	
	5.4.1.3 Waste transport corridor	5.4.1.3.1	
5.4.2 Site preparation	5.4.2.1		
5.4.3 Deposit system	5.4.3.1		
5.4.4 Water treatment	5.4.4.1 Waste sipage water	5.4.4.1.1	

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 33

6. PROJECT SUPPORT

LEVEL 2 / LEVEL 3	LEVEL 4		LEVEL 5	LEVEL 6
6.1 Management*				
6.1.1 Prospecting and exploration adm.	6.1.1.1	Administration	6.1.1.1.1	
	6.1.1.2	Quality assurance quality control	6.1.1.2.1	
	6.1.1.3	Safety management	6.1.1.3.1	
6.1.2 Mining operation administration	6.1.2.1	Administration	6.1.2.1.1	
	6.1.2.2	Quality assurance quality control	6.1.2.2.1	
	6.1.2.3	Safety management	6.1.2.3.1	
6.1.3 Transport vessel administration	6.1.3.1	Administration	6.1.3.1.1	
	6.1.3.2	Quality assurance quality control	6.1.3.2.1	
	6.1.3.3	Safety management	6.1.3.3.1	
6.1.4 Shore terminal administration	6.1.4.1	Administration	6.1.4.1.1	
	6.1.4.2	Quality assurance quality control	6.1.4.2.1	
	6.1.4.3	Safety management	6.1.4.3.1	
6.1.5 Process plant administration	6.1.5.1	Administration	6.1.5.1.1	
	6.1.5.2	Quality assurance quality control	6.1.5.2.1	
	6.1.5.3	Safety management	6.1.5.3.1	
6.1.6 Authorities* relations	6.1.6.1			
6.1.7 Construction* management	6.1.7.1			

6. PROJECT SUPPORT

LEVEL 2 / LEVEL 3	LEVEL 4		LEVEL 5	LEVEL 6
6.2 Contract administration*				
6.2.1 Prequalifications*	6.2.1.1	Data acquistion plan	6.2.1.1.1	
	6.2.1.2	Mining operation	6.2.1.2.1	
	6.2.1.3	Transportation	6.2.1.3.1	
	6.2.1.3	Shore terminal	6.2.1.3.1	
	6.2.1.4	Process plant	6.2.1.4.1	
	6.2.1.5	Project support	6.2.1.5.1	
6.2.2 Tender invitations*	6.2.2.1	Data acquistion plan	6.2.2.1.1	
	6.2.2.2	Mining operation	6.2.2.2.1	
	6.2.2.3	Transportation	6.2.2.3.1	
	6.2.2.3	Shore terminal	6.2.2.3.1	
	6.2.2.4	Process plant	6.2.2.4.1	
	6.2.2.5	Project support	6.2.2.5.1	
6.2.3 Tender evaluations*	6.2.3.1	Data acquistion plan	6.2.3.1.1	
	6.2.3.2	Mining operation	6.2.3.2.1	
	6.2.3.3	Transportation	6.2.3.3.1	
	6.2.3.3	Shore terminal	6.2.3.3.1	
	6.2.3.4	Process plant	6.2.3.4.1	
	6.2.3.5	Project support	6.2.3.5.1	
6.2.4 Purchasing*	6.2.4.1	Data acquistion plan	6.2.4.1.1	
	6.2.4.2	Mining operation	6.2.4.2.1	
	6.2.4.3	Transportation	6.2.4.3.1	
	6.2.4.3	Shore terminal	6.2.4.3.1	
	6.2.4.4	Process plant	6.2.4.4.1	
	6.2.4.5	Project support	6.2.4.5.1	

WORK BREAKDOWN STRUCTURE for an OCEAN MINING PROJECT

WBS SHEET no. 35

6. PROJECT SUPPORT

LEVEL 2 / LEVEL 3 — LEVEL 4 — LEVEL 5 — LEVEL 6

6.3 Planning and control*

- 6.3.1 Cost control*
  - 6.3.1.1 Budgeting
    - 6.3.1.1.1
  - 6.3.1.2 Accounting
    - 6.3.1.2.1
  - 6.3.1.3 Project control
    - 6.3.1.3.1
- 6.3.2 Progress reports
  - 6.3.2.1 External reports
    - 6.3.2.1.1
  - 6.3.2.2 Internal reports
    - 6.3.2.2.1
  - 6.3.2.3 Management reports
    - 6.3.2.3.1
- 6.3.3 Project planning*
  - 6.3.3.1 Time estimates
    - 6.3.3.1.1
  - 6.3.3.2 Logistic network planning
    - 6.3.3.2.1
- 6.3.4 Document control*
  - 6.3.4.1 Filing
    - 6.3.4.1.1
  - 6.3.4.2 Document handling
    - 6.3.4.2.1