

# **Technological Challenges for Manganese Nodule Mining**

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## **ABSTRACT**

The major technological challenges of deep-sea mining venture involve delineation of mine site and development of mining technology to bring out the minerals from extreme conditions (more than 5 km water depth, 0-3 °C temperature and 500 bars pressure). A self-propelled remotely controlled collector at the end of the riser pipe may prove more efficient than a towed collector to collect 3 million tonnes of nodules annually, at 10,000 tonnes per day for 300 active days of mining. Development of an environmentally 'safe' mining system that would cause least possible damage through disturbance at the seabed, discharge at the surface and in the water column is another important consideration from conservation point of view. Collectors with a facility for crushing and filtering of nodule particles to a particular size may reduce much of the waste material from being carried and discharged at the surface. Besides delineation of mine site and development of mining technology, other aspects which need to be organised simultaneously are facilities for ship building and docking; ore transfer, transport, processing and efficient waste disposal. The success of such a large scale operation also depends on close cooperation between industry and research organisations, as well as guaranteed financial support from governmental agencies for an overall development of mineral resources.

## **INTRODUCTION**

Land reserves of strategic metals like Cu, Co, Ni and Mn, are getting depleted at alarming rates and are projected to get exhausted by the turn of the century. In an attempt to anticipate and provide contingency reserves for the projected scarcity of these metals, various countries have started a programme of exploration for marine minerals. Rich deposits of manganese nodules have been located in the Pacific, Atlantic as well as the Indian oceans [6]. Although nodules have a higher economic potential (Ni, Cu, Co, Mn), cobalt-rich crusts are also being explored, as they occur in shallower waters (1000-2000 m) and are closer to land. Extensive explorations are being carried out by various countries and consortia to determine

Table 1 — Tests for Nodule Mining Technology [Source: Ref.3]

	Agency/year	Features	Recovery
1.	Ocean Mining Company (OMCO) 1978-79	Air-lift with remote controlled self-propelled, variable speed collector of 8 × 12 m  Collector movements with propellers and syntactic foam  Crusher for proper consistency and buffer for efficient nodule transfer	1000 tonnes/day, i.e. 40 tonnes/h
2.	Ocean Mining Associates (OMA) 1977-78	Air-lift with towed collector 500 tonnes recovered during test	1200 tonnes/day, i.e. 50 tonnes/h
3.	Ocean Mgmt. Inc. (OMI) 1978	Hydraulic and air-lift with towed collector 1000 tonnes of nodules recovered during test	
4.	Kenecott 1974-75	Tested capability of towed collector	
5.	AFERNOD, 1970, '72	CLB system with two ships	

grade and abundance of marine minerals, to locate potential mine sites in different oceans [4] and some on-site tests of the mining systems have also been conducted in the 70's (Table 1). However, several challenges confront the exploitation of these reserves, which can be achieved by development of a commercial scale mining system for deep-sea minerals, identification of processes for extraction of metals, facilities for transportation of ore to the shore, development of harbours, problems of environmental impact, waste disposal, etc. This paper presents an overview of such challenges which have to be considered and overcome, as well as some of the spinoff benefits that can be realised as a result of development of nodule mining venture.

## CONSIDERATIONS FOR NODULE MINING

### Economic feasibility

The most important criterion for mining of nodule deposits is the non-availability of metals within a country and the cost of importing the metals from other countries. Supply and demand of these metals will determine the world market and exploitation of offshore minerals will be considered economical when all other resources are exhausted to sustain industrial development. Hence, market

trends for metals, such as Ni, Cu, Co, Mn and their non-availability will decide when deep-sea mining would begin.

### Delineation of mine-site

The 'mine-site' is defined as an ocean bottom area where under specific geological, technical and economic conditions, a single mining operation can be carried out for a period of time [4]. Several factors govern the selection of a manganese nodule mine site. The cut-off abundance accepted is  $5 \text{ kg/m}^2$ , which is the lowest concentration that can be feasibly mined. The cut-off for average grade is suggested to be 1.8% of Cu + Ni. Favourable sea-bed topography and shear strength of sediments are also the prerequisites for nodule mining.

The above factors can be used to estimate the total mineable area (M) as follows:

$$M = A_t - (A_u + A_g + A_a)$$

where  $A_t$  = is the total area,  $A_u$  = area unmineable due to topography,  $A_g$  = area below cut-off grade; and  $A_a$  = area below cut-off abundance.

The proportion of unmineable area due to unfavourable factors ( $A_u$ ), with respect to the total area ( $A_t$ ) can be calculated as:  $A_u/A_t$ , which is generally accepted to be less than 20%. The size of mine site ( $A_s$ ) can be calculated as :

$$A_s = \frac{(A_r) (D)}{(C) (E) (M)}$$

where  $A_s$  = size of mine-site ( $\text{km}^2$ ),  $A_r$  = annual nodule recovery rate (dmt/year),  $D$  = duration of mining operation (years),  $C$  = average nodule abundance in mineable area (dmt/ $\text{km}^2$ ),  $E$  = overall mining efficiency (%), and  $M$  = proportion of mineable area.

Detailed two-dimensional exploration methods are necessary for delineation of mine-site. The techniques include *in situ* measurements on sediment for shear strength, tethered and freefall sampling for laboratory analysis, multibeam echosounding for high resolution mapping complemented by deep-towed sounding (1 m or less resolution), sediment profiling, side scan sonar data and underwater imaging with video and photographs. Geostatistical methods for evaluation of data along with the use of computer models is used for delineating potential mining areas. A systematic acquisition as well as compilation, storage, analysis and dissemination of data on marine minerals can ensure reliable identification of a potential reserve [8,10].

### Development of mining system

Mining systems for deep-sea minerals (e.g. nodules) are based on the following three alternative concepts [3]:

- (i) Hydraulic mining system: This system uses the principle of hydraulics in lifting the nodules. A collector mechanism is linked to the end of a pipe,

through which the nodules are lifted using pumps or compressed air injected into the pipe.

- (ii) Continuous line bucket system: This system uses a chain of buckets driven along a line, which go down empty from the stern of the ship and come up partially filled after scooping the nodules from the sea-bed.
- (iii) Modular mining system : In this system, a self-propelled collector (shuttle) is launched with a ballast. As the shuttle moves on the seafloor, the nodules are collected and the ballast is released on an equal weight on water basis. When mining is terminated, some more ballast is ejected; so the vehicle weight is slightly negative. The shuttle is propelled by thrusters, docked to the ship, unloaded and launched for mining.

Since the mining system is to be operated in several kilometres of water depth, it requires a system which is dynamically positioned, remotely operated and can negotiate different types of environmental hazards, such as obstacles on the seafloor, currents in the water column and climatic variations on the surface. The nodule collector should be a self-propelled, actively positioning dredge head instead of a passive collector manouvered from the ship and hence uneconomical. Cost effectiveness of mining depends upon selective mining of ore and screening of the substrate at the ocean floor for which the collector has to be so designed so as to differentiate the ore from the debris at the seabed.

The efficiency of deep-sea mining also depends on the system utilised for lifting the minerals to the surface. Whereas the air-lift system has a higher energy consumption, it is easier to maintain, as the compressors are at the water surface; the pump-lift, which needs lesser power, is difficult to maintain due to underwater pump systems. The pump-lift allows higher transport densities (50 %) and hence needs smaller pipes for lifting the nodules. Although the air-lift lacks in complicated machinery, its energy requirement is 2-3 times higher [2]. An autonomous collector module launched from the ship may make the operation faster and easier, but its development before the first generation mining is not assured.

The overall efficiency (E) of a mining system is expected to be more than 50% and can be calculated as:

$$E = e_d \times e_s$$

where  $e_d$  = dredge efficiency, which is the ratio of marine minerals effectively gathered by the dredge head, *versus* the minerals on the seabed before dredging, and  $e_s$  = sweep efficiency, which is the percentage of the bottom area dredged.

### Ore transfer

The deep-sea mining venture requires the construction of a large mining vessel (100 kt displacement) with facilities for handling massive equipment, storage, accommodation and offshore processing; as well as transport vessels to carry the ores to the shore for metallurgical extraction [1]. This requires extensive ship-

building capabilities as well as development of harbours and facilities for ore transfer from the mining ship to carriers, carriers to shore and shore to processing plants.

Optimisation of cost of ore transfer can be achieved by transporting only the concentrates (and no raw ore) after offshore processing as well as efficient deployment of two-way transport vessels to bring the personnel, supplies and fuel to the mining platform and take ore back to land for which the existing dual-role vessels of about 100,000 tonnes dwt may be modified [2].

### **Metallurgical processing**

Extensive knowledge exists on beneficiation and extraction of metals from land deposits, which can be suitably modified for marine minerals. However, before deciding the metallurgical process for these minerals, a decision must be taken on the requirement of metals: whether three strategic minerals (Ni, Cu, Co) or more (Mn, Fe, Zn, Pb) have to be extracted. This will once again depend on the cost of production *versus* the prevailing market price of these metals.

Besides identification of the route for onshore processing, the economics of offshore mining also depends on reduction in the cost of transportation of these minerals. Partial offshore processing, i.e. concentration of ore (up to 40-50 %) by removal of gangue and reduction in water content, can effectively increase the economic potential of these deposits.

### **Environmental monitoring and management**

The need to collect environmental data is two-fold:

- (i) collect meteorological, chemical and physical information of the water column and geological and geotechnical data on the seafloor, for the development and design of a suitable mining system for commercial exploitation of the minerals, and
- (ii) collect baseline biological, chemical and physical data which can be used as a reference for post-mining studies to assess the impact of mining activities.

Where as extensive data on distribution, abundance, and grade of the minerals will determine the exploitability of the deposit, geological and geotechnical information on features associated with them, such as rocks, sediments, etc; and variations in topography will determine the design and manoeuvrability of the mining system [11,12]. To evaluate the impact of deep-sea mining on the environment, a time-series approach is required (during pilot mining) to determine the changes and time required for the disturbed ecosystem to return to its original state. This will comprise three phases: pre-mining, mining and post-mining. Pre-mining will provide baseline environmental information on the physical, chemical and biological processes in the area just before it is mined. The observations made during and after mining will be evaluated on the basis of this reference informa-

tion. Several studies have been taken up for evaluation of environmental data [7,9] and study of the potential impact of mining on the seafloor [5,13] (Table 2).

### National and international cooperation

Deep-sea mining being a multi-disciplinary venture, active participation of scientists, technicians, policy-makers and legal experts from various organisations within a country as well as between different countries can ensure its success, as it involves resources which occur in 'new' environment as well as in the international waters. Hence, cooperation is required at two levels — technical and political.

(a) *Technical cooperation* — Scientists and technicians with experience in different fields can pool their research findings, resources and expertise, to reduce time and avoid duplication of effort. One example of such cooperation is the joint venture of the French and Germans, where the French submersible 'Nautile' is being used to monitor the seafloor parameters for development of a nodule collector by the German companies. Similarly, a close association of R&D

Table 2 — Development of Deep-sea Mining Systems

Agency	Test site	System features	Pre-test studies
1. Thetis-IFREMER (German + French)	To be tested in 1995 at CCFZ-6X4 km, 15-18 kg/m <sup>2</sup> , nodules on flat seabed	20 tonnes/h, caterpillar type collector with fibre optics wt = 4 tonnes (air) with crusher. 3.5 m base width with 1 m collector head, 1 m/sec speed, 20 deg. slope capability	16 dives of 'Nautile' <i>in situ</i> vane shear, coring, crushing and sieving, water jet nodule bonding. Lab studies with bentonite for crawler-sediment interaction.
2. Rauma-Repola (Finland)	Conceptual model	Recovery 40 tonnes/h. Mechanical crawler with hydraulic lift. Nodules crushed in buffer	Computer models for behaviour of collector and riser pipes in the water column
3. Tech. Res. Assn. of Mn. Nod. Mining, (Japan)	Pilot mining in 1994 at 5000 m off Hawaii	35 tonnes/h, mechanically driven collector with 5 sledges for pick up of nodules using water jets. Wt = 30 tonnes (air), crushing on collector (30 mm). Air-lift system	Tested in tank (14 × 2 × 2 m) with conditions simulated for shear strength of seabed

institutions and private companies is also advisable to realise the objective of nodule mining, as in the case of Technology Research Association for Manganese nodule mining system (TRAM) in Japan, which coordinates the research and development of nodule mining system (see also Table 3 for other nodule mining ventures).

Table 3 — Environmental Studies for Nodule Mining

Agency/test	Description	Studies
1. Inst. for hydro-biology and fisheries, Univ. of Hamburg, Germany	DISCOL — disturbance and recolonisation using plough harrow over 111 km <sup>2</sup> area	Oceanographic parameters and sampling (with box corers, multiple corers, seabeam and OFOS) at 8 locations — before, after 6 months, 3 years later
2. IFREMER, France	Data collected on benthos, sediment properties and oceanographic parameters	Sub-bottom profiling, seabeam shear strength (cores, <i>in situ</i> ) photograph, temp., pressure, currents in water column
3. Ocean Mining Co., USA	Environmental data collected along with nodule data. (No impact studies after the test)	Oceanographic data collection.
4. Marine mining agency, Japan	Disturb and discharge sediment 20 m above seabed and observe effects after 6 months, 1 year	Oceanographic data collection Dev. a method using 3D flow and diffusion model for assessment of impact
5. Suction dredge mining test, Blake Plateau, N. Atlantic (1970)	Environmental effect on water column was estimated — sediment laden bottom water discharged at surface — remained in euphotic zone due to warming and low salinity — may give rise to new species of micro-organisms and affect the food chain	Temp., salinity, Oxygen content, phytoplankton production at the surface. Computer program to predict density of mixture at various depths in water column
6. Continuous line bucket dredge mining test in N. Pacific (Aug-Sept. '72)	Oceanographic data along water column. Visual observations show impact of trigger wt. and other equipment as scars and troughs with turbidity	Physical, chemical, biological data using water samples, CTD sensor, photography sensors before, during and after the mining operation

(b) *Political cooperation* — Global consensus must be arrived at by combined efforts of all the interested parties to find solutions and regulate matters such as:

- (i) decision for beginning of nodule mining, depending on the world market of metals,
- (ii) sharing of technical know how and profits between developed and developing countries,
- (iii) setting guidelines for environmental protection and limits for ecological changes,
- (iv) establishing design parameters for the mining system, and
- (v) monitoring the deep-sea mining activities in all the oceans.

### Financial support

Deep-sea mining being a high risk area due to the number of unknowns and high costs involved in it governmental support to cover the expenditure in the initial stages is very essential for the success of a large scale venture like this.

## TECHNOLOGICAL DEVELOPMENT

Experiences in development of marine mining systems can lead to a wide variety of newer subsystems and applications. As a result of deployment of the mining system at great depths and in hostile environment, a number of developments are expected, which will have large-scale spin-offs for various applications. Some of the anticipated areas are:

- i) Development of composite materials, fibre reinforced plastics for components, such as riser and frame for machinery, which would have low weight, high (compression, static) stress tolerance, immunity from corrosion and low price.
- ii) Fibre glass data transfer with coaxial energy transfer.
- iii) Distributed intelligence with microprocessor controlled data reduction and data handling at all levels (deep-sea, water column and surface).
- iv) Intelligent sensors, including microprocessors signal evaluation for sonar obstacle avoidance as well as speed and direction control.
- v) Visual reconnaissance and ocean floor observation covering a wide area using laser technology for higher range and resolution.

Development of these subsystems along with an active nodule collector will lead to acquisition of knowledge in handling underwater remotely controlled equipment, knowledge of underwater electronics and sensing systems, long distance data transfer, high-pressure instrumentation, etc. This knowledge can be used in applications, such as development of submersibles for military applications, as well as civil engineering purposes, cable and pipeline laying, inspection of underwater equipment and salvaging and rescue of lost equipment.



## CONCLUSION

The exploration for commercially viable marine mineral deposits depends upon proximity of the resource and economic considerations. Offshore deposits may become economical depending upon the availability (or non-availability) of land resources, especially those which are a source of metals for industrial development. Proximity of the resource from the sea surface (i.e. depth) as well as the land (distance) and 'richness' of metal in it (or grade) will directly determine the mineability of such a resource. Similarly, availability of a base, or a seaport and logistic support are also important considerations for commercial scale exploration and exploitation.

Nodule mining may be inevitable in the future, in order to replenish the mineral resources for industrial development, and so steps can be taken in advance to arrive at such design parameters that the mining operation will cause least possible damage to the marine environment. This is one opportunity when damage can be avoided, unlike other mining operations, where the impact is noticed at a later date. Baseline data on oceanographic parameters (biological, chemical, physical, meteorological, etc.) will have to be collected which can be used as a reference for assessing the effects of mining as well as in the design of the mining system.

A large-scale venture, such as deep-sea mining, will need monetary support, manpower and expertise from various sectors, such as private industry, R & D organisations and governmental institutions and the objective can be realised through active cooperation among all these institutions. The deep-sea minerals not only promise a rich resource, but also provide a challenging and risky task to exploit it.

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