CHAPTER - 1

INTRODUCTION
Manganese nodules available in the World Oceans have attracted the attention of the world community in the mid sixties. A regulatory body has been established through negotiation in the United Nations Law of the Sea Conference (UNCLOS III). The International Seabed Authority (ISBA) at Jamica has started functioning from 1994 to oversee various issues related to various mineral deposits available in the international water. The regulation on exploitation of polymetallic nodules in the area has been adopted by Assembly of ISBA in 1998 followed by adoption of environmental guidelines on the basis of available information. Environmental guidelines can be reviewed from time to time. Nodules in the Indian Ocean area vary from centimeter to 10 cm in diameter and potato like shape.

Nodules contain important strategic metals like copper (Cu), Nickel (Ni) and Cobalt (Co). India is the first pioneer investor in the Indian Ocean and the only player in Indian Ocean so far in this regime. The area 150, 000 sq. km allotted to India by pre-com under UNCLOS in 1987. After fulfilling the obligation as a pioneer investor i.e., relinquishment of 50% of the allotted area in March 2002, India retained 75,000 sq. km. for various research and development work. This thesis is to prepare a cost model for a first generation ocean mining project located in the retained area in the Central Indian Ocean Basin.

1.1 Global scenario

It is generally believed that commercial seabed mining will not take place before the middle of this century because of varied reasons. These broadly include the
legal negotiations for an internationally acceptable universal regime for the exploitation of deep seabed resources, the state of the world economy and the demand perspective of the metal markets. Nevertheless, the state of art of the deep seabed mining technology and the extractive metallurgy too, play an important role in deciding the future commercial exploitation of these resources.


For state parties registered as pioneer investor and allotted site for various developmental activities under UNCLOS. India is one of the first registered pioneer investor. Subsequently Three parties (China, Inter Ocean Metal and Korea) also become pioneer investors. All sites except Indian Ocean site were allocated in Clarion Cliperton Fone (CCFZ) in Pacific Ocean. International Seabed Authority (ISBA) started its function at Jamaica as head quarters from 1994. ISBA is monitoring activities of all pioneer investors. The regulation on exploration of Polymetallic Nodules in the area has come into effect from 13th July 1998. Seven pioneer investors signed 15 years contract with ISBA for carrying out various developmental activities in the Area. Subsequently environmental guidelines for carrying out exploration activities at the area have also been adopted by the assembly of ISBA. Germany was likely to sign the contract soon.
1.2 Metal resources in polymetallic nodules

During the last quarter of the century it has been recognized that deep-sea nodules may be regarded as a major potential economic source of metals such as nickel, copper, cobalt, and manganese. These metals are vital for industries and are strategically important. Prosperity of mankind depends much on these resources.

The occurrence of nodules and encrustations on the deep seafloor have been first reported more than 100 years ago in the findings of the research cruise of the British Vessel – HMS Challenger (1872 - 76). The unique results obtained on this deep-sea expedition led to the thinking that marine nodules are an important source of metals. Since then nodules have been extensively sampled and photographed by a number of oceanographic expeditions. The composition and origin of nodules were largely studied as a scientific curiosity till early 1960’s when their economic potential was recognized and since then detailed exploration and studies on exploitation have been carried out.

Mero [1965] has been the first to collate and publish data on nodules and to study the economic feasibility of manganese nodule exploitation. He noted that ferromanganese deposits may be a potentially valuable source of important industrial metals. Subsequently, a coherent hypothesis of nodules as a resource began to appear. Both Industrialized and developing countries have become increasingly aware of the economic importance of these recoverable resources. There is now, little doubt that the nodules form an important source for Ni, Cu
and Co and possibly other elements (Mn, Fe, Zn, Mo, Pb, V, Au, Pt, Ti, Zr, Ag, P and Cd). The increasing demand for minerals and technology advances has now made ferro-manganese nodules a prime target of a massive international effort for deep seabed mining. The formation of OPEC in the early seventies and the apprehension of the developed countries about the interruption of supplies of raw materials from the developing countries provided an added impetus to these efforts. Since then, the feasibility of exploration and exploitation of the manganese nodule deposits has been demonstrated. The possible mining of these deposits has caused a profound concern of the nations, especially in the developing nations, because of the envisaged impact of these materials on the world market and economy. Therefore, during the deliberations of the UN Law of the Sea Convention, the deep seabed beyond the national jurisdiction has been declared “Common Heritage of Mankind” [Pardo, 1967]. First time that such a proposal is put forward to the General Assembly at the United Nations. Pardo’s initiative is both timely and well conceived [Zuleta, 1982]. Barkenbus [1979] regards the role of pardo as that of a “legal catalyst”.

Since 1965, extensive exploration activities have been carried out by a number of companies, universities and governmental institutions from countries such as the United States of America, the Federal Republic of Germany, the United Kingdom, France, Japan, Australia, New Zealand, the then USSR, India and China. The result is an abundance of published papers and articles on manganese nodules [e.g. Glasby and Hubred, 1976]. In early 70’s, major commercial companies of the Western Countries, Japan and the United States of America formed into
various Multinational Consortia and began prospecting for the nodules mostly in
the Pacific Ocean. Simultaneously the technology for the extractive metallurgy of
nodule ores and the designing of mining system was initiated.

Manganese nodules generally occur between 3500 m and 6000 m water depth in
all ocean basins. In order to determine the quality and coverage density of
nodule fields and also with an aim to demarcate areas favorable for deep-seabed
mining, research vessels investigated the deep-seabed in the pacific and the
Indian Oceans, especially the area of high seas beyond national jurisdiction. The
results of these numerous efforts established that the large areas of the seabed
measuring thousands of square kilometers have nodule coverage up to and
occasionally even exceeding 10 Kg/sq. m., equivalent to 10, 000 metric tons/sq.
m., the vast resources perceived are mostly confined to the Pacific and the Indian
Oceans. The Atlantic Ocean does not appear to be a promising area for ore
grade nodule fields [Moore and Cruickshank, 1973].

1.3 Nodule resources in world oceans

Nodules cover an area of approximately $46 \times 10^6$ sq. km., in the world oceans
[Moore and Cruickshank, 1973]. Later, the revised estimates suggested that
nodules are present in a total area of about $54 \times 10^6$ sq. km., [Archer, 1985]. The
estimated area covered in the Pacific Ocean is about $23 \times 10^6$ sq. km., in the
Atlantic Ocean $8 \times 10^6$ sq. km., and for the Indian Ocean between 10 and $15 \times
10^6$ sq. km. The estimated total resources of manganese nodules in the world
oceans range from $1.7$ to $3 \times 10^{12}$ tonnes of nodules, The Indian Ocean $0.15 \times$
10^{12} tonnes and Atlantic Ocean 0.005 \times 10^{12} tonnes of nodules. Pasho [1979] quantified the existing prime areas suitable for first generation mining of manganese nodules. He estimated \(5.20 \times 10^6\) sq. km., in the Pacific Ocean, \(0.50 \times 10^6\) sq. km., in the Indian Ocean and \(0.85 \times 10^6\) sq. km., in the Atlantic Ocean and explored areas. Archer [1979] defined Prime Areas as areas at least part of which there are deposits of relatively abundant nodules with significantly higher grades than elsewhere. Prime Areas are often referred to yield more than one first generation mine-site. The boundaries of these areas are demarcated after detailed exploration and evaluation of data. To qualify as first generation mine-site, a nodule deposit should provide an average combined Ni and Cu content of 2.25% (at 1.81% cut-off) and an average abundance of 10 Kg/sq. m., (at 5 Kg/m^2 Cut-off). The nodule field needs to have a capacity to sustain a production level of \(1.5 \times 10^6\) tons of dry nodules per year and the mining need to last for at least 20 to 25 years. The site may encompass an area of at least 10,000 sq. km with a more or less uniform or even topography. The area may yield about \(60 \times 10^6\) tons of such nodules to describe as first generation mine-site [Archer, 1979]. Prime areas account for only a small proportion of the seabed. The largest, about \(3.5 \times 10^6\) sq. km., being between the Clarion and Clipperton fracture zones and another in the North Pacific covering about \(0.8 \times 10^6\) sq.m., to the southwest of Hawaii [Archer, 1979].

Fraze and Wilson [1980] indicated that the paramarginal and sub-marginal grades of nodules cover an area of \(0.7 \times 10^6\) sq. km., between 10°S to 16° S in
the Central Indian Basin. Based on the grades, the deposits are classified and referred to as 'paramarginal, submarginal and low grade deposits'. Those nodule deposits provide a grade more than 2.47% are called 'paramarginal', and grades falling between 2.47% and 1.63% are called 'submarginal'. Below 1.63% grades, the deposits are referred as 'low grade'. As of March, 1980, the Scripps Sediment Data Bank contained chemical analyses of nodules from 2,401 stations. More than 400 stations are located in the Clarion-Clipperton zone in the northeastern equatorial Pacific Ocean area of about 2.5 million sq. km. in which nodules average 25.43 % manganese, 6.66 % iron, 1.27 % nickel, 1.02 % copper, and % 0.22 cobalt (Heye and Marching, 1977) reported almost identical averages for the several thousand samples collected from the Clarion-Clipperton zone by the Centre National pour l'Exploration des Oceans - namely 25.56 % manganese, 6.40 % iron, 1.25 % nickel, 1.05 % copper, and 0.24 % cobalt. As the comparison in table 1.1 shows, exclusion of Clarion-Clipperton zone values from the world averages decreases somewhat the average nickel, copper, and manganese contents, increases iron content, and has no effect on cobalt content. The world averages estimated by Cronan (1980, slightly revised from 1976, 1977) are even lower in manganese, nickel and copper and higher in iron and cobalt (Table 1.1). In the Indian Ocean only the nodules of the Central Indian Basin (hereafter referred to as 'CIB') meet the criteria for first generation mining [e.g. Fraze and Wilson, 1980; Cronan and Moorby, 1981; Sudhakar, 1989a]. However available data on the grade and abundance until the end of eighties has been inadequate for the identification of a Prime Area and for the estimation of
resources. Later reports based on the India’s continued exploration programme for nodules confirmed that the ore grade nodule resources are mainly concentrated between $10^\circ$ S and $16^\circ$ S in the Central Indian Basin [Sudhakar, 1989 a]. At 2% cut-off grade, nearly 1/3 of the explored area in the Central Indian Basin provides high grade regions [Sudhakar, 1989 a, b]. The data on abundance, grade and resources in two Application Areas (Fig. 1.1) in the CIB is shown in table 1.2. The Indian Ocean is often ranked second to the Pacific Ocean, both in terms of the area covered by nodules and their estimated resources. India’s interest in polymetallic nodules and its nodule programme are detailed in the second chapter.

Table 1.1: Comparison of the world average metal content of manganese nodules listed with the values reported by Cronan (1980)
(The Clarion-Clipperton zone is taken to the area defined by 70 to 150 N, 1140 to 1530 W)

<table>
<thead>
<tr>
<th>Metal</th>
<th>World</th>
<th>World excluding clarion-clipperton zone</th>
<th>World values reported by cronan (in per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>18.60</td>
<td>17.45</td>
<td>16.8740</td>
</tr>
<tr>
<td>Fe</td>
<td>12.47</td>
<td>13.63</td>
<td>15.608</td>
</tr>
<tr>
<td>Ni</td>
<td>0.66</td>
<td>0.55</td>
<td>0.4888</td>
</tr>
<tr>
<td>Cu</td>
<td>0.45</td>
<td>0.34</td>
<td>0.2561</td>
</tr>
<tr>
<td>Ni+Cu</td>
<td>1.12</td>
<td>0.90</td>
<td>0.7449</td>
</tr>
<tr>
<td>Co</td>
<td>0.27</td>
<td>0.27</td>
<td>0.2987</td>
</tr>
</tbody>
</table>
Fig. 1.1: A: Mine site area
B: Mine site allotted to India (Area not hatch marked In the Central Indian Ocean Basin)
Table 1. 2: Indian land reserves and marine reserves in the retained area
(Figures in million tones)

<table>
<thead>
<tr>
<th>Metals</th>
<th>Indian land resources</th>
<th>Reserves in Application areas</th>
<th>Reserved in retained area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manganese(Mn)</td>
<td>142.00 (approx)</td>
<td>247.00</td>
<td>478.00</td>
</tr>
<tr>
<td>Copper(Cu)</td>
<td>9.44</td>
<td>9.51</td>
<td>17.07</td>
</tr>
<tr>
<td>Nickel(Ni)</td>
<td>No proven reserve</td>
<td>10.47</td>
<td>20.81</td>
</tr>
<tr>
<td>Cobalt(Co)</td>
<td>No proven reserve</td>
<td>1.82</td>
<td>3.87</td>
</tr>
</tbody>
</table>

1.4 Earlier explorations

Starting from the British Oceanographic Expedition with HMS CHALLENGER, various scientific ocean explorations were undertaken and these explorations were able to provide valuable information on various aspects of marine minerals. The foremost of the significant explorations namely of that of HMS CHALLENGER was conducted by the British Oceanographic Expedition during 1872 - 76. It was during the expedition that deep-sea polymetallic nodules were recovered for the first time in 1873 at a location about 300 km south west of the island Ferro in the Canary group in the Pacific Ocean. A more extensive exploration was made by the ALBATROSS Expedition during 1899 -1900 and 1904 -1905, during which the extent of nodule distribution in the equatorial Pacific was mapped and an extensive collection of nodules was also made. Thereafter, the explorative activities were sporadic-the MURRAY expedition (1925 -1927), the CARNEGIE expedition (1928 -1929) being some of the important milestones in the deep sea exploration.
During 1947-48, the Swedish Deep Sea Expedition collected sediment samples, the chemical investigations of which established the inter-relationship between manganese, nickel and cobalt. In 1965, Jonn Mero collected data on the regional variation of nodule composition throughout the Pacific and this set the pace for compilation of literature on polymetallic nodules.

During 1971, RSS SHACKLETON conducted an extensive cruise of the Indian Ocean. In planning this cruise, a specified location was selected where both polymetallic nodules and metalliferous sediments were known to exist in variable composition and abundance. The cruise route was designed to cover four major physiographic features in the north-west Indian Ocean - the Arabian Abyssal Plain, the Carlsberg Ridge, the Somali Basin, and the Seychelles Plateau. It has been indicated that poly metallic nodules are most abundant in the basin area far from the land and on either side of Ninety East ridge. High nodule concentrations are said to occur locally on and at the foot of some submarine ridges and occasionally in the vicinity of major fault zones.

1.5 Demand of metals

The consumptions/demands of metals (Cu, Ni, Co and Mn) are basically depends on six forces which may change the topography of the market. They are increased globalization, sustainability, financial performance (profitability and capital productivity), customer expectations, changing work force requirements, and increased collaboration.
Copper is one of the most useful and versatile metals and is used in both pure form and in alloys such as brass, bronze and nickel – silver. The most important use for nickel is in the steel industry, mainly in the production of stainless steels and other alloys. Electro-plating, chemical and other industrial uses also represent important applications. Cobalt has a number of specialized uses in heat corrosion-resistant and tool-steels, in hard facing material for drilling equipment, in the manufacture of permanent magnets and in the chemical industry. It is especially useful in missiles and jet engines. Most of the world Manganese output is consumed by steel plants and foundries and a small percent is used by chemical and dry cell industries.

The percentage growth rate per year for copper was 2.15 % during 1980-2003, however the rate of growth during 1990-2003 was 2.85 %. Similarly Nickel consumption rate increased to 3.33 % during last decade. In case of cobalt the average growth per annum was 2.79 % and that of Manganese was approximately 3 %.

For many years the consumption of manganese has been correlated with steel production. Manganese production is mainly confined to six countries viz., South Africa, the then USSR, Brazil, Gabon, Australia and India; with 80 % of all land reserves being located in the then USSR and South Africa. Technological innovations call for a smaller input of manganese in near future. However, now there is increase in demand in steel mostly due to very high demand in some of the Asian countries.
In the case of manganese recovery from nodules, Nickel and Manganese represent major part of the revenue. Nickel's annual compound growth rate of price increase is 12.47 % during 2000-04. The average compound price growth has been found from the historical data in respect of Cu, Ni, Co, and Mn is 2.49 %, 2.97 %, 3.56 %, and 2.56 %. (USGS., Mineral Commodity Summaries, January 2004.) The present concentration of land reserves are largely located in Canada, New Caledonia (France), Cuba, the then USSR, Indonesia, Philippines and Australia. It is forecasted that the nickel production from the seabed sources shall not affect the nickel price - may be less than or up to 10 percent [Schmidt, 1989].

The volume of nodule metals on the seabed has been a subject of much speculation. Archer [1985] concluded that manganese nodules probably cover about 15% of the ocean floor. He asserts that if, these estimates reflect the actual magnitude, then, the potentially recoverable economic resources of Ni, Cu, Co and Mn in nodules are neither enormously more nor less than economic resources on land. Economic resources of Ni, Cu, Co and Mn on land area are shown in following table 1.3. It is evident that seabed reserves are, in a general approximation and with the exception of Cu, are of the lesser magnitude as those on land. Even though the figures indicate that the earlier market situation of metals does not encourage investment in nodule mining and profitable exploitation, the apparent wealth of the nodule resources makes an obvious target for all the nations to show an active interest Nevertheless, the nodules of
relatively dense coverage and 'high metal grade occurring in other parts of the Pacific and the Indian Oceans, makes them the biggest resources of Ni, Co and Mn ores on our globe.

Table 1.3: Comparative global reserves of metal from land and nodules.

<table>
<thead>
<tr>
<th></th>
<th>Land (Million tones)</th>
<th>Nodules (Million tones)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>940</td>
<td>175</td>
</tr>
<tr>
<td>Ni</td>
<td>140</td>
<td>215</td>
</tr>
<tr>
<td>Co</td>
<td>13</td>
<td>40</td>
</tr>
<tr>
<td>Mn</td>
<td>5000</td>
<td>5000</td>
</tr>
</tbody>
</table>

If we consider the present price of metal values in the Indian reserved area, the estimated value of metals is of the order of about 50 billion thousand rupees, which is very attractive from investment point of view. However the demands and prices of these metals are very volatile, technological, economical, and societal factors influence the supply-demand of metals.

1.6 International efforts on deep sea mining

The polymetallic nodules generally occur beyond the continental rise or outside the continental margin. Earlier explorations have indicated that these nodules occur at water depths ranging from 4000 m to 6000 m and the deposits are reported to be spread over a total ocean floor area of about 46 million square km. Mining of the nodules at such deep oceans require new technological approach and hence special mining systems have to be evolved. To achieve this, different agencies from different countries of the world have grouped them selves into various consortia thereby pooling financial and technological resources. These
consortia have been engaged in various activities connected with intensive exploration and pilot mining studies on different systems for commercial exploitation. These consortia are concentrating their activities in CLARION-CLIPPERTON-ZONE of Pacific Ocean considered to be one of the potential areas of commercial mining.

In the late seventies there were four North American organizations developing deep ocean mining systems – Deepsea Ventures, Kennecott Copper, International Nickel, and Lockheed Ocean Systems, a division of Lockheed Missiles Space Corporation. All four have formed consortia with domestic and foreign companies. All have selected the same basic design of a mining system, i.e., a bottom miner on the ocean floor connected to a surface ship by a nearly vertical pipe. Both a hydraulic air lift system and a mechanical pump system are being examined by the consortia. In addition, one other group, Ocean Resources, Inc., a syndicate of over twenty mineral and energy companies, is developing the technology of continuous line bucket lift system.

The Deepsea Ventures group consists of U.S. Steel (Essex Minerals), Union Miniere (Union Seas), and Sun Ocean Ventures, Inc., with Deepsea Ventures as the project manager. This group has filed a mine site claim and has completed pilot test evaluations of the lift recovery and hydro-metallurgical processing systems.

The Kennecott Copper consortium consists of Kennecott Copper, Rio Tinto Zinc, Consolidated Goldfields, Noranda Mines, Mitsubishi, and Bp Minerals, with
Kennecott designed as the project manager. This group has completed pilot scale evaluations of the sea floor mining vehicles and the hydrometallurgical processing systems. Further unspecified research and development is scheduled.

The international Nickel group consists of INCO, Arbetisgemeinschaft Meerestechnisch-Gwinnbare Rohstoffe (AMR), Sedco, INC., Deep Ocean mining Company, and Ocean Management, Inc., as the management contractor. This group is continuing development of its processing technology and had reportedly scheduled late 1977 at-sea tests using the Sedco 445 drill ship and the R/V Valdivia exploration data.

The Ocean Minerals Company consists of Lockheed Ocean Systems, Amoco Minerals Company, Billiton International Metals, B.V. (a subsidiary of Royal Dutch Shell), and Bos Kalis Westminster Ocean Minerals, B.V., with Lockheed as project manager. The group has conducted on-land evaluation of some components of the mining system and laboratory evaluations of the hydrometallurgical processing system. The group planned to start at-sea tests in late 1977.

The technology surrounding the mining system, comprising the bottom miner, lift system, and surface system is probably known with least certainty. While some technology can be drawn from current offshore drilling operations, government research and development programs, and land mining systems, many of the technical uncertainties must remain until actual on-site experience is gained. The
collector head’s capability to separate bottom clay, the stability of the pipestring, the optimal depth of the lift pump, the maneuverability of the dredge head, and the impact of surface discharge on the environment of the ocean are all likely to remain question marks until the system is operating on station.

Many patents of various components of mining system have already been obtained. The mechanisms of various concepts, their development, their strength and weakness of the system have been examined. As per the UNIDO study in 1982, total 19 components out 388 components were considered for extensive research and development. These areas were for various components of collector, riser pipe.

The engineering concepts in respect of above systems were developed with varying degrees of complexities during last four decades covering above four concepts.

The efforts for developments of prototype mining system by some of the Pioneer Investors/Contractors are still going on. A Group of Experts from COMRA (Chinese Ocean Mining Research Administration) developed mining system based on all considerations of main principles of designing of deep sea mining system. COMRA has already designed and developed the system and planned to test up to 4000 m and then up to 6000 m.
IFREMER’s latest endeavor was to use unmanned submersibles to mine nodules from seabed but could not be used to mine nodules economically. They reoriented the programme but further development not reported.

Japan also planned a comprehensive mining test in 1995. Due to change in the sociological, the perspectives of technologies in the future, cost effectiveness and so forth, the plan was changed. In 1997, ocean test carried out to verify selected common elemental technologies that could contribute to overall ocean development in future. The test was carried out in an area of seamount at a depth of 2200 m particularly with reference to test of collector with a mother vessel, hybrid deep sea cable with optical fibers and power supply, wire rope, underwater positioning and navigation system.

Korea’s deep sea mining programme also aimed at development of various system in phases. They have carried out various laboratory design and test in respect of nodule collectors and collector vehicles. The work of insitu test of pilot mining system was in progress.

Indian also has the plan to design, develop and demonstrate a prototype mining system during 11th plan. The development of metallurgical process route for extraction of metals (Cu, Ni, Co and Mn) has been successfully demonstrated in a pilot scale of 500 kg/day throughput capacity.
Various studies on the feasibility of eventual exploitation of the polymetallic modules from the seabed have been carried out by Australia, France (IFREMER) and MIT. No such study has yet been carried out by India.

1.7 Scope of the study

The objective of the present study is

1. To analyze grade tonnage relationship of the Indian mine site and evaluate the impact of cut-off values on resultant values to help in decision making for site selection.

2. To prepare environmental friendly deep seabed mining system.

3. To predict the likely demand of the metals (Cu, Ni, Co and Mn) by 2020.

4. To prepare the cost model and evaluate the possible economics of deep seabed polymetallic nodule mining.

The scope of the study was defined keeping the above stated objectives in mind. Thus, the scope includes:

- Review of global scenario in deep seabed resources exploration, mining and environment studies.
- Review of metal demands to identify future requirements.
- Optimal estimation methodology and its application for identifying progressively potential areas in terms of polymetallic nodule resources.
- Comprehensive investigation of grade-tonnage relationship leading to the estimates of nodule abundance and metal grades for final mine site selection after meeting pre-specified criteria.
- Comprehensive review of deep seabed mining technologies and a proposed emerging concept meeting the environment requirements.
- Environmental impact of deep seabed mining-an appraisal.
- Demand, supply and price trends of metals in nodules.
- Economic model to evaluate the financial viability of deep seabed mining.