

# Polymetallic Nodule Resources of the Indian Ocean

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## ABSTRACT

*The seabed resources are large and varied and considerable knowledge and technological development are required to exploit them economically. Beyond the Exclusive Economic Zone (EEZ), the deposits which are of utmost interest are the polymetallic nodules. These contain, beside iron and manganese, copper, nickel and cobalt in economically feasible quantities. India has already got a mine site registered in the Central Indian Ocean Basin. As the land resources of strategic metals are declining rapidly because of our ever increasing demand, we will have to go in for the deep sea minerals in the future. For this, the nodules appear to be most promising. Although they vary in their metal contents from place to place, the consistent occurrence of copper, nickel and cobalt in economic quantities in them makes their exploitation attractive. However, what is lacking at present is a technology package to make the proposal economically viable and environmentally sound.*

**KEY WORDS** : Marine resources; Deep seabed mining; Polymetallic nodules, Indian Ocean; Chemical composition; Environmental concerns

## INTRODUCTION

On the 30th August, 1955, the President of India made the following proclamation of far reaching importance:

“Whereas valuable natural resources are known to exist on the sea-

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bed and in the sub soil of the Continental Shelf and the utilization of such resources is being made practicable by modern technological progress:

And whereas it is established by international practice that for the purpose of exploring and exploiting such resources in an orderly manner every coastal State has sovereign right over the sea-bed and sub-soil of the Continental Shelf adjoining its territory;

Now, therefore, I, Rajendra Prasad, President of India, in the sixth year of the Republic, do proclaim that India has, and always had, full and exclusive sovereign right over the sea-bed and sub-soil of the Continental Shelf adjoining its territory and beyond its territorial waters."

Three decades later on 26th August 1987, the Prime Minister late Mr. Rajiv Gandhi stated in the Parliament:

"The registration of our claim for a deep seabed mine site indeed provides a concrete indication of indigenous scientific capabilities and achievements. I am sure this house will agree to place on record our appreciation for the excellent work done by our scientists and engineers who have taken up the challenging task for exploring new horizons of science to unravel the mysteries of the ocean".

The 'exclusive sovereign right' over the 'Continental Shelf' and the new ocean regime has enabled India to acquire about 2.01 million km<sup>2</sup> of seabed as its Exclusive Economic Zone (EEZ). This zone extends to 200 nautical miles from the Indian coastline and is about 3/4th the size of the country. The exploitable resources in this area include petroleum hydrocarbons, construction material, coral deposits, phosphorites and placer deposits such as ilmenite, sillimenite, zircon, rutile, magnetite and garnet. The exploration of the offshore extension of placers revealed some of these deposits to be much larger in area than the onshore deposits. The upwelling areas of the continental margin are also conducive to the formation of phosphorites deposits.

At a time when consumption rate of minerals is expected to increase due to rapidly growing population and rapid industrialization, the land based resources are decreasing. Access to the EEZ resources would supplement the existing onland reserves.

### DEEP SEA MINERALS

Beyond the EEZ and beyond any national jurisdiction in the deep sea region, mineral resources of economic interest include hydrothermal sulphide deposits and polymetallic nodules containing metals like cobalt, nickel, copper and manganese. The polymetallic nodules in the Indian Ocean cover an area of 10-15 million km<sup>2</sup> and the total resources are estimated to be about 0.15 trillion tonnes<sup>1</sup>. The exploitation of these minerals from the seabed had become a very controversial issue at the Third United Nation's Conference on the Law of the Sea from 1973 to 1982 and has led to the adoption of a new convention in Jamaica in December 1982. In April 1982, the convention recognised India, France, Japan and USSR as Pioneer Investors in deep seabed mining. From then onwards, a massive effort was mounted by India for the exploration of polymetallic nodules in the basin of Central Indian Ocean, primarily to identify two mine sites within the stipulated time fixed by the UN Preparatory Commission of the International Seabed Authority. The coordinates of the application area are given in Fig. 1. Two areas of

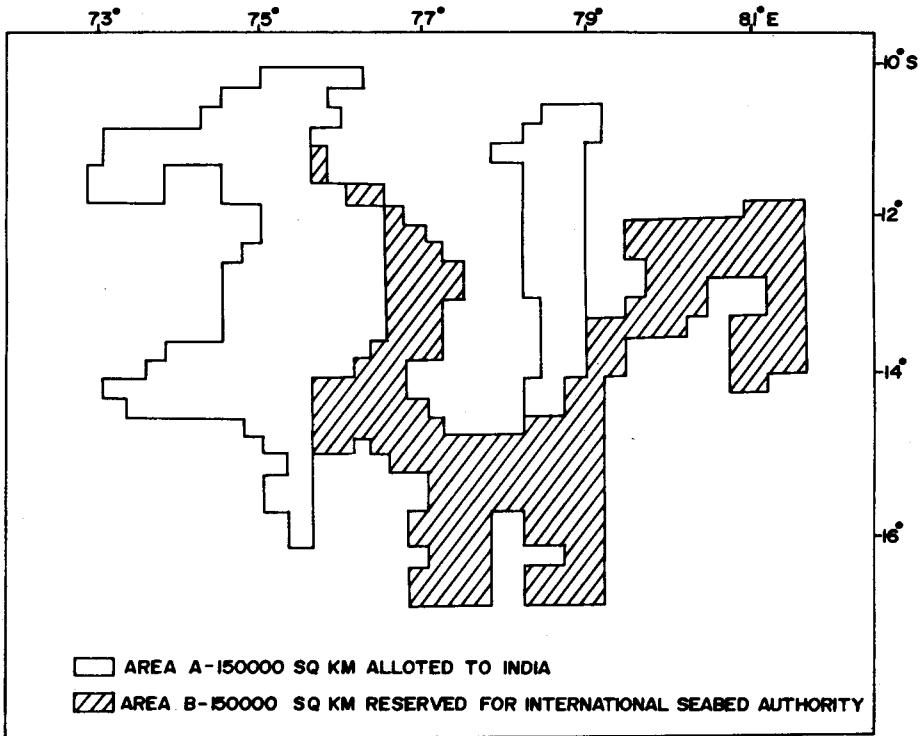


Fig. 1 -- The application area in the Central Indian Baasin

150,000 km<sup>2</sup> each (and of equal commercial value) were determined by the end of 1983 and the application of India was filed with the Commission in January 1984. India's revised application submitted in July 1987 was registered on 17 August 1987. The Indian 'mine site' in the Central Indian Ocean is bigger in size than the 12 out of the 24 existing states in the country and almost equal in size to the state of Orissa. It is tantamount to adding a 25th state to the country, wherein huge deposits of Ni, Co, Cu, and Mn are locked up in the nodules (Table 1).

**Table 1-- Abundance, grade and metal resources in the Pioneer Area of the Central Indian Basin**

	Application Area	Area A	Area B
Area (km <sup>2</sup> )	300,000	150,000	150,000
Av. abundance (Kg/m <sup>2</sup> )	4.51	4.39	4.45
Total nodules (million tonnes)	1335	676.5	658.5
Combined metal (Cu + Ni + Co) (million tonnes)	21.84	10.88	10.96

## NODULE MINING

To mine these nodules from over 5000 m water depth is not an easy process. The past has witnessed mining of construction material, heavy mineral placers from the beaches and oil and natural gas from shallower waters. Successful exploitation of the seabed minerals depends not only on technological development but also on geological, economic, environmental, legal and political factors. Advances in the deep sea exploration technology such as multibeam sonar, deep towed system, submersibles and robotics have helped develop models of mining system. The mining technology for manganese nodules has been designed and tested by different organisations<sup>2</sup> and the Red Sea Pilot Project suggests the technical feasibility of mining deep ocean minerals<sup>3</sup>, though the economic feasibility of mining is still a matter of debate.

The importance of strategic metals like Co, Ni and Cu depends much on their demand in the world metal markets. Cobalt a hard brittle metal has a melting point of 1445°C. Its qualities such as heat resistance, high strength, wear resistance and superior magnetic properties make Co a strategic and critical material. Also it is a vital component of jet engines, of armour piercing shells, aerospace and electronic industries.

Copper is a very versatile raw material characterized by its high electric and heat conductivity, malleability, corrosion resistance, tensile strength and easy workability. The metal is used in for telecommunications, power utilities, lighting, wiring, plumbing and heating appliances, utensils, cutlery, vehicles, aircrafts, wires, cables and many allied products.

Nickel is the second most important alloying metal used specially in steels, next to chromium. Recently it is being used widely in electroplating and also in coinage. It has a melting point of 1452°C and is highly resistant to corrosion.

Manganese is principally used as an alloying element in the production of steel which accounts for about 90% of manganese consumption. Its other important uses are dry cell batteries and in chemicals and non ferrous alloys. Manganese is the major constituent of seabed nodules. Although India, an exporter of manganese ore, has sufficient manganese deposits on land, at the present rate of production and consumption, the deposits will not last for more than a few decades.

Tables (2 and 3) show the reserves and production of cobalt, nickel, copper and manganese in India. The country imports 65% of its copper requirements and 100% of its nickel and cobalt requirements. During the year 1988-89, India imported 160005 tonnes of copper (including brass and bronze), 10650 tonnes of nickel (including ore and concentrate); and 251 tonnes of cobalt<sup>4</sup>. To meet the growing demand of power, transport, communication and defence needs in the near future, the country has to depend on imports all the time, necessitating a huge outlay of foreign exchange.

Table 2 -- Estimated reserves (000 tonnes) - (LAND)

Ore/metal	Proved	Probable	Possible	Total
Manganese ore	18049	37788	98330	154167
Copper ore	83093	171744	69552	324389
Copper metal	798.72	1830.228	679.138	3308.086
Nickel (0.2-0.9%) ore	nil	nil	231410	231410
„ (0.8-1.2) ore	„	„	240000	240000
Cobalt			.....not estimated.....	

**Table 3 -- Production (tonnes) - (LAND)**

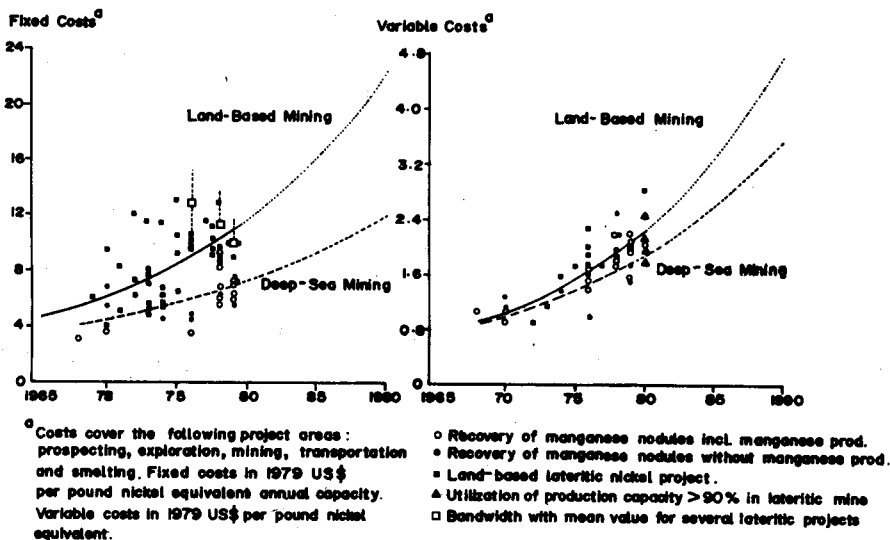
Ore/metal	1986	1987	1988	1989	1990
Manganese ore	1284081	1302509	1355080	1334214	1392847
Copper ore(*)	4461862	5136279	5056263		5293405
Nickel(**)			Not produced		
Cobalt			Not produced		

(\*) Copper content (1.11 to 1.2%).

(\*\*) Nickel is recovered as by product in the form of nickel sulphate during refinement of copper at Ghatsila (1987-154 tonnes; 1988 - 227 tonnes)

[Source : Indian Bureau of Mines, Mineral Year Book 1991]

With a greater demand and less supply from the land resources, the metals produced from the mine site (Table 1) would help in supplementing the growing demand to a large extent. Considering the high risks and sophisticated technology involved, it was speculated that mining deep sea minerals could be a very costly affair. Figure 2 contains



**Fig. 2 -- Deep-sea mining versus land-based mining. Scatter diagrams and trend projection of fixed and variable costs of deep-sea mining (manganese nodules) and of land-based mining. (lateritic nickel ores) (1965-1990). Reproduced from Dick (1985)**

the distribution diagrams of the fixed and variable costs of land based mining and deep sea mining for the period 1965-1990. This diagrammatic comparison by Dick<sup>5</sup> shows the advantages of deepsea mining in the case of fixed costs, as well as in the case of the variable costs. In later years of the production, the cost of deep sea mining becomes lower than the costs for land based mining. In the case of oil and gas also, though the average drilling and equipping costs tend to be three to four times greater in offshore deposits, the large size of the seabed deposits that are in production allows them to compete with their on land counterparts.<sup>6</sup>

Understanding of the distribution pattern and enrichment of the metals in the nodules and knowledge of the seabed topography is a prerequisite for mining. To comprehend this, basic research is a necessity. The basic research on polymetallic nodules conducted by the scientists of the National Institute of Oceanography (NIO) during a decade has generated interesting results regarding the physiography of the basin, its impact on nodule distribution, on metal enrichment, and these are summarised below

### CHARACTERISTICS OF INDIAN OCEAN NODULE DEPOSITS

The Central Indian Ocean Basin (CIOB), located between the Central Indian Ridge and the Ninety East Ridge and bounded in the south by the Southwest Indian Ridge, is believed to have been formed by the turbidity currents which distributed the Ganges and Brahmaputra sediments to the far south. Bottom relief features have a strong influence on the movement and distribution of water masses, on sediment transport, turbidity, chemical activity and on ocean dynamics. These parameters influence the metal enrichment in nodules and their distribution and abundance on the sea floor.

Detailed bathymetry mapping of the mine site with the newly installed multibeam swath bathymetry system - Hydrosweep on *ORV Sagar Kanya* has revealed many geological features in greater detail (Fig. 3). Examples are the southern extension of 79°E Fracture Zone and conspicuous East-West lineations. These lineations appear to bend towards the south against the 79°E Fracture Zone<sup>7</sup>. In addition, three distinct NNE-SSW trending seamount chains, along 75°23'E, 75°44'E and 78° 55' (west of 79° FZ) are identified.<sup>8</sup> The seamounts have heights upto 1300 m and cover an area upto 300 km<sup>2</sup>.

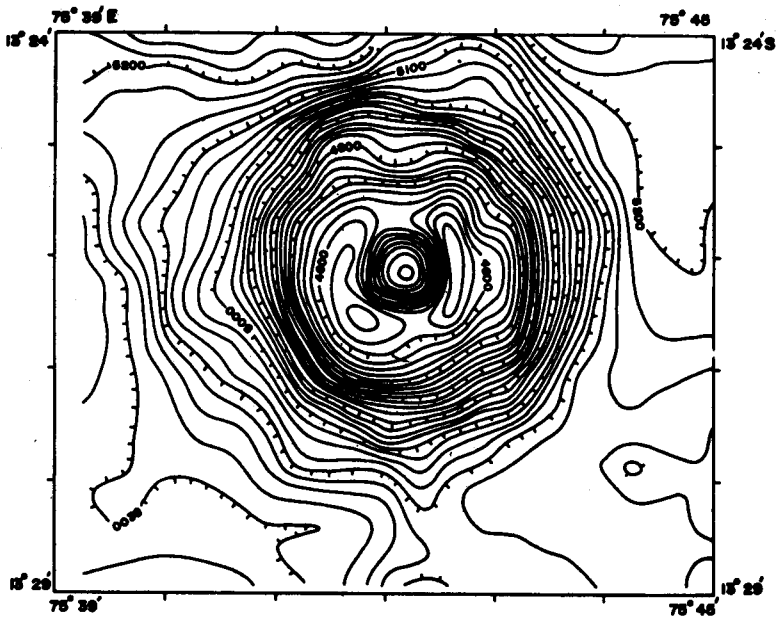


Fig. 3 -- Topography of a seamount

The highest abundance of nodules ( $6.94 \text{ kg/m}^2$ ) are generally associated with the high relief areas like the valleys followed by hill tops and slopes. Abundance is least<sup>9</sup> on the plains ( $2.89 \text{ kg/m}^2$ ). Nodules from plains have the highest content of Ni, Cu and Co while those from the valleys, have the lowest. There also exists an inverse relationship between the abundance and grade of nodules<sup>10</sup> These nodules are found associated with practically all kinds of pelagic sediments and locally with terrigenous sediments. In general, they are associated most commonly with those pelagic sediments which are deposited at an extremely slow rate. The high terrigenous influx by the Ganges and Brahmaputra rivers into the northern part of the basin upto  $8^\circ\text{S}$ , inhibits the growth and abundance of nodules.<sup>11</sup>

Surface density of the nodules in any given area varies considerably within short lateral distances of the order of a few kilometres or even a few metres. Studies carried out by the NIO indicate that the surface density of nodules in the CIOB varies from less than  $1 \text{ kg/m}^2$  to more than  $40 \text{ kg/m}^2$  in adjacent areas.<sup>12</sup> In some locations, however, consistently uniform surficial concentration of the nodules is discernable over hundreds of kilometres (Fig. 4)



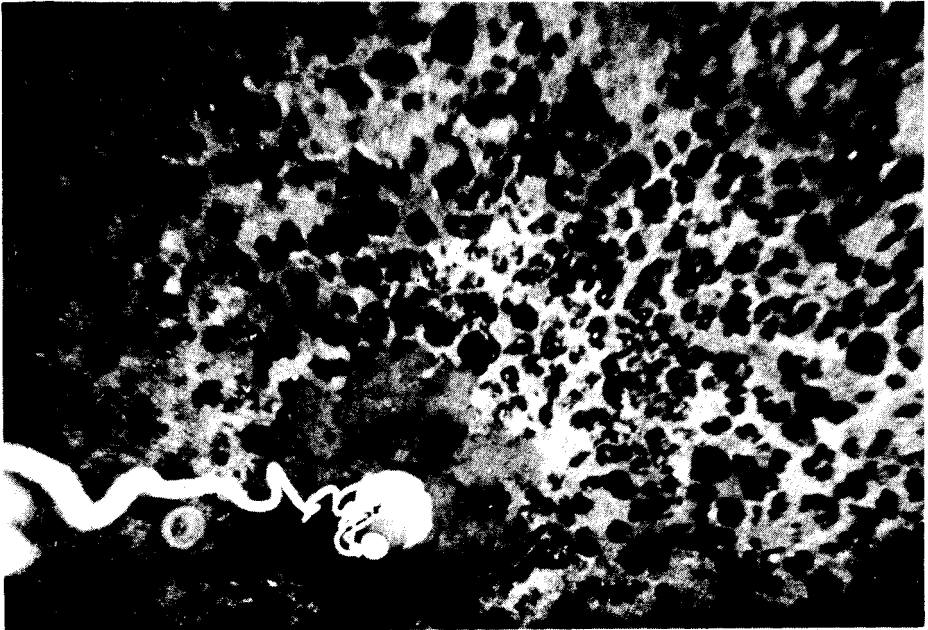


Fig. 4 -- Nodule density on the seafloor, photographed by underwater boomerang camera (area covered 72 x 108 cms, depth 5150 m, coverage 45%)

Nodules look dull earthy black, with shape, size, distribution, elemental composition and mineralogy varying according to their association with the sedimentary facies and availability of nucleus material. The common size<sup>13</sup> ranges from 2 - 6 cm, and more than 13 types of morphological shapes including the common ones like spheroidal, discoidal, intergrown, polynucleate with smooth and rough textures have been identified in the CIOB.<sup>14</sup>

Todorokite, birnessite and  $MnO_2$  are the principal mineral phases in the CIOB nodules. The crystal lattice of todorokite can accommodate ions of other transition metals such as  $Cu^{2+}$ ,  $Ni^{2+}$ ,  $Zn^{2+}$  which have suitable ionic radii to occupy the exchangeable cation positions in the 10 Å interlayer spacing of the todorokite<sup>15</sup>.

Ore microscopic studies<sup>16-18</sup> reveal the presence of dendritic, collomorphic, laminated, well developed internal structures comprising of alternating light (Mn rich) and dark (Fe rich) bands (Fig. 5). The remarkable similarity of these structures with those of shallow water algal deposits-- 'stromatolites'-- indicate the possibility of microbial contribution in the formation of nodules.

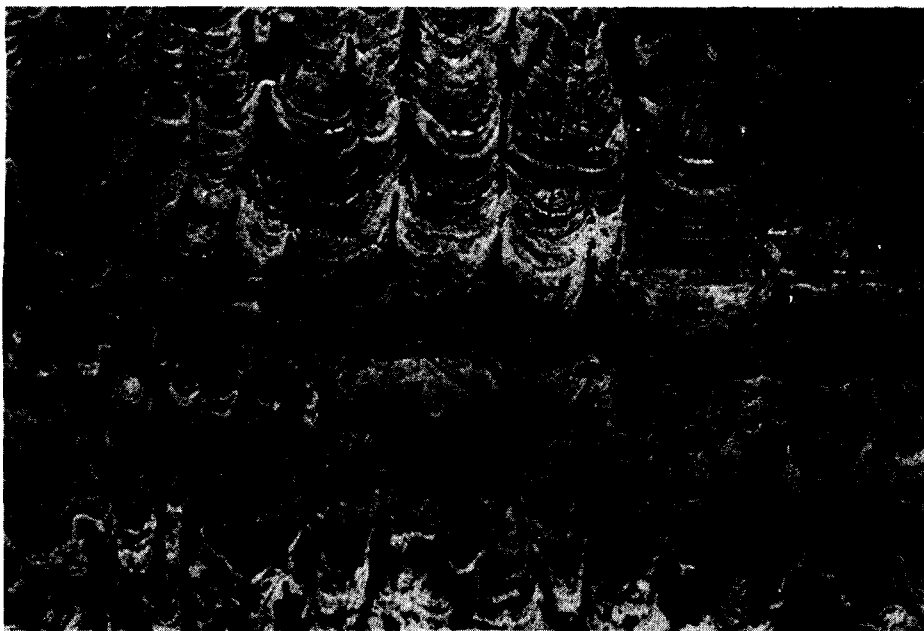


Fig. 5 -- Internal microstructures (2 generation pillar structures separated by thin lamellar growth; x 250) under reflected light

### CHEMICAL VARIATIONS

Variations in the composition of nodules could directly be attributed to the different accretionary processes of their formation<sup>19</sup>. The CIOB nodules generally exhibit three different types of accretionary processes: Nodules having Mn/Fe ratios upto  $< 2.5$ , hydrogenous type, with Mn/Fe ratio  $> 5$  the early diagenetic type, and the mixed type in between.

The variations in Mn/Fe ratio reflect variability in the composition of bottom water which in turn influences the type of underlying sediments and the supply of metals to the deposits. The higher concentrations of Mn, Ni and Cu in the nodules from siliceous sediments reflect the influence of early diagenesis of the biogenic components, whereas the higher Fe and Co contents in the nodules occurring in red clay areas are a result of their precipitation as authigenic oxyhydroxides<sup>19</sup>. The association of higher concentration of certain elements in the siliceous sediments, which are areas of higher biological productivity, is possible due to the decomposition and oxidation of organic matter and dissolution of the labile biogenic components which release biologically bound

Mn, Cu, and Ni for incorporation into the nodules. The interelement relationship between Ni, Cu and Mn reflects a balance between the release of Ni and Cu from biogenic phases and the reductive remobilization of Mn oxide<sup>19</sup>.

## ENVIRONMENTAL CONCERNS

Environmental concerns resulting from large scale mining are expected to be in the form of 'plume' at the seafloor, turbidity in the water column, and addition of bottom waters to the surface resulting in the change of productivity patterns. A study conducted covering this aspect leads one to conclude that because of the location of the CIOB and other factors, the impact of mining on the environment in this area is likely to be minimal<sup>20</sup>, but this needs confirmation by actual field experiments.

## CONCLUSION

Minerals have influenced the quality of life since the conception of civilization. Minerals and their products have been used to symbolize various eras of civilisation, for example the Stone Age, the Bronze Age, the Iron Age and the Nuclear Age. The basic needs of today's society is continually influenced by the uses of minerals. Be it as fertilizers for food production, coal, steel, cement, petroleum, natural gas, atomic energy as a source of power, all engineering and structural machinery and anything from pins to planes are manufactured from the metals and their innumerable alloys. There is not a single industry in which minerals or their products are not being used. It is therefore needless to emphasize the fact that the quality of life in all its multifarious aspects directly improves with the increase in mineral production whether from land or from beneath the waters of the oceans. Success of this project, despite many odds, has also helped the researchers and engineers to develop multidisciplinary coordination in the country, spawned research activities in nodule metallurgy as well in the challenging field of ocean mining technology<sup>21</sup>.

Although India's marine resources from the coast to the deep sea are unquestionably large and important for the national economy, to obtain maximum potential of these, sustained and enlightened support has to be assured on a sufficiently long term basis.

## ACKNOWLEDGEMENT

We thank Dr. S.Z. Qasim and P.S. Rao for their assistance in the preparation of the manuscript.

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