

Prospects of offshore mining in India

Marine geological investigations of the western continental shelf, covering an area of about 300,000 sq. km and having a maximum water depth of 120 metres, suggest that it has promising areas for offshore mining. These areas are the continental shelf between Goa and Cape Comorin for heavy minerals; the offshore region of the Saurashtra Coast, and between Goa and Mangalore for phosphorite; the outer continental shelf off Bombay for calcareous sands and off Kerala for quartz sand.

Mining of these sea floor deposits by various forms of dredging result in the ecological modification of the environment. Some of the ecological impacts are discussed and the baseline environmental conditions that must be studied in advance of offshore mining operations have been proposed.

Introduction

The oceans are known to be endowed with rich sources of many minerals and they are undoubtedly capable of meeting the needs of mankind for thousands of years. However, despite the enormous quantity of resources available, only very small quantities of mineral deposits are exploited economically and these are largely confined to the continental shelf. A notable exception of course are the manganese (polymetallic) nodules found in the deeper parts of the ocean at depths of about 5,000

metres. Although economically attractive because of the nickel, copper and cobalt contents these nodules have, their exploitation is not being undertaken on a commercial scale because of the existing controversy about the problem of their ownership.

Among the minerals already being mined from the shallower part of the sea (less than 50 m) are the placer deposits of tin off Malaysia, Thailand, Indonesia, gold and platinum off Alaska, diamonds from the mouth of the Orange River, Southwest Africa. The phosphorite deposits found on the continental shelves off Peru, Chile, Mexico, the U.S.A., N. Africa and around the Socotra Island in the Indian Ocean also have a great future. Barring a single venture to mine the phosphorites off California (U.S.A.), no attempt has yet been made for its large-scale exploitation elsewhere. Oil and natural gas from the continental shelf have to date formed the most valuable mineral source. They are being produced from offshore fields in California, the Persian Gulf, Lake Maracaibo, Western Africa, the North Sea, Eastern Brazil, Northern Java, South-western and Western Australia, Western New Zealand, Northern Alaska, South-eastern Thailand, Northern Taiwan, and Western India.

All the minerals mentioned above have a high price per unit volume, and therefore they are considered worth exploration and exploitation. The details and approximate prices of some of the placer minerals are shown in Table I and Table II. The major companies

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TABLE—I. MINERAL STATISTICS

Mineral	Reserves (million tonnes)	Production (1970, tonnes)	Price per tonne
Limestone	17,952 (all grades)	Lime kankar : 361,074	Rs. 15/- Rs. 90/- depending on grade.
		Lime shell : 80,598	
		Calcareous sand : 996,201	
Quartz sand	Extensive	Sand : 621,494	Rs. 18/- Rs. 55/- depending on grade.
		Silica sand : 282,945	
Phosphorite	60.9 (all grades)	Phosphorite : 156,353	N.A.*
		Apatite : 15,997	
Monazite	183 Total; 17.53 (Kerala)	76,770	Rs. 81/- (58% TiO ₂)
Ilmenite	1.27 (Kerala)	3032	Rs. 985/- (92% TiO ₂)
Monazite	0.12 (Kerala)	N.A.	N.A.

* Compiled from Indian Minerals Year Book 1970.

* Not Available.

TABLE—II SOME ECONOMIC DETAILS OF PLACER DEPOSITS

Mineral	Approximate price ^a	Sp. gravity	Economic Range
			(Cu. yd)
Diamondiferous Diamonds	\$00-60/ct.	4.5	
Metallic minerals			
Platinum	\$180.00/oz.	14-19	
Cassiterite	\$1.75/lb	6.8-7.1	
Beach sands			
Ilmenite	\$ 20.00/ton	4.5-5	1.5-2.0%
Rutile	\$160.00 "	4.2	0.3%
Zircon	\$ 70.00 "	4.2-4.8	0.3%
Monazite	\$117.00 "	4.9-5.3	0.1%
Magnetite	\$ 10.00 "	5.2	3.0%

^a Prices are for 1970

involved in offshore exploration are given in Table III.

Not much interest has been shown by various countries in the exploitation of such minerals which have a low cost per unit volume. These minerals include quartz sand and calcareous sand utilized by the chemical industries and by the building engineers for construction purposes. Quartz sand is extracted off California, Florida and from the English Channel. Calcare-

ous materials are abundant on many shelves of the world. They are of local importance, and when sufficiently pure, they could be used for cement manufacture (e.g., the calcareous materials of Vembanad Lake in Kerala and the Gulf of Kutch in Gujarat) or for the chemical industry as is the case for the off-shore colite deposits in the Bahamas (Schmitz and Aldrich, 1970). A general classification of the offshore mineral deposits, excluding oil and natural gas, is given in Table IV.

TABLE—III COMPANIES UNDERTAKING OFFSHORE MINERAL EXPLORATION (modified from Lampietti and Valentine 1970)

Company	Country	Mineral	Year of commencement	Approx. expenditure in dollars
Rio Tinto Zinc	Malaysia	Tin	1965	200,000
Union Carbide	Thailand	Tin	1964	1,000,000
Billiton M.S.	Thailand/ Malaysia	Tin	1968	500,000
Shell	Alaska	Gold	1964	800,000
Kennecott	Pacific	Mn. nodule	1962	600,000
Bethlehem	"	"	1965	800,000
Bethlehem	Australia	Tin	1966	200,000
Tenneco	Atlantic	Mn. nodule	1964	4,000,000
de Beers	S. Africa	Diamonds	1963	2,000,000
Electro Zinc	Australia	Tin	1966	2,000,000
Planet Mining	Australia	Rutile/zircon	1967	650,000

TABLE—IV GENERAL CLASSIFICATION OF OFFSHORE MINERAL DEPOSITS, EXCLUDING OIL AND NATURAL GAS.

Unconsolidated		Consolidated	
Surficial	In situ	Surficial	In situ
1. Shallow placers, beach or offshore iron sands, silica sands, calcareous sands.	Buried river and beach placers of gold, tin, platinum, diamond.	1. Exposed stratified deposits of coal, iron stone, limestone, coral.	Massive vein or tabular deposits of sulphur, copper, iron, tin, coal.
2. Authigenic nodular deposits (Mn, Co, Fe, Ni), phosphorites.		2. Authigenic coating of manganese and phosphorite.	

Sedimentary framework of the western continental shelf of India

The unconsolidated mineral deposits of the continental shelf are related to the geologic history of the shelf and more specifically to the sediments and sedimentary processes (McKelvey & Chase, 1966; Emery & Nokes, 1968).

We restrict our discussion to the western continental shelf because it is much better studied than the eastern shelf of India. Moreover, the continental shelves on both the coasts are well within the 200-mile economic zone.

The western continental shelf has an area of about 900,000 sq. km. It is about 280 km broad off Bombay and gradually narrows towards the south and off Kerala. It is only about 60 km wide. From the continental shelf region, the NIO has collected about 1,000 bottom samples using gravity and piston corers, grabs and dredges. Other supporting data on topography have also been collected by continuous echo-sounding and sub-bottom profiling. Most of the work has been done from the research vessel Gaveshani during 1976-77.

A brief review of the sediments including the topographic and sedimentary processes of the western shelf has been given here. Further details of the work can be obtained from Siddiquie (1974), Nair (1975) Hashimi and Nair (1976).

Echo-sounding has shown that the bottom topography is generally smooth and featureless down to a depth of 60 m. Seaward from 60 m and up to the edge of the shelf (120 m), the sea floor has numerous undulations, pinnacles, depressions etc. The pinnacles are about 10 m high. The shelf-break ranges from 90 to 120 m in depth. The sediments in the shelf region are of three distinct types: (i) the nearshore sand from the low tide mark on the shore down to a depth of about 10 m in the sea. This strip of sand is a few kilometres wide and largely consists of quartz with small quantities of heavy minerals, (ii) the silt and clay regions in the inner shelf which extend from about 10 m to 50 m or 60 m depth, (iii) the region of calcareous sand which extends from about 60 m to the end of continental shelf.

These three types of sediments have different origins. The first two (nearshore sands and silt and clay from the inner shelf) are formed as a result of geological processes of weathering and erosion occurring under the present climatic (hot and wet) conditions on coastal lands. These sediments strongly reflect the lithology of the parent rocks from which they are derived. Thus, the different types of rocks contribute different minerals to the sediments.

In contrast to the nearshore sands and muds of the inner shelf, there are the calcareous sands and carbonaceous rocks of the outer shelf. These sediments are of late Pleistocene origin when the sea level stood between 60 to 90 m below the present level. The radiocarbon age of the calcareous sediments is between 9,000 to 11,000 years and they are therefore, termed "relict sediments". Many old shorelines have been found to be associated with low stands of sea level and some of these have become preserved on the shelf as scarps and terraces at depths ranging from 31 to 92 m. These old shorelines are important because they have a concentration of heavy minerals (Fig. 1). Some of the ancient

shorelines are difficult to recognise because the more recent changes in the sea level redistribute the sediments of the old shorelines or cause them to be buried under the more recent sediments. Details of drainage pattern occurring during the periods of low sea levels are not available at present. However, one may presume that the buried channels of old rivers exist on the western shelf and these in turn may form the source of heavy mineral concentrations like those found on land (Fig. 1).

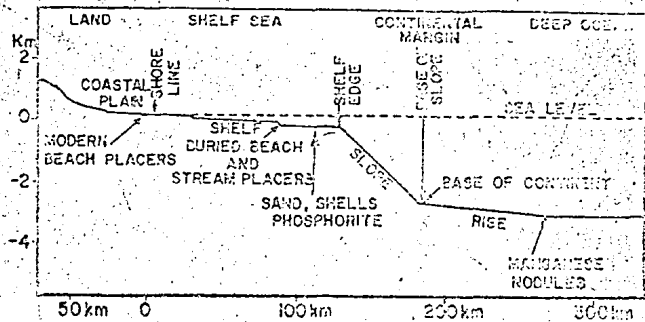


Fig. 1, Diagrammatic representation of the occurrence of minerals in the continental shelf.

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Promising offshore areas for different types of minerals

HEAVY MINERALS

Heavy minerals such as ilmenite, magnetite, monazite, zircon and garnet occur as placer deposits in discontinuous patches along the shores of both the west and east coasts of India. The most important of these deposits are the ilmenite and monazite sands of Kerala. Concentrations of these minerals on the beaches occur as a result of the natural process of weathering and erosion of the hinterland of Kerala. The selective removal of the light fraction (quartz, feldspar) from the sand by the action of waves and currents, has led to further enrichment of the sand with heavy minerals. Extension of these deposits to deeper waters is a logical possibility, and therefore, off-shore exploration for heavy minerals in promising areas of the west coast is most important (Fig. 2). Recent geological exploration of the continental shelf from Goa and Cape Comorin provide

supporting evidence of the extension of the placer deposit into deeper waters. Studies of the sediments indicate that the entire outer continental shelf is blanketed with quartz sand with varying proportions of heavy minerals. In contrast, the sediments of the outer shelf regions from the Saurashtra coast to Goa are dominated by calcareous sand which is poor in quartz and heavy minerals. Recently the NIO has discovered an offshore extension of ilmenite in the shallow waters off Ratnagiri (Fig. 2).

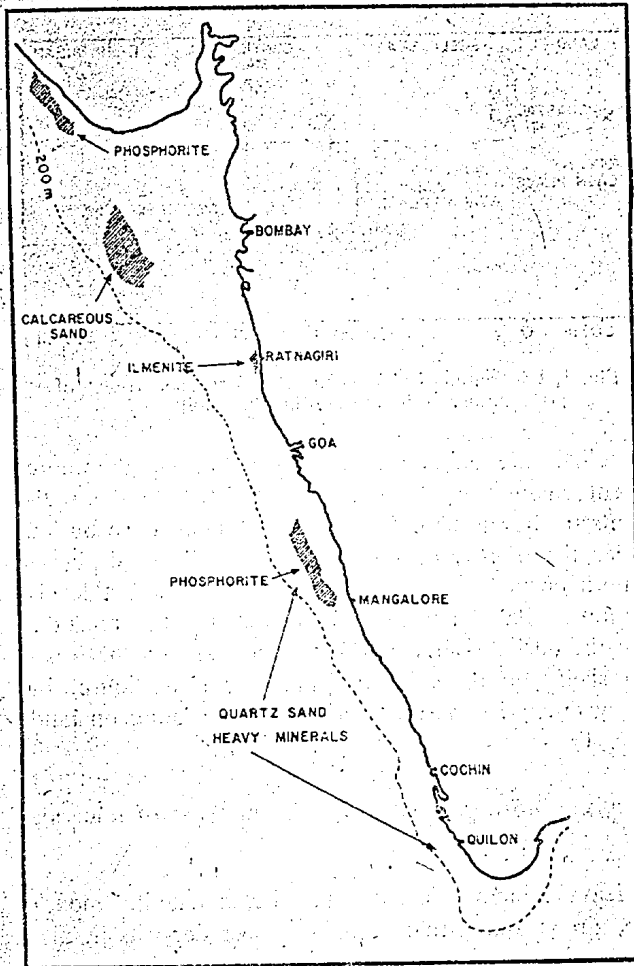


Fig. 2. Promising areas for exploration of unconsolidated mineral deposits on the western continental shelf of India.

PHOSPHORITES

Favourable conditions for the occurrence of sediments rich in phosphorite (calcium chlorapatite/calcium fluorapatite) on the continental shelf are as follows:

- (a) The presence of an upwelling area through which relatively cold, phosphate and nitrate rich waters from the bottom layers of the oceans could reach the surface layers,
- (b) the presence of calcareous sediments on the shelf to form nuclei around which phosphatisation occurs
- (c) low rates of sedimentation leading to exces-

sive dilution and burial of the phosphate-rich sediments. These conditions have been shown to occur on the western shelf and further evidence is available as to the existence of phosphatised oolites and algal fragments from the outer shelf. However, a greater enrichment of phosphate in the carbonate sediments, in relation to other types of sediments merits further investigation. The areas suggested for phosphorite exploration are off the Saurashtra coast and on the shelf between Goa and Mangalore (Fig. 2).

QUARTZ SAND AND CALCAREOUS SAND

A large part of the continental shelf sediments from Goa to Cape Comorin, include quartz sand. These sediments are of recent origin and have low carbonate content. Some of these deposits may have to be exploited in future to meet the growing needs of construction work in our coastal towns where fast expansion of urbanization may soon lead to acute shortage of sand coming from inland areas. However, the removal of sand from the beaches creates the problem of beach erosion and several areas of our coastline have been adversely affected. Removal of sand had led to severe erosion endangering the lives and property of thousands of inhabitants. It is, therefore, necessary that the removal of one type of sand from an area may be followed by the replenishment of another type of sand and for this purpose offshore sand deposits may have to be dumped on the shore.

Calcareous material, in the form of oolites and shells of various organisms, are found in large areas of the northern part of the outer continental shelf. The calcareous material constitutes 60% to 70% by weight in the sediment and in certain areas of the Fifty Fathom F off Bombay, it increases to 90% by weight. Bulk analysis of these carbonates indicates that they contain insoluble residue of less than 1.5%. They are thus eminently suitable for the chemical industry. Their occurrence as unconsolidated deposits extends over an area of about 50,000 sq. km. Their purity favours their exploitation while the depth of water (60-90 metres) and the distance from the coast which is about 100 km, is a constraint in their mining.

Economics of offshore mining

The existence of a useful mineral on the sea bed in large quantities does not necessarily mean that it will be easy to exploit. The recovery of a mineral depends on the development of a technology which is economically feasible. McKelvey (1968) has classified mineral resources which would help in placing a mineral in a proper economic perspective. This classification has been diagrammatically shown in Fig. 3. As can be seen from the Figure, the classification

	KNOWN			UNDISCOVERED
	PROVED	PROBABLE	POSSIBLE	
RECOVERABLE MARGINAL	RESERVES			
	RESOURCES			
	+	+	+	

3. Classification of reserves and resources as given by McKelvey (1968).

deposit progressively changes with exploration, development of technology and economic conditions. Recoverable resources from marketable materials which could be used under locally prevailing economic and technological conditions. Resources close to the shores are promising because they can be exploited at a cost about 1.5 times greater than the prevailing rates. The resources which can be recovered at a cost higher than 1.5 times the prevailing rates are also important because with the development of cheaper technology it would be possible to exploit them in the immediate future.

Mining methods for unconsolidated surficial deposits

The most important consideration in the exploitation of unconsolidated surficial deposits is the overlying water. In general the technology of marine mining is basically the technology of dredging and hence several types of dredges such as bucket-ladder dredge, dragline dredge, wireline clam shell, and hydraulic cutter suction dredge have been developed. Dredging operations in shallow waters close to the shore are relatively less hazardous than those carried out in the deeper waters. Deep water operations require oceanographic data on wave characteristics, current directions and magnitude and biological and chemical characteristics of water to ensure safety and efficiency.

Ecological impact of offshore mining

The extraction of any type of mineral from the sea bed will involve the removal or redistribution of sediments and benthic organisms. Resuspension of sediments in the waters close to the bottom and a marked increase in the turbidity of surface water are some of the environmental problems of offshore mining because the material is transported in hopper barges from the mining site to the storage site.

The mining activity may affect the oceanic environment either favourably or adversely. Gerard (1976) gives the following effects of mining:

- Disturbance or destruction of benthic organisms.
- Resettlement of stirred-up sediment and possible destruction of such benthic animals which may have a very slow reproductive cycle.
- Change in the chemistry of bottom water as the water may retain in solution the compounds leached out from the recovered sediment.
- An increase of dissolved nutrients in the water resulting in increased biological productivity in the euphotic zone.
- A change in the light penetration of surface waters because of turbidity.

It is, therefore, necessary that baseline environmental conditions must be studied before any mining operation, small or large, is undertaken. Roels (1974) has proposed the following systematic plan to be followed for deep-sea mining of manganese nodules:

- Establishment of baseline conditions in the potential mining areas.
- Environmental monitoring of pilot and/or full-scale mining operations.
- Documentations of changes caused in benthic and pelagic ecosystems by deep-sea mining and evaluation of their implication in relation to current or potential marine resources.
- Recommendations on the changes, if necessary, in the mining methods and equipment.
- Formulation of environmental criteria and regulations for future mining operations to minimize harmful environmental effects.

The plan suggested by Roels (1974) for manganese nodules is just as applicable to the mining operations in the shallower areas of the continental shelf and all of the points noted above are of immediate relevance to India. The increasing activity in offshore oil productions and transportation are often associated with oil spills, oil-well blowouts and discharge of oil into the sea during its transport. A mining operation can come into conflict, for example, with the fishery operations and this particular point is of utmost importance to several areas in our country where a large export-oriented prawn fishery is thriving at present.

Conclusion

The geological information available for the western continental shelf clearly indicates that, apart from oil and gas, the offshore mining for heavy minerals, phosphorites, quartz sand and calcareous sand has a great

future in India. In the case of heavy minerals and phosphorites, their high cost per unit volume will soon lead to an accelerated pace of exploration and exploitation. In India we have only made a beginning in offshore mining and as more and more knowledge becomes available about the geological wealth of our coastal waters, offshore mining will progressively meet our fast expanding needs for minerals.

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