

PART II

POTENTIAL OFFSHORE MINERAL RESOURCES

A. OFFSHORE MINERAL RESOURCES

The western continental margin of India up to a depth of 2000 m (excluding Laccadives) occupies an area of about 0.473 million sq km which corresponds to 20.4% of the Exclusive Economic Zone of India and equals to about one sixth of the land area of the country. Compared to the eastern continental margin, the wider shelf, the gentler slope and the relatively lower terrigenous influx on the outer shelf, provides an unique opportunity to explore non-living resources of various types such as terrigenous, biogenous, and chemogenous/authigenic and hence needs a special attention on a priority basis. Based on the geochemical data presented earlier (Part I), following mineral resources are identified. These need to be explored in detail so as to evaluate their commercial exploitation potential.

1. CALCAREOUS DEPOSITS

Very large areas on the outer shelf and upper slope between Gulf of Kutch and Mangalore and the entire margin along the southern tip of India are occupied by carbonate rich sands (> 75%) (Fig. 2). These sands are composed of relict components (oolites) and biogenic fragments north of Mangalore while skeletal constituents dominate south of Quilon. Although the overall carbonate concentration is high (> 50%), richest deposits (up to 94%) are encountered in the offshore areas of Bombay and contain less than 1.5% insoluble residue. Mineralogy of these sediments reveal that aragonite is the dominant mineral (99% maximum), followed by low magnesium calcite (77% maximum) and high magnesium calcite (39% maximum). These carbonates are of recent age, formed around 9000 to 11000 years BP, and have not undergone any diagenetic change. Calcium/magnesium ratios are high in outer shelf sediments where oolites are predominant and low in the middle shelf where skeletal components dominate. Further, the content of various metals (aluminium, iron, manganese, nickel, copper, cobalt) within the carbonates is very low. Thus these studies suggest that carbonates, on an average, are high grade deposits, especially between Bombay and Mangalore. The economic potential of these calcareous deposits is not estimated but their extensive occurrence over wider shelf appears to be promising reserves for the future.

2. ORGANIC-RICH DEPOSITS AND HYDROCARBON POTENTIAL

From the perspective of cost, endeavor and economic returns, the recovery of hydrocarbon resources is the major activity on the continental shelf and slopes of the world. It is now known that 35% of global oil reserves are confined to offshore areas beyond 200 meters depth. In India, oil production from the EEZ (confined to the shelf) accounts for about 75% of the total production.

Oil exploration and developments on the west coast of India is presently concentrated on the broad shelf off Bombay in areas shallower than 200 m depth and the producing horizons are of Miocene, Oligocene and Eocene periods. In our country, as the GNP rises, so does the consumption of petroleum products. As the population grows, there is corresponding need for additional energy sources so as to maintain the economic standards. Since the foremost policy of our nation is to raise the standards of living, a tremendous pressure on the energy requirements is already being felt.

The demand for oil in India is ever increasing and so as to maintain the industrial and economic growth, the oil requirement by the year 2000 is estimated to be 120 MMT whereas the hydrocarbon potential (crude) will be only 59 MMT. This means that there is a large gap between consumption and production and India will have to import or step up its production or find new reserves of oil in the years to come. The western Indian margin is one such promising avenue.

The foremost control to oil-source rock deposition is that the organic matter in sediments has to be of marine source and the kerogen present must be hydrogen-rich (Type I or Type II). The sediments of the upper continental slope between 150 to 1500 m depth are highly enriched in organic carbon (> 4% and up to 12%) (Fig. 3) which is mainly of marine origin. This remarkable organic enrichment is attributed to its preservation under reducing conditions favored by the juxtaposition of the oxygen minimum zone on the floor of the slope. These environmental conditions have been prevailing for the past 54 million years.

Under such anoxic/reducing conditions, there is every possibility for the retention of higher percentage of hydrogen in the kerogen fraction of organic matter. This results in more lipid rich and more reduced residue which is critical for the genesis of oil source beds. The organic matter on the slope is dominantly of Type II and has excellent hydrocarbon generation potential. The presence of thermogenic hydrocarbons indicates that the area could be prospective for hydrocarbon accumulation. These characteristics of surficial organic matter point to very high chances of finding oil bearing horizons at greater depths. Moreover, the shelf margin basin across the continental slope has developed stratigraphic and structural features within sedimentary deposits which are attractive targets in deeper waters and appear to be favorable locales for hydrocarbon generation. This view is also supported by the fact that the sediments as old as 60 million years occur on the western slope of India.

All these evidences together suggest that the continental slope of western India can act as source beds for petroleum generation. More particularly, the slope with gentler topography and an appreciable sediment thickness of upto 4 km between Ratnagiri and Mangalore, and south of Cochin where the surficial organic rich band is wider, have greater potential for hydrocarbon exploration.

3. PHOSPHORITE DEPOSITS

India is mainly an agricultural country. Phosphate deposits form a basic raw material in the manufacture of fertilisers which are essential for agriculture. The indigenous production meets only a fraction of national requirements of rock phosphates and hence rock phosphate, fertilisers, phosphoric acid and elemental phosphorus are being imported.

The present resources of the country are about 20 millions tonnes of high grade ($> 25\% \text{P}_2\text{O}_5$) land based phosphatic material, whereas India's cumulative demand is 17 million tonnes of phosphate by the year 2000 A.D. This indicates that the present limited reserves are not in a position to meet the rising demands. A viable solution is to explore offshore phosphorites since high grade phosphate deposits are reported from continental shelves world over under the influence of upwelling, a phenomenon which is also observed along the western continental margin of India.

Phosphorites are consolidated rocks containing more than 6% P_2O_5 . Around 1970, phosphatic formations containing 7.6% P_2O_5 were reported off Quilon at a depth of 260-300 m and are believed to be as old as 33,000 years. At the same time phosphatized oolites between 70 and 120 m water depths and phosphatized algal nodules at 120 m water depth were reported off Bombay - Mangalore.

Our investigations on the western continental margin revealed that phosphate content of shelf sediments ranged from 0.03 to 6.57% on the carbonate free basis (Fig. 4). Recently phosphatized algal nodules, with a P_2O_5 content between 2 and 10%, were dredged between Ratnagiri and Goa from a depth of 70 and 100 meters. In the outer shelf between Bombay and Goa, a series of ridges, 2 to 3 m high, composed of algal, coral and shelly limestone, revealed the presence of 5 to 6% phosphate. Our mineralogical investigations have revealed the presence of apatite in the carbonate-rich and organic-rich upper slope sediments. However, the presence of francolite in association with the phosphatized oolites/pelletoides from the outer shelf off Bombay is also reported.

The association of P_2O_5 and carbonate, a sympathetic relationship of phosphorus with organic carbon and high concentration of inorganic phosphate (5000 to 7000 $\mu\text{g/liter}$) of interstitial waters of sediment suggest that phosphatogenesis is authigenic (chemical precipitation) and/or diagenetic (partial replacement of pre-existing carbonates).

Environmentally, the upper slope offers a favourable locale for the formation of phosphorites. Because of intense upwelling, higher organic content, ideal carbonate substrates, negligible terrigenous contamination, and the interception of oxygen minimum zone, the upper slope can provide ideal conditions for phosphatisation. It is therefore suggested that modern phosphorites are presently being formed on the western continental shelf and slope as observed in other parts of the world.

In view of these facts, it is suggested that a detailed investigation on the outer shelf and slope between Bombay and Mangalore and off Quilon are essential in order to delineate the economically viable phosphorite deposits. Considering the prevalence of reducing conditions since 54 million years, it would be worthwhile to study sediments even older than 0.01 million years in order to look for the ancient phosphorite deposits along the continental margin.

4. HEAVY MINERAL RESOURCES

The TiO_2 content is high ($> 0.50\%$) (Fig. 7) throughout the inner western shelf of India, and to some extent along the slope off Mangalore-Cochin. Our studies have revealed that a considerable part of titanium is associated with the silt/clay fraction in the area north of Mangalore while

it is confined to the sand fraction south of Mangalore. Chemical analysis indicate that titanium is mainly contributed by detrital minerals and its distribution coincides with the areas of heavy mineral distribution. Moreover, our data has shown that titanium bearing heavy minerals such as ilmenite, rutile, titano-magnetite comprise important fractions of heavy mineral suites on the western continental margin of India. Hence, the distribution map of TiO_2 has proved to be helpful in deciphering possible areas of heavy mineral concentration.

So far, there have been some attempts to explore the offshore extension of onshore (beach placers) heavy minerals. Results of these exploratory investigations are highly encouraging. Offshore extensions of placer deposits, comprising ilmenite and monazite (an important thorium and rare earth bearing nuclear mineral) sands are reported along the coasts of Kerala, and ilmenite along the coast of Maharashtra, up to a water depth of 10-13 meters. The surveys so far carried out by NIO off the coast of Ratnagiri district (Maharashtra) indicate that the ilmenite bearing sands cover more than 96 sq km of the seabed. Assuming an average ilmenite concentration of 10% and minimum thickness of one meter, the reserves are inferred to be about 12.5 million tonnes. The seismic profile indicates that the thickness of ilmenite bearing sands ranges from 2-10 m and extends to a water depth of about 20 m, covering an area of 436 sq. km. These ilmenite bearing sands off Maharashtra contain an appreciable quantity of vanadium (up to 0.5%) and chromium. Although our studies represent TiO_2 concentrations beyond this depth, it is recommended that heavy mineral searches be intensified in all the enclosed bays along the west coast of India. Since titanium is associated with the sand fraction south of Mangalore, this area merits attention as far as eventual exploration is concerned.

Higher TiO_2 content on the slope off Mangalore - Cochin which is also supported by higher concentration of aluminium, iron, nickel, copper, zinc and heavy minerals suggests that this area also needs attention as far as ancient placers deposited during lowered sea levels are concerned. The presence of buried channels on the shelf also support this view.

B. EXPLORATION STRATEGIES

In view of the above mentioned potential mineral resources, the target areas for offshore exploration are demarcated in Fig. 12. The following exploration strategies are recommended:

- A. *Considering the availability of the land resources whose estimates are likely to shift upward, the present knowledge regarding the offshore carbonate deposits is more or less adequate for the time being and does not warrant immediate attention. However, calcareous sand deposits of shallow offshore areas may be exploited in the near future for developmental activities considering paucity of local construction materials.*
- B. *The exploration in nearshore areas of the inner shelf needs a systematic approach for inferring the offshore extensions of heavy mineral placer deposits. This involves collection of long sediment cores by vibrocorer especially in the areas wherever silts/sands are encountered. These surveys are necessary not only to understand the concentration of titanium but also for associated elements such as vanadium, chromium and thorium bearing monazite sands.*

- C. *The outer shelf and upper slope are certainly more strategic areas since these need prime attention for the exploration of phosphorite deposits and hydrocarbon source beds. The organic-rich sediments here are deposited under reducing conditions and therefore, the search for uranium and barium deposits is also warranted. Hence, these regions have to be investigated by taking a multidisciplinary approach comprising geology (geochemistry, sedimentology, mineralogy) and geophysics (seismics, magnetics, hydrosweep, side scan sonar) between the depths of 90 and 1500 m. These surveys will also include finding ancient heavy mineral deposits on the slope between Mangalore and Cochin. The search for hydrocarbon deposits needs special logistics and hence complementary efforts from the oil industry are essential. In all the cases, there will be a need for the development of improved exploration and recovery technology.*

APPENDIX I

BIBLIOGRAPHY

APPENDIX I

BIBLIOGRAPHY

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