

Hydrocarbon Prospects of the Western Continental Slope of India as Indicated by Surficial Enrichment of Organic Carbon

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Abstract

The sediments from the continental mid-slope (150-1500 m depth) of the western Indian margin are highly enriched in organic carbon (upto 16%) occurring as a long and wide band off Bombay to southern tip of India. Organic carbon is essentially of marine origin and is enriched due to its preservation under anoxic conditions caused by impingement of oxygen minimum zone. The DSDP data in the southeastern Arabian Sea have revealed the initiation of upwelling and productivity during Early Eocene and establishment of reducing conditions since Mid-Miocene, which continue till today. Under such a reducing environment there is every possibility of retention of higher amount of hydrogen in the kerogen part of organic matter. Published literature has indicated the organic matter is of type II, the slope sediments have a structural capability for the retention of hydrocarbons and the sediments are significantly thick. All these evidences suggest that sediments from the Indian continental slope can act as source beds for petroleum generation. The continental slope between Ratnagiri - Mangalore and south of Cochin, with gentler topography and appreciable sediments thickness (2-4 km) where surficial organic-rich band is wider, are more potential sites for hydrocarbon exploration.

INTRODUCTION

Production, accumulation and preservation of undegraded organic matter are prerequisites for the formation of petroleum source rocks. Understanding the environmental controls on the present-day surficial distribution of organic carbon in the marine environment is useful in predicting how petroleum source rocks were formed and can also be used as guidelines for the search of hydrocarbon source beds.

The western continental margin of India is characterized by a wide continental shelf of 300 km in the north but gradually narrows down to 50 km

off Kerala in the south. The continental slope is narrow in the north as compared to southern part where it is wider. According to Biswas and Singh (1988), because of the distinct tectonic and depositional settings of the early and post rift phases of the western Indian margin, the petroleum prospects of this region warrant a proper evaluation.

Since the last two decades, the National Institute of Oceanography, Goa, has conducted several cruises for the collection of sediment samples from the continental margins of India. Around 600 samples were analysed to ascertain their organic carbon content. The aim of this paper is to discuss areas of

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organic enrichment with particular reference to hydrocarbon generation, based on the surficial expression of organic carbon.

DISTRIBUTION OF ORGANIC CARBON

A comprehensive map (Fig.1) showing the distribution of organic carbon in sediments of the western continental margin of India has been compiled taking into account about 600 samples analysed by the authors as well as other published data. It is observed that sediments from the inner continental shelf of India contain upto 4% of organic carbon whereas on the outer shelf low values (< 1%) are encountered. In comparison, sediments from the continental slope are found to be highly enriched in organic carbon where extremely high concentration of 16.71% (Ramamurthy and Murthy, 1989) has been reported. Such organically enriched sediments are located on the mid-slope and occur as a continuous long and wide band all along the slope from Bombay till the southern tip of India (Paropkari et al., 1992). It must be emphasized that this band of organic-rich sediments is widest on the Ratnagiri-Mangalore slope and also off Cochin (Fig.1). It is precisely these areas which merit attention from the oil generation point of view.

DISCUSSION

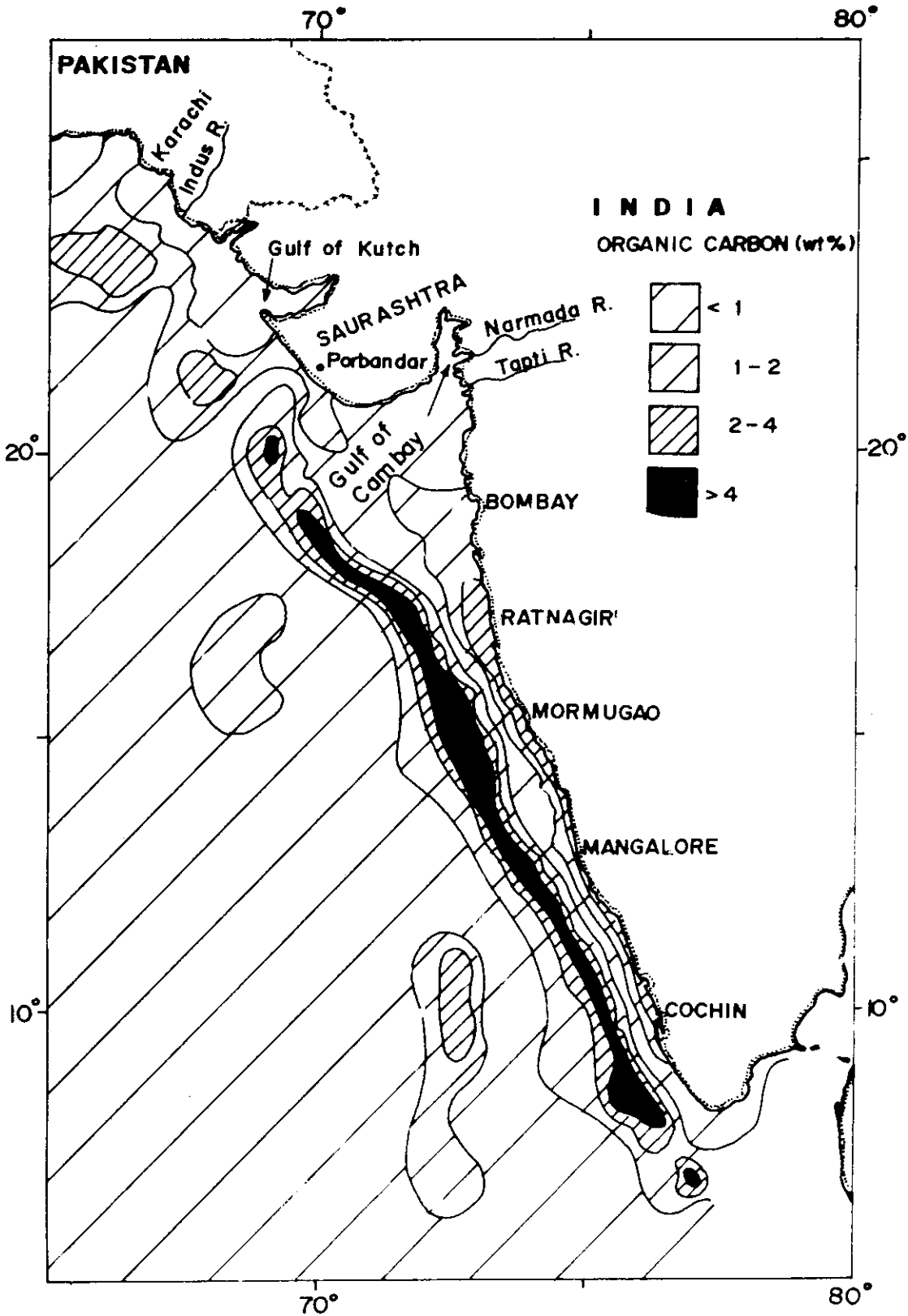
The enrichment of organic carbon alone does not necessarily characterize an oil prone region. The organic matter deposited in sediments must be hydrogen-rich capable of transforming mostly to liquid hydrocarbons. Therefore, the foremost control on oil source rock deposition is the preservation of organic hydrogen in the sedimentary organic matter rather than the sole preservation of organic carbon in the sediment.

The source of organic matter also needs to be examined as organic matter from marine sources is more prone to generate liquid hydrocarbons than transported terrestrial organic matter. Marine organic matter is rich in nitrogen (Premusic et al., 1982). The

distribution of total nitrogen in the Arabian Sea is similar to that of organic carbon (Kolla et al., 1981). Paropkari et al., (1987) showed a significant positive correlation between organic carbon and total nitrogen for the sediments of the western continental margin of India. These observations show that these two components are genetically related. The C/N ratios along the entire western slope of India generally fall below 6 (Marchig, 1972; Paropkari et al., 1987) indicating that organic matter is predominantly of marine origin. The studies on the $\delta^{13}\text{C}$ (Fontugne and Duplessy, 1986) has also confirmed that organic matter along the western slope of India is mainly marine.

In the recent past, there has been a lot of speculation concerning the preservation of organic matter in the oceanic environment from which it appears that world wide, productivity and/or anoxia are the key controlling factors. It can be clearly observed that along most of the western Indian margin, productivity is low (0.25-0.75 gC/m²/day; Qasim, 1977) and yet the overall organic carbon contents are high. It must be noted that highest organic carbon values (upto 12%, Paropkari et al., 1987; and upto 16%, Ramamurthy and Murthy, 1989) occur between Ratnagiri-Mangalore, precisely where productivity is very low (<0.25 gC/m²/day). This clearly indicates that the organic carbon enrichment does not necessarily reflect surface productivity (Paropkari et al., 1992).

A characteristic feature of this organic rich (4-16%) band (Fig.1) in the middle part along the entire continental slope is its exact coincidence with the oxygen minimum zone (<0.5 ml/l dissolved oxygen). The highest values occur in the central part of this band where the oxygen content of the bottom water is the lowest, often undetectable. Sediments from this environment, have also been found to emit a strong H₂S odour. Therefore, we attribute the enrichment of organic carbon along the Indian slope to its preservation under oxygen deficient conditions caused by oxygen minimum zone (150-1500 m water depth), which incidentally is permanent hydrographic feature



Map showing the distribution of organic carbon in surficial sediments from the western continental margin of India (after Paropkari et al., 1992).

of the entire Arabian Sea. Similar observations in world oceans have also confirmed high organic content wherever oxygen minimum zone intercepts the continental slope (Premusic et al., 1982).

The above discussion clearly demonstrates the role of anoxic bottom waters as a fundamental control in the preservation of organic carbon. According to Kolla et al., (1981), the degree of preservation of organic matter along the Indian continental slope is 15-80 times higher than the rest of the Arabian Sea.

Thus, it is seen that the organic matter is essentially marine and is preserved under anoxic conditions, the two prerequisites for identifying hydrocarbon source beds. Nevertheless, factors like paleoenvironment of deposition, character of organic matter, tectonic evolution and sedimentary structures of the slope have to be considered.

Based on faunal assemblages and geochemistry of a DSDP drill site in the eastern Arabian Sea (Site 219, Whitmarsh et al., 1974) it has been proposed that productivity in this region is high since the Early Eocene although evidences suggest that upwelling and deposition under oxygen-poor benthic environment took place since Middle Miocene. These conditions are prevalent today in the eastern Arabian Sea comprising the western continental slope of India. Under such anoxic conditions there is every possibility for the retention of higher percentage of hydrogen in the organic matter. The degradation of organic matter is minimal due to restricted biological activity (Demaison and Moore, 1980) as well as due to less susceptibility to microbial attack by toxic metal complexes formed there (Degens and Mopper, 1976). This results in more lipid rich and more reduced (H-rich) residue than produced by aerobic degradation and is critical for the genesis of oil source beds.

Tissot and Welte (1978) have proposed that if surface organic-rich deposits contain hydrogen enriched organic matter, then there is every likelihood of finding oil bearing horizons at greater depths.

Organic geochemical studies (Singh et al., 1987) of the surficial sediments from the slope north of Ratnagiri have revealed that the organic matter is dominantly of type II and has excellent hydrocarbon generation potential (>5 mg HC/g rock). They observed that organic matter is of autochthonous nature, preserved under reducing environment. Presence of thermogenic hydrocarbons indicated that the area could be prospective for hydrocarbon accumulation.

The western continental margin of India is an Atlantic type passive margin (Biswas, 1989). The shelf basins evolved since Paleocene time following stabilization of the Indian plate after its collision with the Eurasian plate. A relatively narrow linear shelf margin basin occurs along the entire length of the Indian continental margin, but forms a part of slope region southward of Ratnagiri. The shelf margin basin across the continental slope in deeper waters (200-2000 m) has developed stratigraphic and structural features and sedimentary deposits which are attractive targets in deeper waters and appears to be the favourable locales for hydrocarbon generation.

The occurrence of extensive oil fields in the offshore areas from the western shelf of India (Sahay, 1978; Basu et al., 1980) can be extrapolated to decipher the oil source bed potential of the Indian slope sediments. The Bombay Offshore Basin consists of Tertiary sediments which at places are more than 5 km thick (Shukla, 1983). The oldest sediments above the basement are of Late Paleocene encountered in a well adjoining the deeper continental slope (Mohan, 1985). The important oil and gas bearing pay zones are of Middle Eocene and Middle Miocene age. Taking the stratigraphic succession of Bombay offshore field, it would not be wrong to suggest that sediments as old as Paleocene occur on the western slope of India. This may be true because the average sediment thickness of the slope is more than 1.5 km and sediments as thick as 4 km (Naini and Talwani, 1982) have been reported on the slope of Ratnagiri as compared to the total thickness of 5 km in the Bombay High region. These areas (Ratnagiri - Mangalore and

Cochin) where the slope is gentle and where a wide band of extremely rich organic sediments occur, deserve greater attention as far as petroleum exploration is concerned.

Geochemical exploration for petroleum has revealed that accumulation of organic matter on the slopes is a global phenomenon and is evidently a part of a process which has repeatedly occurred in geological times (Emery, 1969). Indeed, zones of upwelling contain some of the richest known petroleum source beds (Emery, 1969; Dow, 1978). The Louisiana-Texas oil depocentres were formed during Late Cenozoic time (Woodbury et al., 1973) which means that a large accumulation of organic matter occurred during Miocene, Pliocene and Pleistocene times (Premusic et al., 1982).

From the foregoing discussion, it can be concluded that productivity in this region began in Early Eocene, surficial organic-rich slope sediments are characterized by type II kerogen preserved under anoxic conditions present since Miocene, the structure of the shelf margin basin can favourably hold hydrocarbons, the sediment thickness in this basin is appreciable. 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 large sediment thickness (2-4 km) between Ratnagiri-Mangalore and south of Cochin, where surficial organic-rich band is wider, are better potential sites for hydrocarbon exploration.

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