Organic matter distribution pattern in Arabian Sea: Palynofacies analysis from the surface sediments off Karwar coast (west coast of India)

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Central Arabian Sea region, situated off the Karwar coast, is characterized by intense mid depth (~120-1200 m) oxygen minima zone and shows preservation and accumulation of relatively high organic matter content. Palynofacies analysis was carried out with a view to understand the organic matter production, preservation and degradation in the surface sediments of Arabian Sea from 15 m-2750 m depth off Karwar [14.47-14.40° N-70.77-74.25° E transect]. Palynofacies analysis, which involves qualitative and quantitative estimation of terrestrial and marine organic matter is a useful tool to decipher and assess paleoenvironmental changes in various water depth zones from shelf-slope region off the Karwar coast. There is a marked change in the palynofacies characteristics of the organic matter recovered from various depth zones. High SW monsoonal activity over Karwar coast results in increased runoff and nutrient loading in the coastal waters. This enhances primary productivity in the inner shelf region. Organic walled dinoflagellate cysts as important constituent of primary productivity, predominate under such conditions, being converted into Amorphous organic matter (AOM) as a result of degradation under low oxygen environment. Hence, in the present study high AOM is used as proxy for the low oxygen content at sediment-water interface. It also provides evidence of high primary productivity in the photic zone. Study further reveals that terrestrially derived charcoal and woody plant tissue resistant to degradation, are transported to continental slope regions at greater depths. Occurrence of a large proportion of well preserved labile organic matter (exoskeleton fragments of planktonic crustaceans) and AOM in the mid-outer slope surface sediments indicate enhanced primary productivity and high rate of burial efficiency making these areas, characteristic of low oxygen. The study shows that the Karwar coast margin is highly productive as a result of runoff related nutrient loading and is the primary cause for oxygen minima conditions.

[Key words: Palynofacies, primary productivity, oxygen minima zone, Karwar coast, Arabian Sea, west coast of India, organic matter, sediments, amorphous organic matter]

Introduction

Arabian Sea is amongst the most productive regions in the world ocean and is characterized by one of the largest bodies of oxygen deficient waters on the Earth1. A stable oxygen minimum zone (OMZ) exists in the northeastern Arabian Sea characterised by greater accumulation of organic matter2, 3. Since organic matter is supplied to marine system from both terrestrial and marine sources, it becomes essential to characterize various organic matter types to decipher runoff and productivity related changes. Identification of modern analogues for the environment of hydrocarbon source rock formation requires compilation of information on the distribution of organic carbon in marine bottom sediments. More recently, there has been considerable interest in carbon cycle in the ocean, which involves settling and burial fluxes of carbon and associated biogenic elements at discrete oceanic sites. During past few decades, palynofacies studies are being used in the hydrocarbon exploration as well as in deciphering paleoenvironment of pre-Quaternary sediments4-7. Palynofacies study has an advantage over bulk geochemistry as it provides direct means to identify source and constituents of particulate organic matter assemblages and hence has been effectively used in paleocenographic interpretations7-10. Vast amount of data have been generated on the geochemical aspects of organic matter characteristics in marine sediments, however, the mechanisms controlling the correlation between organic matter production, composition, selective preservation and sedimentation in Arabian Sea sediments are still insufficiently understood. Wiseman & Bennette11 first studied the distribution of organic matter in the sediments of Arabian Sea. Murty et al.12 gave an account of the depth wise distribution of organic matter in surface samples collected from the shelf and slope regions off Bombay, Karwar,
Mangalore, Cochin and Alleppey. Their study showed that the sediments from inner shelf and slope regions have high organic content whereas the sediments of outer shelf are comparatively poor in organic content\textsuperscript{12}. These studies mainly deal with the geochemical aspects of organic matter and do not provide any information as regards to the nature of organic matter production, its provenance, morphologic characterization and selective preservation in the Arabian Sea sediments.

Palynofacies studies that involve relative distribution pattern of various organic matter types in the marine sediments can be effectively used as an aid in paleoenvironment and hydrographic interpretations\textsuperscript{7, 10}. Complementary to geochemistry, palynofacies studies can be a useful tool in deciphering variability in the primary productivity, differential transport of organic matter and its preservational potential during sedimentation as well as its differential degradation\textsuperscript{7}. Its advantage over other techniques is that it provides a visual assessment of the origin, characteristics, provenance and state of preservation of organic matter\textsuperscript{7}. It has been demonstrated that the degree of organic matter preservation are positively correlated with sedimentation rate and that the nature of sediment affects the rate and extent of organic matter degradation\textsuperscript{3}. Both terrestrial and marine organic matter biomacromolecules are of different origin and hence show different nature and resistance to degradation\textsuperscript{7}.

Continental shelf break in Arabian Sea\textsuperscript{13} varies considerably ranging from 132-140 m off Bombay and 100-115 m off Ratangiri and continental slope from 200-2600 m. Shelf break is gradual in the area off Bombay but becomes steeper towards southern region\textsuperscript{13}. The sediment varies from silty sand to sand in the inner to outer shelf region, however, slope region shows progressive fining of sediment from outer-shelf-slope region\textsuperscript{13}.

The present study deals with the documentation, distribution and selective preservation of various sedimentary organic matter types in the surface sediments of Arabian Sea from continental shelf-slope [from 15 m-2750 m depth in the 14.47-14.40° N - 70.77-74.25° E transect] off Karwar coast, and to evaluate the relative proportion of phytoplanktonic and zooplanktonic remains and relate them to their productivity and preservational potential according to changes in the water depth.

**Materials and Methods**

Nine surface sample (SC 21 - SC 28) covering both shallow shelf to slope region (15 m-2750 m) at latitude 14.47-14.40° N and longitude 70.77-74.25° E collected during cruise of ORV Sagar Kanya (SK-117), October 1999, from the region off central west coast of India (Fig. 1). The samples were provided by NIO, Goa for the study of palynofacies analysis. Samples were dried and 2 gm of each were used for palynological processing. The carbonate was dissolved with HCl (10%) and silicates with HF (40%). Use of oxidizing reagents (HNO\textsubscript{3}) was avoided in order to analyse organic matter as a whole and to avoid alteration of organic matter preservation during chemical processing. Slides were made with polyvinyl alcohol and mounted in Canada Balsam.

Thirteen sedimentary organic matter (SOM) categories were chosen to represent the total SOM assemblages. Their biological sources and constituent’s sensu Tyson\textsuperscript{7} are summarized. In order to quantify the individual components as percentages of the SOM, a minimum of 200 counts were made for each sample.

Distribution patterns of palynodebris or sedimentary organic matter have been extensively used for environmental interpretation of Pre-Quaternary sedimentary successions\textsuperscript{8, 14}. von Waveron & Visscher\textsuperscript{15} applied palynofacies analysis interpretation in modern sediments for environmental and burial efficiency of organic matter. In the present study, individual palynodebris components were classified into the categories, based on the physical characteristics of recovered organic matter (Table 1).

![Fig. 1](image-url)—Location of surface samples collected at various depth in Arabian sea off Karwar coast.
Results and Discussion

In the present study, terrestrial debris (degraded brown, structured) and marine debris (amorphous) dominated in the inner shelf sediments (Fig. 2). Shelf region 15 m-147 m depth shows enhanced peridinioid dinocyst and decrease in black oxidized debris and gonayaulacoid dinocyst content. Low salinity tolerant dinocyst taxa *Tuberculodinium vancompoae* occurs in inner shelf sediments and shows sharp reduction in the outer-shelf region (Fig. 2). Gonayaulacoid dinocysts along with amorphous organic matter dominate in the inner-mid slope sediments. However, the mid-outer slope sediments are rich in black and brown degraded debris, labile organic matter, copepod egg envelopes, scolecodonts, tintinnids and various other zooplanktonic organic matter remains (Figs 2 and 3). The inner slope sediments around 200 m depth are also rich in organic matter content, albeit dominated by Cyanobacterial remains (Figs 2 and 4).

The distribution of allochthonous fraction (black, brown degraded and structured debris) in the marine environment is controlled mainly by physical processes. By contrast, the autochthonous fraction (dinocyst, tintinnids, scolecodonts, copepod egg envelopes and amorphous organic matter) can be significantly affected by biological/ecological processes. The hydrodynamic conditions together with relative buoyancy of organic particles seem to be the essential factor controlling the distribution of the allochthonous organic fraction in marine environment. In addition to that, the degree of resistance to decay also plays an important role in the distribution of organic particles in the marine sediment. Black oxidized debris are opaque fragments commonly designated as inertinite and originate from highly oxidized higher plant tissues. Usually occurring as blade shape particles, these are highly buoyant, hence their settling to the sea floor is delayed as in the case of the mica flakes. Selective degradation of organic matter also plays a very important role at the time of burial in marine environment. The aromatic compound derived from lignin are broken down very slowly, which shows that the lignin rich woody debris occurring in greater portion in black and brown debris have greater chance of survival in marine sediments. These are characteristically found in abundance in the outer slope sediment in the present study. Amorphous organic matter, mostly derived from decomposition of phytoplankton remains, tends to form fluffy aggregates known as “marine snow”. Being highly susceptible to oxidation, their presence in the marine sediments indicates reducing conditions in the water column and sediment water interface. Hence, large proportion of amorphous organic matter content in the slope sediments further points to the prevalence of low oxygen conditions in this region. Amongst the zooplankton remains, the transparent, subangular, pentagonal-hexagonal shaped particles identified as exoskeleton fragments of planktonic crustaceans, represent the most labile (low resistant) fraction of the zooplankton remains. In the present study dominance of pentagonal-hexagonal exoskeleton fragments of planktonic crustaceans in the mid-outer slope (1900 m-2750 m) region provides evidence of low oxygen environment or extension of OMZ in the slope region. It is interpreted that the organic aggregates or the “marine snow” produced during the period of phytoplankton blooms, tend to show a

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<th>Table 1—Sedimentary organic matter types documented in the present study (Modified after Tyson, and von Waveren &amp; Visscher)</th>
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Fig. 2—Distribution pattern of sedimentary organic matter types in various water depths.
Fig. 3—Palynomorphs and zooplanktonic remains in palynological assemblages from surficial sediments of the Karwar coast, Arabian Sea. *Scolecodont* sp. 1327273, 32Q1, *Scolecodont* sp. 1327274, 21Q4, Foraminiferal test lining 1327280, 27P1, Tintinnid 1327274, 33G4, Copepod egg envelope 1327275, 20M4, Copepod egg envelope 1327274, 24H2, Copepod egg envelope 1327274, 13F4, Microthyraceous fungi 1327274, 20U2, Protoperidinioid dinocyst (*Lejeunecysta* sp.) 1327276, 16J1, Protoperidinioid dinocyst (*Votadinium calvum*) 1327273, 16H3, Protoperidinioid dinocyst (*Trinovantedinium* sp.) 1327273, 20I4, Protoperidinioid dinocyst (*Quinquecuspis* sp.) 1327279, 48N1, Protoperidinioid dinocyst (*Stelladinium* sp.) 1327277, 23Q3, Protoperidinioid dinocyst (Round brown) 1327272, 32G2, Gonyaulacoid dinocyst (*Spiniferites* sp.) 1327276, 24E1
rapid downward flux and in the process other organic particles and mineral matter get attached to the aggregates, increasing the burial efficiency. The high organic matter burial fluxes will have the effect of protecting more labile organic material from microbial attack. Organic particles with less residence time in the water column would result in lesser period of degradation from aerobic bacteria. Hence, relatively high amount of most labile crustacean remains in the mid-outer slope sediment not only indicates high productivity zone but also high burial efficiency.

It is considered that where the oxygen minimum layer intercepts the continental slope, the bottom water and some times the sediment water interface becomes anoxic\textsuperscript{16, 17}. The intense oxygen minimum in the Arabian Sea where it intersects the western Indian continental slope, shows zone of high organic carbon values with concentration reaching 6.9 wt % on the inner-mid slope\textsuperscript{18, 19} between 200 m-1500 m. Thiede & van Andel\textsuperscript{20} and Slater & Kroopnick\textsuperscript{21} stated that the accumulation of organic matter content in the bottom sediment is controlled by the oxygen content.
of the overlying water. Whelan & Farrington\textsuperscript{22}, considered that the organic matter content of the sediment is strongly and positively correlated with the silt and clay content and shows that the sediments occurring in outer shelf region are generally coarse grained with high CaCO\textsubscript{3} and low carbon values. However, the amount of sand decreases seaward, so that the inner slope sediments are significantly fine grained. It is suggested that the lateral transport of organic matter plays an important role in the distribution, quality and burial of organic matter along continental slopes in high productive areas\textsuperscript{23}. In the present study occurrence of well preserved highly resistant black oxidized terrestrial plant debris in mid-outer slope region is quite interesting. Even if such a long distance transport is evoked, their highly buoyant nature rules out downward settling to such great depths in any reasonable period of time. Alternatively, it may probably suggests spread of Indus Fan during LGM when the sea level was considerably lower (~120 m) than the present to facilitate their quick transport and burial. However, it remains highly speculative and needs to be backed by C14/AMS dates to reach to any logical conclusion.

It is surmised that the marginal areas or inner shelf region of eastern Arabian Sea are generally much more productive in terms of primary productivity. High SW monsoonal activity in Karwar region\textsuperscript{24} leads to high runoff in Arabian Sea. High nutrient loading induces primary productivity in the euphotic zone that increases the organic production in the upper water column which ultimately leads to degradation beneath the euphotic zone. The oxygen consumption increases with depth under areas of high primary productivity, mainly due to microbial respiration during the degradation of organic matter\textsuperscript{16}. Hence, oxygen minimum layer is formed beneath the euphotic zone where oxygen demand is greater than supply and is also maximum in carbon dioxide and nutrient content\textsuperscript{16}. Decomposition of large amount of phytoplankton leads to high amorphous organic matter production below the euphotic zone within oxygen minima layer\textsuperscript{7}. Moreover, the low oxygen concentration in the water column also prevents its degradation and helps in preservation in the sediment\textsuperscript{7}.

The intensity of oxygen depletion is dependant on the residence time of oxygen minima layer within the water column and the productivity of the overlying euphotic zone\textsuperscript{12}. Hence, occurrence of large amount of organic detritus including amorphous organic matter in the eastern Arabian Sea sediment all along the inner shelf to mid slope region provides evidence for considerably stable oxygen minima conditions in this region.

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References:


