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Impact of climate induced hypoxia on calcifying biota in the Arabian Sea : An evaluation from the micropaleontological records of the Indian margin

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सार – अत्यधिक जैवीय उत्पादकता एवं वायुसंचरण में कमी के कारण अरब सागर के ऊपरी मध्य भाग के जल में ऑक्सीजन की मात्रा में अत्यधिक ह्रास (हाइपोक्सीया) हो रहा है। वर्तमान समय में महासागरीय क्षेत्र में अरब सागर न्यूनतम ऑक्सीजन क्षेत्र (ओ.एम.जेड़.) के रूप में जाना जा रहा है। यह न्यूनतम ऑक्सीजन क्षेत्र ओ.एम.जेड़. भारतीय सीमा क्षेत्र से टकराता है यहाँ ऑक्सीजन सान्द्रण का मान 0.05 मि.ली./ली. से कम है जिसके कारण विनाइट्रीकरण हो रहा है। हाल में किए गए अध्ययनों से पता चला है कि भूतकाल की तुलना में ओ.एम.जेड. की शक्ति में काफी बदलाव आया है जिसके कारण भूमंडलीय जलवायु में परिवर्तन हुआ है। परन्तु पूर्वी अरब सागर के मध्य जल क्षेत्र के वातावरण में रहने वाले समुद्री जीवों पर इन परिवर्तनों के प्रभाव के बारे में अभी जानकारी नहीं मिल सकी है। इस शोध पत्र में हमने कैल्सीफाइंग माइक्रोफौना समूहों के दो बड़े समूहों – टेरोपॉड्स सीक्रीटिंग ऐरगोनिटिक शेल्स और फोरएमीनिफेरा सीक्रीटिंग कैल्साइटीक शेल्स पर इनकी अधिकता और विभिन्नता को ध्यान में रख कर इन पर हुए अल्पकालिक परिवर्तनों के 30,000 वर्षों के अभिलेखों का विश्लेषण किया है। इस अध्ययन से वायुमंडल में कार्बन डाइऑक्साइड की बढ़ोतरी से समुद्री परिस्थितिक तंत्र पर पड़ने वाले संभावित प्रभावों को बारीकी से समझने में मदद मिलेगी।

ABSTRACT. High biological productivity combined with the poor ventilation produces severe oxygen depletion (hypoxia) in upper intermediate waters of the Arabian Sea. The naturally developed Arabian Sea oxygen minimum zone (OMZ) is one of the most pronounced low oxygen ocean environments known today. The OMZ impinges the Indian margin where oxygen concentration reaches values less than 0.05 ml/l leading denitrification. In recent studies, it has been observed that the OMZ strength has varied considerably in the past, in tune with the global climate change. But the effect of changes in natural mid-water hypoxic environment on the marine biota particularly of the eastern Arabian Sea is unknown. Here, we analyzed 30,000 yr record of temporal changes in two major groups of marine calcifying microfauna pteropods secreting aragonitic shells and foraminifera secreting calcitic shells in terms of abundance and diversity variations. This study will provide an insight into our understanding of potential impact of rising atmospheric CO_2 on marine ecosystem.

Key words – Oxygen depletion, Global climate change, Aragonite lysocline, Calcitic shells.

1. Introduction

In recent years, there has been a great concern amongst environmentalists and oceanographers over the rapidly changing climate and its impact on marine biota and its conservation and management. The physico-chemical and biological environments of oceans are closely coupled with the atmospheric chemistry and global climatic conditions. Changes in physico-chemical condition profoundly influence marine biotic communities in respect of their biogeographic distribution, abundances, diversities and morphologies. The nature of biotic patterns depends on sensitivity of biota and how do they respond to changes in various ecological parameters. Many marine animals and plants form shells and skeletons (corals, molluscans, foraminifers, ostracodes, phytoplanktons etc) using carbonate minerals and they represent an important component of marine ecosystems. These calcifying organisms are very sensitive to changes in the ocean chemistry with respect to saturation state of carbonate minerals like calcite and aragonite. The carbonate saturation level in the sea water column depends primarily on carbon dioxide content that influences pH condition (acidity/alkalinity) and carbonate ion availability and temperature. An increase in CO_2 lowers the seawater pH and as a consequence reduces carbonate saturation level. Thus, changes in dissolved CO_2 concentration in seawater have major consequences on marine ecosystem particularly for those organisms secreting $CaCO_3$ shells (Riebesell *et al*., 2000).

There are several areas across the globe, where naturally occurring oxygen depleted conditions result seawater under-saturation with respect to $CaCO_3$ minerals such as marginal seas (Black Sea, Baltic Sea, Gulf of Aden) and along the margins of the Arabian Sea, the Pacific and the SE Atlantic. Such natural environments are ideal to examine how various calcifying biota responded to changes in the past ocean conditions associated with natural forcings and also to evaluate the impacts of current rising atmospheric CO_2 concentration and to sketch future scenario if the same trend continues. Valuable information about the biological responses to the past changes in physico-chemical conditions of oceans are extracted from the shells preserved in sediments (as fossils) that were secreted by microscopic fauna and flora remarkably sensitive to minor changes in oceanic environment.

2. Natural mid-water hypoxia in the Arabian Sea, approach and methodology used in this study

The Arabian Sea is characterized by its mid-water zone of oxygen depletion (oxygen minimum zone, OMZ) between 150 and 1200 m depth (Altabet *et al*., 1995). The release of CO_2 and high levels of oxygen consumption due to respiration of sinking organic matter produced in surface waters creates oxygen depleted environment in the water column (Singh *et al*., 2006). The OMZ impinges the continental margins surrounding the Arabian Sea basin. The variation in mid-depth oxygen condition *i.e*., OMZ intensity influences the distribution of calcifying biota in terms of changes in carbonate saturation level affecting their shell calcification, abundances and diversity. Foraminifera and pteropods are the major marine microfaunal groups sensitive to changes in ocean environment including oxygen condition. Pteropods use mineral aragonite to form shells, thus they are more susceptible to the carbonate dissolution as compared to the calcitic foraminifera. Pteropods are exclusively planktonic in nature, whereas foraminiferal group represents both the planktonic and benthonic organisms.

We analysed temporal variations of fossil assemblage records of pteropods and foraminifera in a sediment core collected from 840 m water depth off Goa (Lat. 15° N). The core site is situated within present day OMZ. The main focus of this study was to record pattern of changes in abundances and diversities of these microfaunal groups in response to variation in OMZ intensity along the Arabian Sea Indian margin in the last 30,000 years. Recently, it was observed that oxygen depleted environment over the West Indian continental shelf intensified due to anthropogenic activities (Naqvi *et al*., 2000). In this context, data presented here would be useful in evaluation of impact of hypoxia (oxygen depletion condition) on the composition of marine biota.

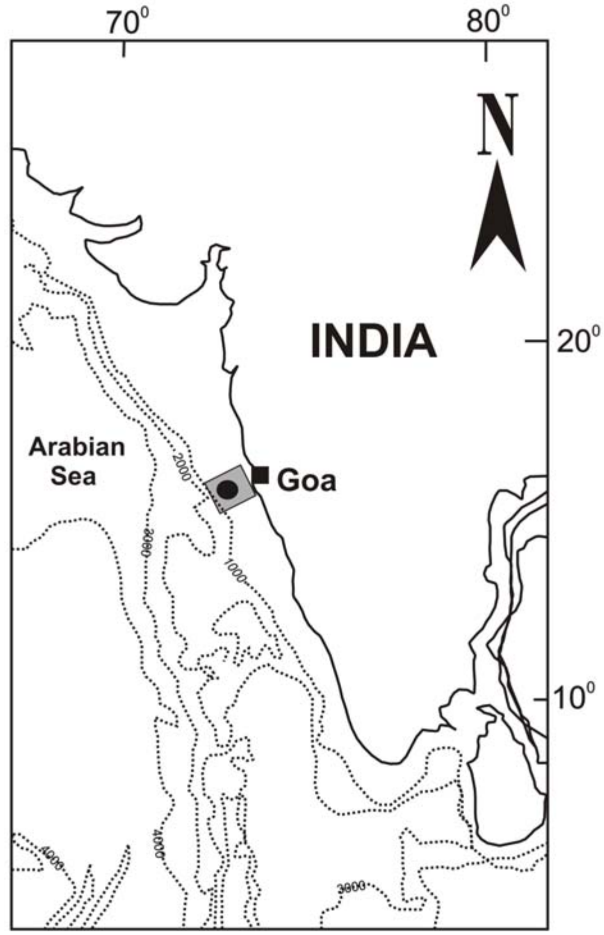

Fig. 1. Study area (shaded portion) with core location. Bathymetric contours in meters

3. Results and discussion

3.1. *Past variation in mid-water hypoxia (low oxygen zone) and its global climatic linkage*

Earlier studies have revealed that the strength of oxygen minimum zone varied in the past and that has been

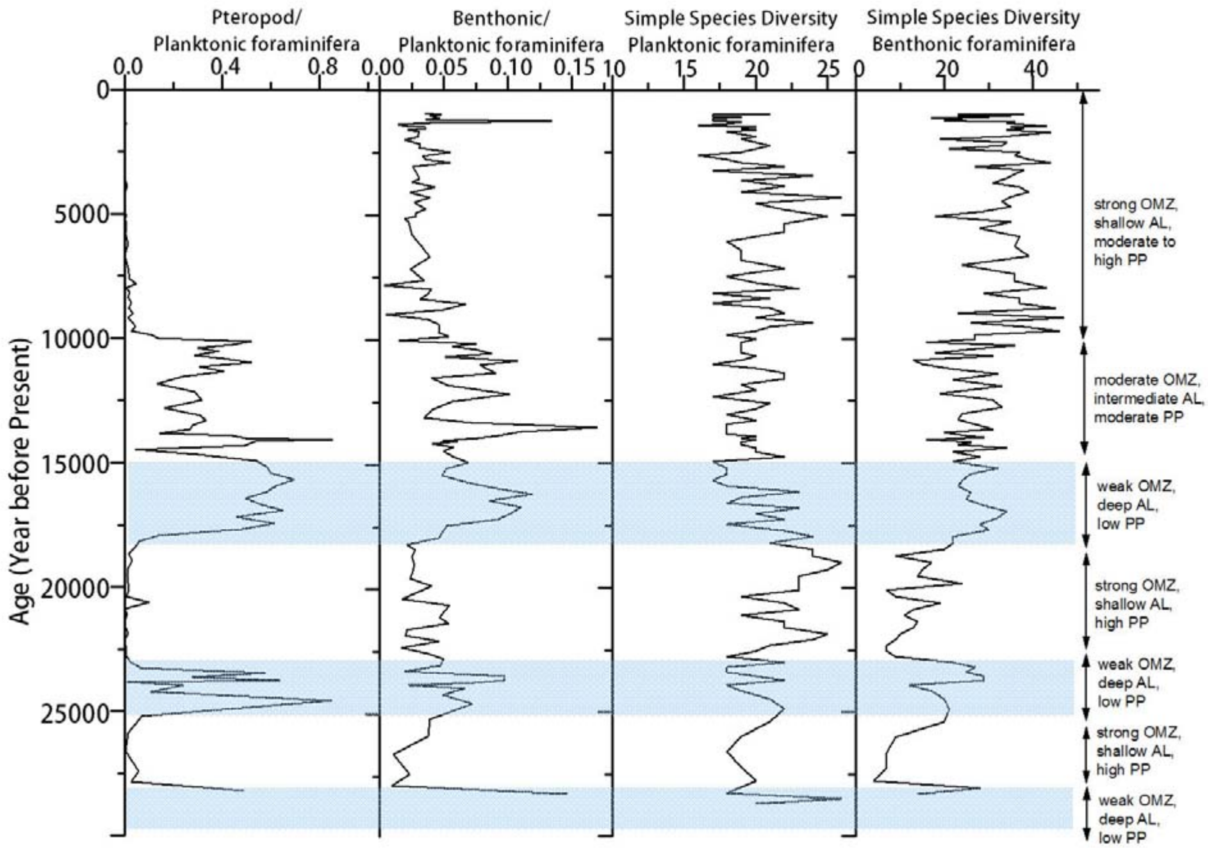

Fig. 2. Records of abundance ratio of pteropods to planktonic foraminifera, benthonic to planktonic foraminifera and simple species diversities of planktonic and benthonic foraminifera in a 4.73 m core retrieved from the Arabian Sea Indian margin off Goa. Shaded bands indicate the timing and duration of northern hemisphere cold events. OMZ, oxygen minimum zone; AL, aragonite lysocline; PP, primary productivity

attributed mainly to the changes in monsoonal wind induced primary productivity, water column ventilation and the advection of oxygenated intermediate waters (Reichart *et al*., 1998; Singh *et al*., 2006, Singh, 2007). However, biological productivity is considered to be a main factor governing oxygen minimum condition. Singh *et al*. (2006) and Singh (2007) based on their studies on the same core used here have suggested a close link between the seasonal monsoonal wind strength and the high latitude northern hemisphere climate and therefore water column oxygenation history is coupled with the global climatic perturbations. It has been shown that the oxygen minimum zone was at its weaker mode during northern hemisphere cold glacial periods when the primary productivity in the Arabian Sea was very low due to weakening of seasonal monsoonal winds (Singh *et al*., 2006). On the other hand, mid-depth oxygen minimum was intensified during high productivity periods associated with northern hemisphere warm periods.

3.2. *Impact of changes in water column oxygen condition over the abundances of aragonitic pteropods and calcitic foraminifera*

Pteropods are the important contributors to the total pelagic carbonate production but their shells are commonly not preserved in the ocean bottom sediments because they are aragonitic in composition. Aragonite, a metastable polymorph of $CaCO_3$ is more soluble in seawater than calcite, by an approximate factor of 1.5 and therefore it dissolves at shallow depth than calcite (Millero, 1996). The calcification of pteropods depends on the saturation state of the upper water column with respect to the mineral aragonite. A favorable condition for pteropod shell building occurs when water is supersaturated with respect to aragonite. The dissolution of aragonite mineral takes place in the undersaturated water. The water depth at which, aragonite dissolution begins is called aragonite lysocline. The dissolution becomes progressively more intense with the depth below the lysocline in proportion to increase in carbonate ion undersaturation. The aragonite compensation depth (ACD) is the depth at which aragonite shells are completely dissolved. Similarly, the calcitic shells (*e.g*., foraminifera) completely dissolve at the calcite compensation depth. Present day, the ACD in the investigation area lies within middle of the OMZ at about 500 m which is much shallower than the CCD at about 2400 m. The seawater in the OMZ is undersaturated with respect to aragonite because of low pH due to high consumption of oxygen and CO_2 addition. Equilibrium between aragonite precipitation and dissolution is related to the dissolved O_2/CO_2 concentration. Therefore, intensity of the OMZ controls the ACD and consequently the calcifying rate of pteropod shell, its preservation and dissolution conditions. Previous studies in the Arabian Sea have shown that abundances of pteropods have significantly varied in tune with the changes in the oxygen minimum zone intensity (Singh *et al*., 2006, Singh and Singh, 2010; Singh, 2007). In the present study, we recorded temporal variation in abundances of pteropods in order to evaluate the effect of changes in dissolved CO_2/O_2 concentration on pelagic aragonitic shells. To overcome the close sum effects in drawing inferences, we considered abundance ratio of pteropods (aragonitic) to planktic foraminera (calcitic) because later is unaffected by any dissolution as core site is well above the CCD. The record shows high values of abundance ratio between 10 and 12 ka, 15 and 17 ka, 23 and 25 ka and at around 29 ka suggesting high abundances of pteropod shells during these intervals. Pteropod abundance was also high between 12 and 14 ka. However, rare occurrence of pteropod shells was noticed during 7 - 10 ka, 17 - 23 ka and 25 - 29 ka and since the last 7 ka pteropod shells were completely absent in sediments. The intervals of high abundances of pteropods correspond to the periods of the weak OMZ when water column was relatively more oxygenated and dissolved CO_2 concentration was low. Pteropod shells were absent or very low in abundance during times of strong OMZ implying high concentration of dissolved CO_2. It is inferred that high pH of seawater in oxygenated environment resulted lowering of aragonite lysocline and the ACD and that might have led a condition for better calcification and preservation of pteropod shells. On the other hand, increased CO_2 concentration attributing low pH and shallow depth of aragonite lysocline might have resulted serious loss of pteropod shells. It is obvious that the OMZ intensity variation will not influence the calcification foraminiferal shells as the OMZ waters are saturated with respect to calcite. Therefore, the abundance variation in foraminifera assemblages in this core setting is probably related with other ecological parameters. We made an attempt to examine temporal variation patterns of planktonic and benthonic foraminifera in order to evaluate those ecological factors governing the abundances of these groups living in pelagic and benthic environments respectively. Record of abundance ratio of benthonic to planktonic foraminifera reveals significant variations during the periods corresponding global climatic cycles (northern hemisphere cold/warm events). Interestingly these climatic cycles also correspond to the major changes in the OMZ intensity linked with the monsoonal wind strength. It is found that the variation in the abundance ratio of BF and PF is mainly due to changes in benthonic foraminiferal abundances. Benthonic foraminifera are sensitive to the ocean bottom oxygen condition and food supply. The examined core site today is bathed by the oxygen depleted water mass. Hence, the variation in OMZ intensity might have profoundly influenced bottom oxygen condition and also the benthic fauna. The main source of the food supply is organic matter produced in the surface water. Our data suggest that the abundance variation of planktonic foraminfera is primarily governed by the primary productivity, whereas benthonic foraminiferal abundance is greatly influenced by the oxygen condition and the organic matter flux. Moreover, both the oxygen condition and food supply are intimately related to the OMZ intensity and the primary productivity.

3.3. *Effect of hypoxia on pteropod and foraminiferal diversities*

Living population of pteropods in the Arabian Sea is characterised by the low number of species as compared to planktonic and benthonic foraminifera. Being aragonitic in composition, they are prone to dissolution in carbonate undersaturated waters. The OMZ water at certain depth is undersaturated with respect to the mineral aragonite. From this study; it is clear that the simple species diversity (total number of species) of pteropods has significantly varied in the last 30, 000 years in response to the changes in the mid-water oxygen condition. The species diversity records of planktonic and benthonic foraminifera indicate major change during 15 - 17 ka corresponding to the high latitude cold event. The benthic diversity has rapidly increased during this period when sea bottom condition was oxygenated associated with a weak OMZ. Interestingly, planktic foraminfera show a gradual decline during this period. It is noteworthy that the amplitude of temporal variation in diversity pattern is high in benthics than that of the planktics. However, there has been a general opposite trend of diversity variation in these two groups. Data further reflect an increase in benthic diversity for the short periods during 23 - 24 ka and at 29 ka. These time intervals are also characterised by the weak OMZ and correlatable to the millennial scale cold periods of the northern hemisphere. The benthic diversity was very low between 17 and 23 ka, and between 25 and 28 ka, the periods of the intensified OMZ. The diversity was moderately high between 10 and 15 ka and in the last 10 ka it further increased reaching to modern value, though with intermittent short term fluctuation.

We found interesting results on benthic diversity variation as it shows different patterns in time slices between 10 to 30 ka and since 10 ka. Between 10 and 30 ka diversity increased in the periods of oxygenated bottom condition and decreased in low oxygen condition. But this trend did not continue from 10 ka onwards, instead since then the diversity was generally high in oxygen depleted condition. It seems that in addition to the oxygen condition other factors are also responsible for controlling diversity of benthic foraminifera. Earlier studies demonstrate that the benthic foraminifera show species-specific microhabitat preferences within sediments depending on their adaptation capabilities to the changing bottom environment governed by the oxygen condition and the nutrients. Benthic foraminiferal population includes species having both epifaunal and infaunal microhabitats. Epifaunal species have preference for high oxygen bottom water condition, whereas infaunal taxa prefer low-oxygen condition. It is to be mentioned that benthic assemblage of the last 10 ka is dominated by the infaunal taxa. Thus, it can be inferred that benthonic foraminfera also respond to changes in bottom oxygen level in term of their microhabitat preferences in order to adapt the changing environment. It appears that the planktonic foraminiferal diversity is controlled mainly by the surface nutrient supply and the primary productivity with high diversity during eutrophic periods and low in the oligotrophic periods.

It is concluded that past changes in naturally developed mid-water hypoxia in the Arabian Sea had significantly affected the calcification rate and diversity of calcareous microfauna particularly those build aragonitic shells. Further, those among the calcitic fauna (*e.g.*, foraminifera) having benthonic habitat are more sensitive to oxygen condition as compared to their pelagic counterparts. The rising atmospheric CO_2 concentration is expected to intensify further the O_2 depletion in the Arabian Sea waters and that may have serious consequences on calcifying biota.

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