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CYCLICITY IN LATE HOLOCENE MONSOONAL CHANGES FROM THE WESTERN BAY OF BENGAL: FORAMINIFERAL APPROACH

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ABSTRACT

Benthic foraminiferal characteristics, including abundance of total benthic foraminifera, angular asymmetrical benthic foraminifera, *Uvigerina* sp. and *Bulimina marginata*, have been studied in a piston core (exihibiting ~700 years record as per AMS dating) collected from the region off central east coast of India. Six prominent peaks have been noted in the down core variation in all of these parameters. Based on the already well established inverse relationship between angular asymmetrical benthic foraminifera and monsoon precipitation from the region off west coast of India, it is inferred that the six prominent episodes of variations as noted in the core, indicate changes in monsoon intensity in this region. Based on the spectral analysis, a periodicity of 200±50 years has also been inferred in the monsoonal changes.

Keywords: Angular asymmetrical benthic foraminifera, Paleomonsoon, Bay of Bengal, Holocene, cyclicity

INTRODUCTION

In view of its vital importance for the economy of many Asian countries including India, monsoon has always been a matter of concern. Recently, monsoon has become the focus of wider scientific community all over the world due to the apprehension that global warming may alter the pattern of monsoonal rainfall. It has necessitated the study of factors governing monsoon dynamics. Such studies have led to the development of several models for achieving predictive capability. At the same time it is also felt that we need monsoon rainfall records for longer time, much beyond the instrumental records. Such studies are clubbed under "Palaeomonsoon", a term coined more than two decades back.

Reconstructing the past short, and long term monsoon changes helps understand the factors that affect monsoons. Therefore, past monsoon records are generated from different parts of the world, using various types of techniques. Out of the available set of techniques, those based on characteristics of marine microorganisms, especially foraminifera, from the oceanic regions are very helpful to reconstruct past monsoon changes. Based on temporal changes in foraminiferal characteristics, both short and long term monsoonal changes have been generated from various parts of the Indian Ocean (Prell, 1984; Prell and Kutzbach, 1987; Nigam, 1988; Naidu and Malmgren, 1996; Gupta *et al.*, 2003; Anand *et al.*, 2008). These studies indicate a weakened southwest monsoon and intensified northeast monsoon during cold glacial periods. Such high-resolution monsoon records help plan the future course of action with regard to changing monsoon. Palaeomonsoon records have to be generated from different places in order to understand the regional monsoonal changes, if any. Here, we have generated a high-resolution palaeomonsoon record from the east coast of India, based on benthic foraminiferal characteristics.

Benthic foraminifera have been widely used to understand changing monsoon intensity from the Indian Ocean (Nigam, 1988; Gupta and Thomas, 2003). Application of benthic morphogroups for reconstructing the past monsoon changes from the region off central west coast of India has been proposed by Nigam *et al.*, (1992); Nigam and Khare, (1994b). Severin (1983) and Nigam *et al.* (1992) have discussed the reasons for preference to foraminiferal morphogroups in place of species, for palaeoclimatic studies. They suggested various shortcomings of application of species count for paleoclimatic studies, including the inconsistency in providing a single name to a species, variations in isotopic study results due to intra-specific variations (morpho-types) (Williams *et al.*, 1988), different responses of same species in different geographic provinces (Bandy, 1960) and finally the amount of time required for species level identification. Severin (1983) reported changes in morphogroups with changing water depth. He attributed these changes to the sediment turbulence associated with the depth. Kaiho (1991) used the foraminiferal morphogroups to distinguish oxygenated and anoxic conditions. Nigam *et al.* (1992) effectively applied this technique to generate high-resolution past monsoonal record from the region off central west coast of India.

A significant finding of these paleomonsoon studies is the presence of cyclicity of various orders, in monsoonal intensity (Nigam and Nair, 1989; Nigam *et al.*, 1995; Naidu and Malmgren, 1995; Tiwari *et al.*, 2005). However, all of these records are confined to the Arabian Sea. No such cyclic nature of monsoon changes has yet been inferred from the Bay of Bengal.

In this study, this well established relationship between angular asymmetrical foraminiferal morphogroups and monsoon is applied to study the past monsoon changes from the east coast of India. Additionally, an attempt has also been made to infer periodicity (if any) in the rainfall, as has been reported earlier from the west coast of India (Nigam *et al.*, 1995; Sarkar *et al.*, 2000) and other parts of the world (Lamy *et al.*, 2001).

STUDY AREA

The Bay of Bengal forms the shallower northeastern part of the Indian Ocean. Ganges, Brahmaputra, Irrawady, Mahanadi, Krishna and Godavari are among the major rivers, which drain their water along with the sediment load in to the Bay of Bengal. A few of these rivers are perennial, while others are fed by monsoonal rain. The Bay is characterized by the positive water balance due to excess precipitation and fresh water discharge through rivers, in comparison to evaporation (Venkateshwaran, 1956). The surface seawater salinity at the core site varies from 25.10 psu during summer season to 32.03 psu during spring season, whereas the surface seawater temperature varies from 26.77- 29.17 °C. The water column profile of annual seawater salinity and temperature is shown in figure 1.

Krishna River, which drains into the Bay of Bengal, east of Vijaywada, is the river nearest to the sample location (latitude 15⁰22.88 N and longitude 80⁰45.205' E). In this area, the continental shelf is 21 km wide and the water depth at the shelf break is 70 m (Singh and Swamy, 2006). The Krishna River delta is typical of the wide deltas along the southeast coast of India (also known as the Coromandel Coast). The braided stream channels, broad floodplain, and extensive sandbars suggest that this part of the Krishna river flows through relatively flat terrain and carries substantial amounts of sediment, especially during the monsoon season. It carries a huge amount of sediments from Deccan traps (55%), metamorphic terrain, Precambrian sediments, and alluvium (Singh and Swamy, 2006).

A few of the characteristics of Krishna river are listed below (Singh and Swamy, 2006):

MATERIALS AND METHODOLOGY

The top 150 cm section of a piston core (SK 187/PC 21) collected from the western Bay of Bengal (Fig. 2) at a water

Mean annual discharge at Vijaywada	:	1730 m^3/s
Maximum discharge at Vijaywada	:	33,180 m^3/s
Suspended load at Vijaywada	:	141.1 million m^3/s
Annual sediment discharge	:	10.56×10^9 kg/year
Annual sediment load	:	$32,397\times10^6$ m^3/year
Average annual discharge	:	67,675 mcum

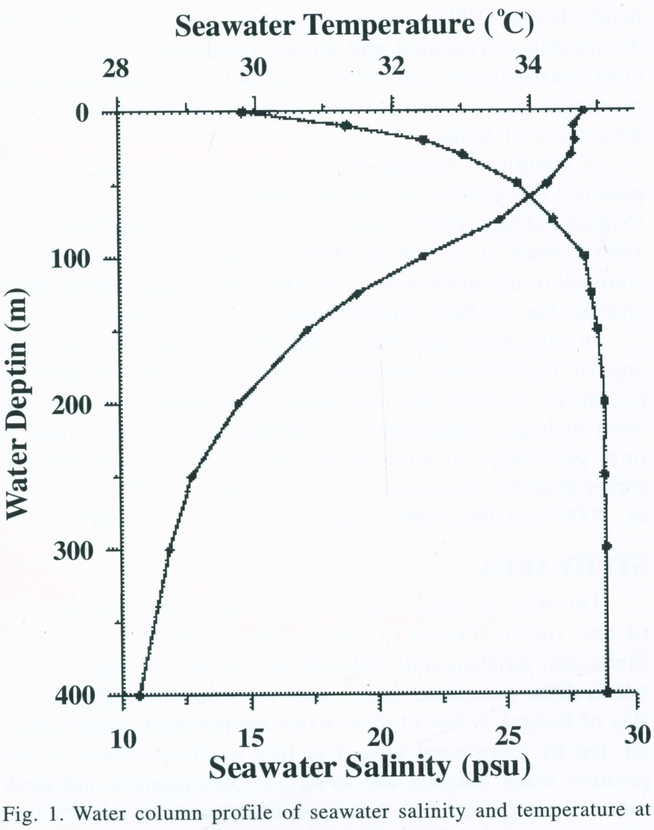

Fig. 1. Water column profile of seawater salinity and temperature at core site.

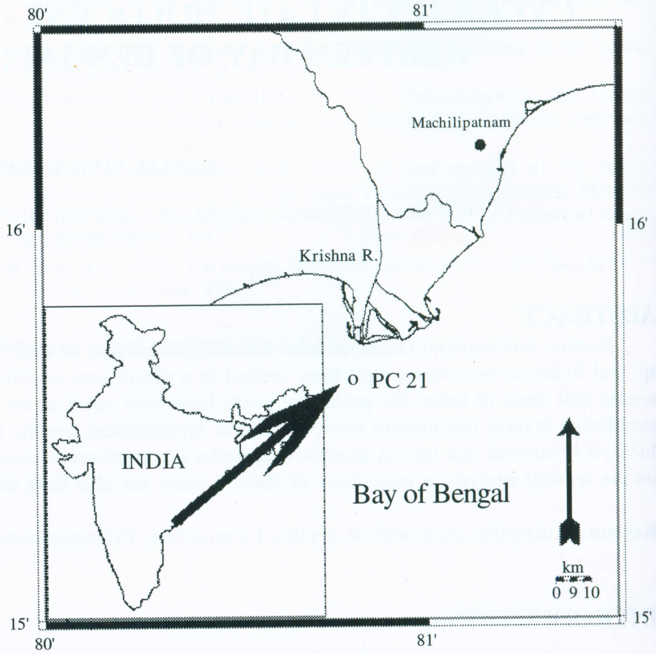

Fig. 2. Location map of the core.

depth of 483 m during 187th cruise of ORV *Sagar Kanya* under the Ministry of Earth Sciences funded project has been used for this study. The core was sub-sampled at 2 cm interval. Thus, the 150 cm section comprised of 75 samples.

The samples were processed by following standard procedure of soaking in distilled water and decanting to get rid of colloidal particles and subsequent treatment with sodium hexametaphosphate and hydrogen peroxide to disintegrate clay lumps and to dissolve organic matter, respectively. The sediments were then sieved over a 63 µm sieve. A representative sample from >63 µm fraction was taken after coning and quartering and a minimum of 300 benthic foraminiferal specimens were picked from each sample. From the total number of benthic foraminifera, the number of rectilinear forms were counted. Additionally, among the rectilinear benthic foraminifera, two species, namely *Uvigerina* sp. and *Bulimina marginata* were also counted separately.

Spectral analysis of these faunal abundance records was carried out using a Fortran 90 program 'Redfit 3.8' (Schulz and Mudelsee, 2002) to check the periodicity, if any, in the down-core foraminiferal parameters. In order to establish the chronology for the core, Accelerator Mass Spectrometer (AMS), radiocarbon dates of four sediment samples were obtained from Kiel University, while one additional ^{210}Pb dating was carried out for the core-top sample in Geochronology laboratory of National Institute of Oceanography, Goa.

RESULTS

The ^{210}Pb activity of 13.42±3.2 at the core-top (0-2 cm) indicates that it comprises Recent sediments. The details of AMS radiocarbon dates are given in the table 1. Four radiocarbon dates indicate that the core covers a time span of ~700 years. The sedimentation rate varied widely.

The downcore abundance of benthic foraminifera, angular asymmetrical benthic foraminifera, *Uvigerina* sp. and *Bulimina marginata* show large variations. In order to reduce the large insignificant fluctuations and to delineate major events, 3-point

Table 1: Details of Accelerator Mass Spectroscopic dates.

Sample Number	AMS Radiocarbon Date	Calibrated Age (Yr BP)
SK 187/PC 21; 0-2 cm	570 ±25 BP	16 ± 16
SK 187/PC 21; 34-36 cm	1015±35 BP	529 ± 36
SK 187/PC 21; 74-78 cm	1050±25 BP	563 ± 36
SK 187/PC 21; 126-128 cm	1155±35 BP	642 ± 36

and 5-point running average has been calculated and plotted along with the original data. The Maximum abundance of benthic foraminifera (538/g sediment) is reported at 126 -128 cm while the lowest number of benthic foraminifera (12/g sediment) is reported at 10 - 12 cm. A total of six depth intervals (14 -16, 42 - 44, 56 - 58, 76 -78, 114 - 116 and 132 -134 cm) corresponding to 227, 536, 548, 566, 624 and 652 yr BP, have an increased abundance of benthic foraminifera. The peaks and lows in down-core benthic foraminiferal abundance curve also match with the changes in abundance of angular asymmetrical benthic foraminifera (AABF), as well as down-core variations in *Uvigerina sp.* and *Bulimina marginata* species abundance (Fig. 3). The AABF abundance varies from 4/g sediment to 153/g sediment with highest abundance reported at 78 - 80 cm and the lowest at 10 - 12 cm.

In the Power spectrum plots, abundance of total benthics (Fig. 4A) is showing periodicity of 250, 175 and 145 yr at 95%-Chi^2 while *Bulimina marginata* (Fig. 4B) shows periodicity of 250 and 175 years at 95%-Chi^2. In angular asymmetrical benthic foraminifera (Fig. 4C) periodicity of 350, 250, 175 and 145 years at 95%-Chi^2 was observed. For *Uvigerina* sp. (Fig. 4D), the periodicity of 250 at 95%-Chi^2 and of 175 years at 90%-Chi^2 are prominent.

DISCUSSION

Increased benthic foraminiferal abundance indicates favourable environment, which has to be seen in view of the vicinity of core location to the Krishna River. According to the Nigam and Nair (1989), rivers affect the bio-geo-chemical processes of the continental shelf regions adjacent to their mouth, creating a distinct microenvironment in the area. Though the core is located at a water depth of 483 m, the steepness of the slope makes the distance of the core from the coast, immaterial. Thus, the fluctuations in the abundance of benthic foraminifera can be attributed to the major changes in the form of sediment and fresh water influx. The change in the amount of sediment influx and the fresh water discharge in Indian peninsular rivers is caused by the changes in the intensity of the monsoon precipitation in the subcontinent. The peak in the abundance means that during those intervals the monsoon was low causing less change in salinity and minimum turbulence and thus more abundant benthic foraminifera.

Angular asymmetrical benthic foraminifera are elongate bi- and triserial flattened forms with generally parallel margins in side view. From the earlier studies carried out along the west coast of India, the relationship between angular asymmetrical forms and monsoon has already been established (Nigam *et al.*, 1992; Nigam, 1993; Nigam and Khare, 1994a and b; Nigam *et al.*, 1995; Nigam and Khare, 1999). Abundance of angular asymmetrical foraminifera is inversely related with the intensity of monsoon. During intensified monsoons, rivers drain large amount of fresh water as well as sediment into the ocean causing low saline and increasingly turbid waters, especially near the river mouth. It has been observed that the angular asymmetrical forms are less abundant adjacent to the river mouth. Their turbulence-susceptible nature can be reasoned from the absence of angular asymmetrical foraminifera from turbid waters (Severin, 1983; Nigam *et al.*, 1992).

Uvigerina is mainly an infaunal genus with a free mode of life. It prefers muddy substrate. Its salinity preference ranges from 32-37 ‰ (Murray, 1991). In the study area, high salinity is reported during intermonsoon period, i.e. during reduced river discharge periods (Levitus, 1994). The lower salinity caused by increased fresh water influx as a result of heavier monsoon will adversely affect the abundance of *Uvigerina* sp. In the present study, peaks of *Uvigerina* sp. abundance thus indicate low monsoon intensity during such periods. Similarly, *Bulimina* is an infaunal genus with free mode of life, which prefers mud to fine sand as substrate. Its salinity preference also ranges from 32-37 ‰. Like the *Uvigerina* sp., the abundance of *Bulimina marginata* also gets affected by monsoon. Thus, the down core variation in the abundance of total benthic foraminifera, angular asymmetrical benthic foraminifera, *Uvigerina*, and *Bulimina marginata* shows past monsoonal changes from this region. It is inferred that that there were six dry periods with significantly reduced precipitation.

Relation between abundance of this fauna and palaeomonsoon can be interpreted as periodicity in the precipitation in this region. In the downcore plots, along with major peaks, relatively smaller peaks can also be observed. In order to find cyclicity, if any, in the past monsoon events, spectral analysis was carried out. In the downcore abundance of total benthic foraminifera, angular asymmetrical foraminifera, *Bulimina marginata* and *Uvigerina* sp., cyclicity of 200 ± 50 years is most pronounced, indicating that at every ~200 yr, low precipitation is affecting the abundance of this fauna. Previously, Hong *et al.* (2001) have reported a periodicity ranging from 70 to 1061 years in the peat $\delta^{13}C$ time series for humidity or precipitation based on C3 plants which were very similar to the atmospheric ?^{14} C-derived periodicities of solar variability (Stuiver *et al.*, 1991). Similarly, a series of periodicities in climatic events have been deciphered based on variety of data. From the Indian Ocean, especially from the Arabian Sea, efforts have previously been made to relate monsoonal changes to periodic changes in solar activities through different palaeoclimatic proxies (Nigam *et al.*, 1995; Sirocko *et al.*, 1993, 1996; von Rad *et al.*, 1999; Sarkar *et al.*, 2000; Neff *et al.*, 2001; Agnihotri *et al.*, 2002; Agnihotri and Dutta, 2003; Fleitmann *et al.*, 2003). Nigam *et al.* (1995) have identified a cyclicity of 77 years, which was suggested to be the result of solar Gleissberg cycle. Similarly, Naidu and Malmgren (1995) reported a cyclicity of 2,200 years. The cause for the 200±50 year cyclicity reported in this study can also be attributed to be the changes in solar intensity as reported by Tiwari *et al.* (2005). However, the present study is the first report from the Bay of Bengal region, indicating possibility of regional nature of the cycle.

CONCLUSIONS

Temporal changes in abundance of total benthic foraminifera, angular asymmetrical benthic foraminifera, *Uvigerina* sp. and *Bulimina marginata* indicate six prominent events (652, 624, 566, 548, 536 and 227 yr BP) of dry periods in the central East Coast of India during the last ~700 years. The spectral analysis of abundance curves shows periodicity of

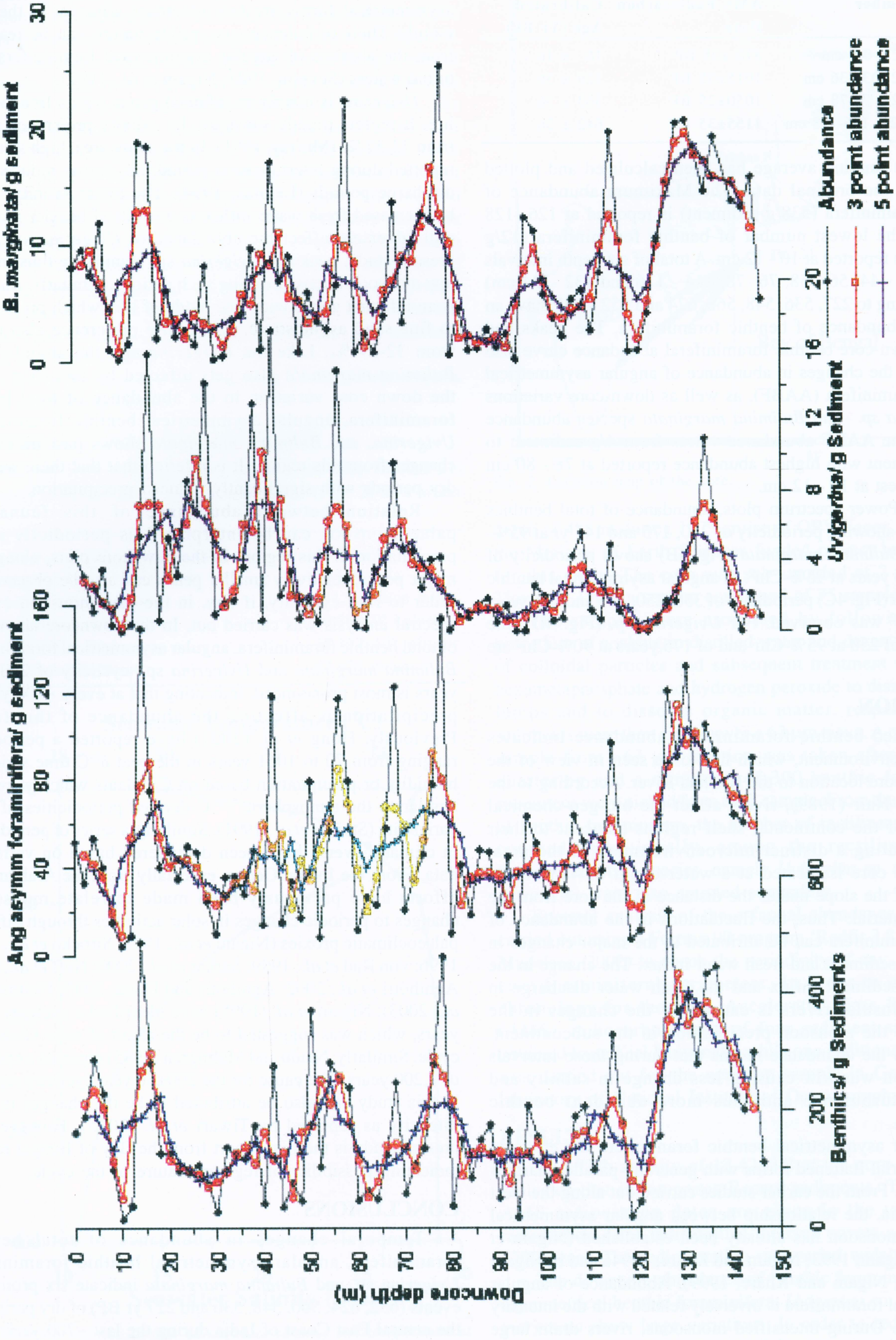

Fig.3. Downcore abundance of total benthic foraminifera, angular asymmetrical benthic foraminifera, *Uvigerina* sp. and *Bulimina marginata*

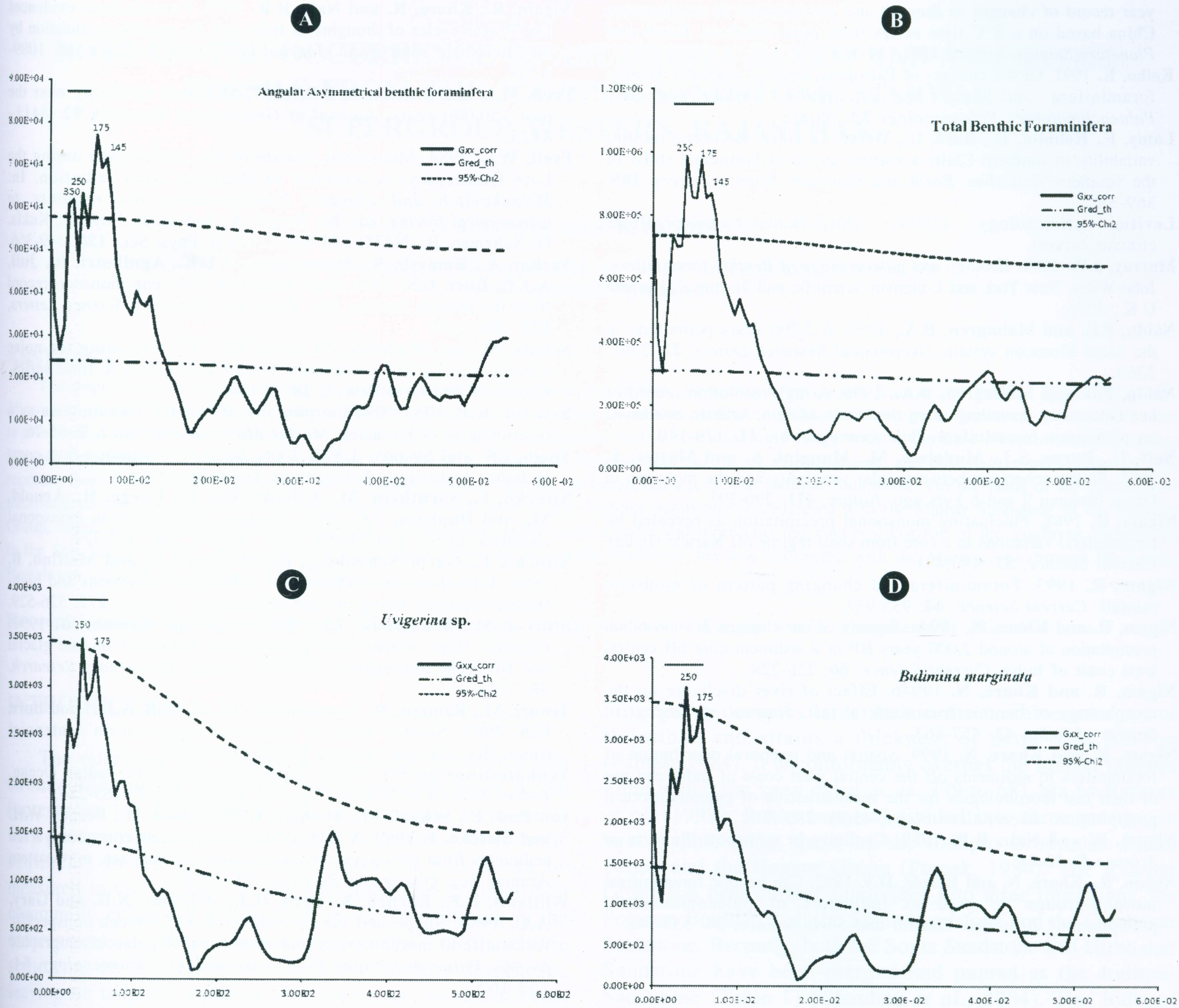

Fig. 4. Results of spectral analysis on downcore variation in a: Total benthic foraminifera, b: Angular asymmetrical benthic foraminifera, c: *Uvigerina* sp. and d: *Bulimina marginata*

200±50 years indicating the effect of solar variability on the monsoonal changes in this region.

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