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High resolution climatic records of the past ~489 years from Central Asia as derived from benthic foraminiferal species, Asterorotalia trispinosa

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A B S T R A C T

Speciation in foraminifera is a function of their ecology and habitat. Thus, their extreme sensitivity and specific responses to specific set of physio-chemical conditions in their environment, has led to their extensive application in palaeoclimatic studies. During the study of Recent benthic foraminiferal distribution on the Ayeyarwaddy Delta Shelf off Myanmar, the occurrence of the species *Asterorotalia trispinosa* was very conspicuous. Though many previous workers have reported the occurrence of the species *A. trispinosa* as a major constituent in foraminiferal assemblages from different regions, its ecological significance has never been studied before. The present work on the surface distribution of *A. trispinosa* species in the study area, establishes its preference for low salinity. The ecological preferences of *A. trispinosa* make the species a useful proxy for the delineation of wet and dry periods of the past. The downcore variation in the abundances of *A. trispinosa*, its reproductive behaviour viz. its MPS and stable isotopic values were analysed, in sediments of the core GC-5 collected at 37 m water depth on the delta front. Downcore variations in the abundance and MPS of *A. trispinosa* indicate two significant climatic conditions in the study area since 1513 AD; a dry climate prior to 1650 AD and warm and wet climate since 1650 to present. They also reveal that since 1650, 3 major freshwater pulses are recorded in the core at ~1675, 1750 and 1850 AD. The multi-proxy data also support these findings. This high-resolution palaeoclimatic data representing the past 489 years, may be the Asian signatures of the European Little Ice Age. The present work shows extreme relevance with the interest of workers around the world, trying to understand the dramatic events in global climates over the past 500 years.

1. Introduction

Foraminiferal species inhabit a wide range of marine environments. The distribution of individual taxa is a function of their ecology and habitat and often quite distinctive. Knowledge of ecological behaviour of single foraminiferal species has been used extensively to draw palaeoclimatic interpretations. For example, Nigam and Setty (1982) identified the applicability of *Virgulinella pertusa* as an indicator of sandy substrates with low organic carbon. The influence of cold to temperate waters has been repetitively identified with the help of *Hyalinea balthica* (Bock, 1970; Collen, 1974; Ross, 1984). Nigam and Rao (1987) used the mean proloculus size (MPS) and Nigam and Khare (1992) used the coiling direction in species *Rotalidium annectans* as an indicator of varying salinity. Diameters of *Orbulina universa* and *Globorotalia menardii* (Bhonsle, 2005) are directly proportional to varying temperatures, and the peaked abundances of *Epistominella exigua* indicate increased seasonal food supply (Gooday, 1988, 1993, 1994; Hayward et al., 2004; Saraswat et al., 2005).

Although *Asterorotalia trispinosa* (Thalmann, 1933) (Fig. 1) has been recognised as an important component in demarcating biofacies within different sedimentary basins (Frerichs, 1970; Subbarao et al., 1979; Lambert, 2003), its ecological preferences that control its distribution have never been ascertained. In the present study, the distribution of *A. trispinosa*, in a large number of samples collected off Myanmar (the former Burma) coast, on the continental shelf characterised by the Ayeyarwaddy River Delta, have specifically been studied to understand its ecological niche and its probable utility in palaeoclimatic reconstructions.

1.1. Previous reports on the occurrence of Asterorotalia trispinosa

Benthic foraminiferal species *Asterorotalia trispinosa* ranges from the Pliocene to Holocene where it is often an important index fossil. For example, it is reported from the lowermost part of the Pleistocene Toukoshan formation of western Taiwan (Huang, 1964) where it defines a very important regional biostratigraphic horizon.

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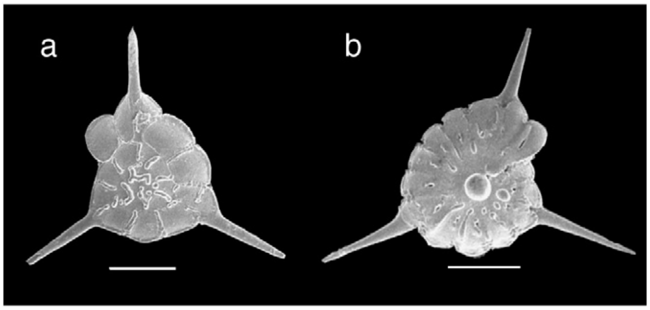

Fig. 1. Benthic foraminiferal species *Asterorotalia trispinosa* (a) ventral view; (b) dorsal view. Scale bar = 500 μm.

In Recent sediments, Thalmann (1933) reported *Asterorotalia trispinosa* in fine-grained sediments off the coast of Java. He hypothesised that its long spines provided buoyancy to the test, which would let them remain suspended above settling sediments for a longer time. Bhatia and Bhalla (1959) reported rare occurrences of this species in beach sands from Puri, Orissa (East Coast of India), which was the first report of the taxa from the Indian region. Ghose (1966) carried out a morphometric analysis on 88 specimens collected from beach sands at Digha, the east coast of India, and determined that this common species was referable to *A. trispinosa* and not *A. pulchella* as previously reported (Hofker, 1951). In an analysis of the distribution of benthic foraminifera Frerichs (1970), probably misidentified his species as *Asterorotalia pulchella*, which made up 37% of his assemblage. Occurrences of *A. trispinosa* have been widely reported subsequently by many researchers (e.g., Rao, 1998; Lambert, 2003; Mellis and Violanti, 2006) ranging in abundance from rare (e.g., Subbarao et al., 1979) to abundant (e.g., Rao, 1998; Gandhi, 1999; Rana, 2009) primarily from shallow coastal waters (11–55 m). Recent occurrences have been summarised in Table 1.

2. Materials and methods

As part of the 'India–Myanmar Joint Oceanographic Studies', 13 gravity cores and 124 surface sediment samples were collected in April 2002 on the Ayeyarwaddy Delta Shelf at water depths ranging from 10 to 1030 m. (Fig. 2) on board the ORV Sagar Kanya. Conductivity–temperature–depth (CTD) profiles were obtained at few select stations to assess the temperature and salinity variability in the area (Fig. 3). The geographic co-ordinates, depth of collection, the grain size distribution, temperature and salinity corresponding to each sample station are shown in Table 2.

2.1. Surface samples

~15 g of sediments from each of the 124 surface samples was dried overnight at 60 °C. Each dried sample was weighed and soaked in distilled water. They were subsequently treated with 10 ml of 10% sodium hexa-metaphosphate to dissociate the clay particles followed by 5 ml of 10% hydrogen peroxide to oxidise the organic matter, if present. The treated samples were wet sieved through 63 μm (250 mesh) size sieve. The sand residue retained over the sieve was dried at 60 °C to get the weight of the sand fraction. The filtrate collected in a measuring cylinder was used for pipette analysis to determine the silt and clay fraction in each sample.

The sand fraction was coned and quartered to obtain a representative aliquot from which a minimum of 300 benthic foraminiferal specimens were picked to obtain statistically adequate numbers to portray the faunal distribution (Ujjié, 1962; Chang, 1967; Dennison and Hay, 1967). They were mounted on micropalaeontological slides and percentages of the individual benthic species were calculated. From these picked benthic foraminifera, specimens of *Asterorotalia trispinosa*, a particular species under discussion in this study, were sorted. Its occurrence was seen only in 39 surface samples and their abundances in those samples are tabulated in Table 3.

2.2. Statistical analysis

Linear correlation coefficients (r) among various water and sedimentological parameters and the abundance of *Asterorotalia trispinosa* recorded at different sampling stations in the study area, showing at least some abundance, were computed individually. Looking at the trends in the abundance pattern, the complete dataset (also including zero abundances), was subjected to stepwise regression by removing outliers in the model by using Sigmastat for Windows (ver. 3.5). As a measure of goodness of fit, the values of the coefficient of determination (R^2) were calculated. To ensure the statistical significance of the computed regression coefficients, they were subjected to a detailed *t*-test statistical analysis.

2.3. Sub-surface samples

For studying the sub-surface signatures, core GC-5 with a length of 178 cm was selected. It was collected at the delta front at a water depth of 37 m (Fig. 2, location same as that of surface sample no. SK-175/22). Four sub-samples were obtained from the first 10 cm of the core and the rest was sub-sampled at every 2 cm interval. Thus, 88 sub-samples were used for the sub-surface studies. All the procedures carried out on surface sediments for foraminiferal studies were also repeated for sub-surface samples. However, for reconstructing past environmental events in this region, a multiple proxy approach was adopted. The downcore variation in foraminiferal distribution was supplemented with the morphometric analysis of the species *Asterorotalia trispinosa*, stable isotopic (oxygen) and elemental (Mg/Ca and Sr/Ca) studies.

Results of all downcore parameters were plotted along with their three-point running averages in order to smoothen large variations.

Table 1
Comparison of statistics related to *A. trispinosa* reported from different regions of the world.

Region	Reported by	Maximum abundance	Depth (m)	Salinity (psu)	Temperature (°C)
Java	Thalmann, 1933 Hofker, 1951	–	–		
Puri, Orissa, India	Bhatia and Bhalla, 1959	Rare	Beach sands		
Digha, Bengal	Ghose, 1966	Well represented	Beach sands		
Andaman Sea	Frerichs, 1970	37%	20–32	32.32–33.07	26.44–27.01
Visakhapatnam Shelf, East Coast of India	Subbarao et al., 1979	6%	20	32.6–32.8	27.5–27.9
Shelf region off Madras, East Coast of India	Rao, 1998	36–38%	38–55	32.48–32.90	24.2–24.5
Palk Strait, Southeast Coast of India	Gandhi, 1999	41–53%	11		
Mahakam Delta. East Kalimantan (Indonesia)	Lambert, 2003	70–100%	2–4	33.3–33.5	28.7–28.9
Central East Coast of India	Rana, 2009				
Eastern Bay of Bengal and Andaman Sea	Present work	38–43%	18–40	31.78–32.56	27.20–27.77