Quaternary International 377 (2015) 18–27

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Biofaciological zonation of benthic foraminifera of the continental shelf of Campos Basin, SE Brazil

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ARTICLE INFO

Article history:
Available online 8 January 2015

Keywords:
Benthic foraminifera
Biofaciological zoning
Campos Basin
South Atlantic

ABSTRACT

Data on the microbiofaciological zonation of benthic foraminifera were obtained from 82 sub-samples from the subsurface sediments of the continental shelf of Campos Basin, in southeastern Brazil. The abundance and distribution of the 93 species identified during the study were related to depth and temperature of the water, as well as to sediment grain size. Four biofacies were established: biofacies I, represented by the sandier coastal sediments and dominated by *Pseudononion atlanticum* and miliolids; biofacies II, associated with carbonated substrates, and represented by *Amphistegina lessonii* and miliolids; biofacies III, represented by mini-cores A2, where *Bulimina marginata* is predominant in all the samples; and biofacies IV, associated with the muddy substrates of the outer continental shelf, dominated by *B. marginata*, *Discorbis orbicularis* and *Globocassidulina subglobosa*. In general, the miliolids were more abundant in sandy sediments (except A2), while the bolivinids and buliminids predominated in the sediments with a silt fraction, which were normally associated with higher levels of organic matter. The highest species diversity and equitability, and lowest dominance indices were recorded in the sandy sediments, whereas the silty sediments were characterized by a predominance of opportunists such as *Bolivina* spp. and *Bulimina* spp. Species that were abundant in one stratum of a mini-core tended to be abundant throughout the core, indicating stable conditions over long periods, which guaranteed the settlement of these species.

1. Introduction

The present sedimentation in the continental margin off Southeast Atlantic is strongly dominated by the oceanic water mass dynamics and shelf circulation due to the lack of any considerable river input. The hydrodynamical processes determine primary productivity and sediment redistribution on the shelf, leading to the establishment of the differences in sedimentation rates and sedimentary faciology (Mahiques et al., 2010). Sedimentation rates in the Campos Basin shelf, off the coast of southeastern Brazil, have been well documented, with average values varying from 70 cm/ky, to the north area, and from 120 cm/ky, to the southern area, and are strongly correlated with areas of higher primary productivity and/or of terrigenous input, as well as with the flow of the Brazil Current (Viana et al., 1998; Mahiques et al., 2004).

Understanding biofaciological zonation of benthic foraminifera in samples of mini-cores collected in the Campos Basin is important because it presents the opportunity to carry out a historical study of how the depositional environment and associated foraminiferal assemblages have changed through recent times. Previous studies of benthic foraminiferal distributions on the SE Brazilian shelf have shown terrigenous influence inshore, coarse carbonate sediments with abundant *Amphistegina* along the outer shelf where terrigenous influence is restricted by coastal or shelf geomorphology, and muddier sediments offshore where terrigenous influence provides source material and hydrodynamics allow their accumulation. Mahiques et al. (2005) reported that sediment deposition rates in

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http://dx.doi.org/10.1016/j.quaint.2014.12.020
1040-6182/

this region are several mm/decade. The goal of our study was to examine 10 cm cores to establish a microbiofaciological zonation of the benthic foraminifera of the continental shelf of Campos Basin and test the hypothesis that sediment composition and foraminiferal assemblages have remained relatively stable over the past several hundred years.

2. Regional setting

The study area corresponds to the continental shelf of the Campos Basin at depths of between 25 m and 100 m, limited by the coordinates 21°09′09″ and 23°08′07″ S and 40°17′54″ and 42°00′55″ W (Fig. 1). The superficial sediments of the inner and middle continental shelf range from siliciclastic to bioclastic formations. The outer shelf is dominated by sandy sediments, primarily siliciclastic ones, followed by carbonates. The siliciclastic sands that predominate over most of the outer shelf form extensive fields of sand waves. The mud content of these substrates is normally less than 5% (Viana and Faugères, 1998; Viana et al., 1998; Mello e Sousa et al., 2006).

In addition to the many kilometers of banks of carbonates that form well-defined ridges in some places, the outer margin of the shelf is marked by an extensive system of deep gullies. The edge of the continental shelf is defined by an escarpment between the 120 m and 220 m isobaths, with a slope of up to 14° in places (Viana and Faugères, 1998; Gonthier et al., 2003; Machado et al., 2004).

The sedimentation process that predominates on the continental shelf off southeastern Brazil is dominated by the mass of oceanic waters and the circulation of currents on the continental shelf itself. These hydrodynamic processes determine primary production and the redistribution of the sediments on the shelf, and are thus responsible for the establishment of geographic variation in sediment accumulation rates and sedimentary facies distribution (Mahiques et al., 2002).

The continental shelf is characterized by the interaction among coastal or shelf waters (CW; $33 < S < 33.7$ and $4\ ^{\circ}C < T < 21\ ^{\circ}C$), Tropical Waters (TW) and the Waters of the Central South Atlantic (WCSA) that form the Brazilian Current (BC). Resurgence events induced by the local winds are observed in the area adjacent to Cabo Frio principally between September and April, in association with the coastal intrusion of the WCSA. The local physiography also contributes to the generation of a low pressure divergence zone between the coast and the Brazilian Current, which is diverted, allowing the upsurging of the masses of cold water from the bottom (Bentz et al., 2005).

This phenomenon is one of the principal mechanisms responsible for the intrusion of the WCSA onto the continental shelf. When this water reaches the surface near the coast, it causes a reduction in the temperature, which is normally associated with an increase in primary productivity, in particular of the phytoplankton. At Cabo Frio, the upwelling occurs within a narrow zone of less than 100 km from the coast (Moser and Gianesella-Galvão, 1997).

3. Material and methods

3.1. Data collection

Samples were collected for the analysis of sedimentary parameters, the physical–chemical characteristics of the water column, and the composition of the benthic foraminifera in April and May, 2008, by the Environmental Heterogeneity of the Campos Basin Project (HABITATS), which was coordinated by PETROBRAS-CENPES, in Rio de Janeiro. Sediment samples were collected using a box core sampler, which retrieved the 0–2 cm strata. Granulometric analyses were based on the method of Folk and Ward (1957) for granules of over 2 mm, whereas the particles of less than 2 mm were analyzed by laser diffraction (Shimadzu model SALD-3101). The levels of calcium carbonate ($CaCO_3$) were determined by gravimetric analysis.

Temperature and salinity were measured using a CTD (Conductivity, Temperature, and Depth) sampler. The analyses of the benthic foraminiferal were based on the examination of nine mini-cores of up to 10 cm divided vertically at intervals of 1 cm, with a total of 82 samples being collected. The samples were preserved in 10% formaldehyde buffered with borax (sodium tetraborate).

3.2. Laboratory analyses

3.2.1. Foraminifera

The samples of benthic foraminifera were stained with Rose Bengal (2 g per liter) for 24 h before being washed in a 0.062 mm mesh sieve, and dried at 60 °C. Sample volume was standardized to 1 g per sample. A minimum of 300 foraminiferal (total fauna) tests were picked per sample. In this study, the dead fauna was considered to be equivalent to the total fauna, given that the tests of living organisms were not stained.

A number of studies (Stigter et al., 1999; Murray and Bowser, 2000; Edelman-Furstenberg et al., 2001; Licari and Mackensen, 2005; Hayward et al., 2006; Horton and Murray, 2006) have shown that, for the investigation of distribution patterns, the live sample represents the instantaneous composition of the assemblage at a given moment in time, whereas the dead fauna provides a more reliable and representative sample of the composition of the fauna over the long term, which will be preserved in the sediments. Short-term variations in environmental conditions, which have a limited impact on the fauna, have little effect on the general characteristics of the assemblage. In this case, only the permanent conditions that affect the living organisms will be identified (Albani and Serandrei Barbero, 1982; Albani et al., 1998).

Given the possibility of post-mortem alterations in the characteristics of the specimens, extreme care was taken to identify potential evidence of alterations of the test (wear or fragmentation) or dissolution. No evidence of these processes was found in the specimens analyzed, however, indicating that they represented a predominantly *in situ* material.

3.2.2. Data analysis

The statistical analyses focused on the species that presented a density of at least 1% in at least two different substrates (Denne and Sen Gupta, 1991; Mackensen et al., 1995). Based on these criteria, the taxa analyzed together represent 98% of the total foraminiferal abundance.

The one way ANOVA test was used to identify significant differences in the mini-cores regarding the composition of the assemblies. Assessment of the associations among foraminiferal species was based on a *Q*-mode cluster analysis derived from a Bray–Curtis similarity matrix, in order to determine the distribution patterns among the different samples. This analysis weights rare and abundant species equally (Clarke and Warwick, 1994) and groups samples in pairs. In order to understand the relationship between the distribution of foraminiferal species and the refined environmental variables, the results of this cluster analysis were run in a Canonical Correspondence Analysis (CCA).

The data were log-transformed ($\ln(x + 1)$) for ordination in order to reduce the effects of the different scales and homogenize variances, reducing the relative importance of the dominant