PALEOCEANOGRAPHIC CHANGES THROUGH THE LAST 130 KA IN THE WESTERN SOUTH ATLANTIC BASED ON PLANKTONIC FORAMINIFERA

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ABSTRACT – This work reconstructs Late Quaternary paleoceanographic changes in the western South Atlantic Ocean based on sedimentary core GL-77, recovered from the lower continental slope in the Campos basin, offshore SE Brazil. The studied interval comprises the last 130 ka. Changes in sea surface temperature (SST) and paleoproductivity were estimated using the total planktonic foraminiferal fauna and oxygen isotope analyses. The age model was based on the oxygen isotope record, biostratigraphic datums and AMS 14C dating. It was observed that the Pleistocene/Holocene transition occurs within Globorotalia menardii Biozone Y, and is not coeval with the base of Biozone Z. The range between summer and winter SST estimates is larger during the glacial period compared to interglacials. Three peaks of low SST around 70, 50-45 and 20 ka coincided with periods of enhanced SE trade winds. Despite faunal differences between the last interglacial (MIS 5e) and the Holocene, our SST estimates suggest that SSTs did not differ significantly between these intervals.

Key words: Western South Atlantic, planktonic foraminifera, late Quaternary, marine isotope stage, glacial, interglacial.

INTRODUCTION

During the late Quaternary, the Earth witnessed significant climate fluctuations triggered by variations in the Earth’s orbital parameters and amplified by important feedbacks involving the expansion and retreat of ice sheets, re-organizations of the atmospheric and oceanic circulation, and changes in the concentration of greenhouse gases (e.g. Lorius et al., 1990). Climate changes, however, were neither spatially homogenous nor temporally synchronous (e.g. Mayewski et al., 2004). Knowledge of the exact sequence of events and the geographically different responses to climate forcing is vital if we are to understand the mechanisms behind climate change. There is currently a lack of proxy data from the western South Atlantic. This paper reconstructs the paleoceanographic changes that occurred in this part of the South Atlantic basin during the last 130 ka. To accomplish this task, we carried out an integrated analysis of the faunal composition, the oxygen isotopic ratios and AMS 14C dating of planktonic foraminifera obtained from a piston core retrieved from the lower continental slope of the Campos Basin, offshore SE Brazil.

Quaternary paleoceanographic studies of the Western South Atlantic have been conducted only relatively recently. They have mainly been based on three microfossil groups: foraminifera, ostracodes, and calcareous nannofossils. The
Campos Basin, on the SE Brazilian margin, contains the largest oil production areas in Brazil. However, most of the research on microfossils has focused on Cretaceous and Paleogene biostratigraphy, with direct application to the petroleum industry (e.g. Antunes et al., 2004; Arai & Lana, 2004). Those few biostratigraphic studies of the Quaternary have been conducted by the oil industry for geotechnical purposes. Vicalvi (1997, 1999) proposed a subdivision into foraminiferal biostratigraphic zones and subzones, following Ericson & Wollin’s (1968) model, which relies on the occurrence or absence of some key species of planktonic foraminifera. Sanjinès (2006) and Sanjinès et al. (2007) analyzed three cores retrieved from the Campos Basin (among them core GL-77, used in this study). They performed biostratigraphic studies using planktonic foraminifera and sequence stratigraphy for the Pleistocene-Holocene interval in the basin, subdividing the Globorotalia menardii biozones and identifying a Maximum Flooding Surface between biozones W and X. Tokutake (2005) and Maciel et al. (2012) performed biostratigraphic studies using calcareous nannofossils, while Ferreira et al. (2012) proposed a paleoclimatic zonation based on planktonic foraminifera for the Quaternary of Santos Basin, adjacent to Campos Basin.

Ericson & Wollin (1968) were the first to propose a biostratigraphic zonation for the Atlantic covering the Quaternary based on planktonic foraminifera. This zonation was based on the disappearances and reappearances of Globorotalia menardii. The zones were named from Q (the oldest) to Z (the most recent) wherein biozones Q, S, U, W, in which G. menardii was rare, were thought to correspond to glacial periods, while biozones R, T, V, X, and Z, in which G. menardii was abundant, were thought to correspond to interglacials. This biozonation has been suggested to be consistent with paleoclimate fluctuations, since the presence of this species in the Atlantic Ocean depends on its reseeding from the Indian Ocean through the Agulhas leakage, which is enhanced during interglacials (Berger & Vincent, 1986; Peeters et al., 2004). Analyzing cores from the Gulf of Mexico, Neff (1985) observed an inverse relationship between the abundances of G. menardii and Globorotalia inflata through the Pleistocene. Biozone Y can be further subdivided in the Atlantic and Caribbean using the appearance and disappearance of Pseudoselatina obliquiloculata in response to salinity changes (Prell & Damuth, 1978; Xu et al., 2005).

Most paleoceanographic studies along the SE Brazilian margin have focused on the time slice extending from the Last Glacial Maximum to the Holocene (e.g. Arz et al., 1999; Toledo et al., 2007a,b; Chiessi et al., 2008, 2014, 2015; Razik et al., 2012; Pivel et al., 2013). So far, little attention has been paid to changes that occurred during the whole last glacial interval. Matters such as the intensity of hydrographic changes through the last glacial and the similarities and differences between the last interglacial and the Holocene along the western South Atlantic are only now being addressed, with studies by Iwai (2010), Leonhardt et al. (2013), Ferreira et al. (2014) and Portilho-Ramos et al. (2014a,b), in the Campos and Santos basins. Here we enhanced the coverage of these studies into the Campos Basin focusing on biostratigraphy, as well as changes in paleotemperature and paleoproductivity.

**STUDY AREA**

Core GL-77(40º02’50”W, 21º12’22”S; 1,287 m water depth) was retrieved from the lower continental slope of the northern Campos Basin (Figure 1). The sequence corresponds to Holocene and Pleistocene sediments of the Campos Group, Ubatuba Formation (Machado et al., 2004). The base of this formation is drawn at an unconformity 1.6 Ma old, related to global eustatic sea level fall, while its upper boundary is represented by modern seabed sediments (Winter et al., 2007). The continental slope is dissected by muddy and sandy canyons. Turbidites and mud dominate the base of the continental slope and also occur in the most distal areas intersected by rare sandy canyons (Caddah et al., 1998).

The Campos Basin is under the influence of the Brazil Current (BC), which transports warm oligotrophic Tropical Water (TW) at the surface and South Atlantic Central Water (SACW) at the pycnocline layer (Silveira et al., 2000) (Figure 1). Mean annual sea surface temperature at the studied location is 25.5°C (Locarnini et al., 2013). In this basin, coastal upwelling occurs during summer, while shelf break upwelling occurs year-round, decreasing locally the depth of thermocline and nutricline (Palma & Matano, 2009). Both types of upwelling bring the nutrient-rich SACW into the photic zone and thus promote ocean productivity.

**MATERIAL AND METHODS**

Total sediment recovery from Core GL-77 was 18.15 m, of which the upper 14.65 m are analyzed here, comprising 60 samples (Figure 2). The analyzed interval comprises Ericson & Wollin’s (1968) biozones W (partially), X, Y, and Z (Figure 2), covering approximately the last 130 kyr. This core was previously studied from a strictly biostratigraphic viewpoint using planktonic foraminifera (Sanjinès, 2006; Sanjinès et al., 2007) and calcareous nannofossils (Maciel et al., 2012). In this study, we performed faunal and isotopic analyses of planktonic foraminifera to build the age model and obtain estimates of past changes in sea surface temperature (SST).

The samples were wet sieved with a 62 μm mesh sieve and then dry-sieved through a 150 μm mesh. Between 300 and 600 specimens of planktonic foraminifera from the >150 μm size fraction were identified and classified to the species level in each sample. The material examined is held in the foraminiferal section of the collection of the Paleontology Museum, Federal University of Rio Grande do Sul, under record numbers MP-F-3133 to MP-F-3143. The taxonomy followed Bé (1967, 1977), Bolli & Saunders (1989) and Hemleben et al. (1989). The proportional abundance of benthic foraminifera relative to total foraminifera in each sample was also recorded as an indication of past changes in paleobathymetry and paleoproductivity, with higher relative abundances of benthics being linked to lower sea levels (van der Zwaan et al., 1990).
Oxygen stable isotope analyses (δ¹⁸O) were conducted on tests of the planktonic species *Globigerinoides ruber* (white). Samples 01 to 37 were analyzed on a MAT-253 dual-inlet isotope ratio mass spectrometer with a Kiel IV carbonate device at the Stable Isotope Laboratory of the University of California, Santa Cruz (SIL-UCSC). Samples 38 to 60 were subsequently analyzed at the Analytical Laboratory for Paleoclimate Studies, of the University of Texas, Austin, also on a dual-inlet isotope ratio mass spectrometer Thermo 253 with a Kiel IV carbonate device. The isotopic data are reported relative to the Vienna Pee-Dee Belemnite (V-PDB) standard.

The age model was built based on the correlation of the δ¹⁸O curve in *Globigerinoides ruber* (white) with the standard LR04 δ¹⁸O stack (Lisiecki & Raymo, 2005) using six calibrated AMS ¹⁴C datings and one biostratigraphic datum as control points. The correlation was performed using the program AnalySeries 1.1 (Paillard et al., 1996). AMS ¹⁴C dates were measured at Beta Analytic (Miami, FL) on monospecific samples of *G. ruber* (white and pink chromotypes). Conventional radiocarbon dates were converted to calibrated ages by applying the Marine13 calibration curve (Reimer et al., 2013) using a delta-R of -59. The biostratigraphic datum corresponds to the W/X boundary, which has an estimated age of 130 ka (Kohl et al., 2004).

Paleotemperature estimates were obtained through application of the Artificial Neural Networks (ANN) technique, a machine learning method (Malmgren & Nordlund, 1997). This technique analyzes the relative abundance of species in each sample and, through comparison with a calibration database (composed of foraminiferal census counts of samples taken from sites with well-known environmental conditions); it provides estimates of winter, summer, and mean annual temperatures and their respective errors. A specific calibration database is used for each ocean basin. This minimizes the error introduced by cryptic species, *i.e.*, species that are morphologically similar, but differ by their genetics and environmental preferences (Kucera et al., 2005). The technique is based on the premise that temperature is the main factor controlling faunal distribution. Calculations were performed at the University of Bremen, Germany, using the same calibration dataset and trained networks as in Kucera et al. (2005).

**RESULTS AND DISCUSSION**

**Oxygen isotopes and age model**

We identified Marine Isotope Stages (MIS) 5 to 1, the first of these being supported by the age model (Figure 3) and by the correlation with the ages of the limits between MIS established by Lisiecki & Raymo (2005) (Figures 2, 4A). The age model obtained a correlation coefficient of 0.81. The results from the six AMS ¹⁴C dates measured on *Globigerinoides ruber* tests are presented in Table 1.

We identified the *Globorotalia crassaformis* optimum event proposed by Portilho-Ramos et al. (2014a,b) between 84 and 71 ka, at the end of MIS 5 (Portilho-Ramos et al., 2014b) and in Biozone Y4 (Portilho-Ramos et al., 2014a). Our identification of this *G. crassaformis* optimum event reinforces this datum as a local biostratigraphic marker and demonstrates the coherence of our age model (Figure 5).
Based on the ages obtained for each sample, within the Ericson and Wollin (1968) Zonation, the Y3/Y2 boundary, estimated here as being between 56 and 59 ka, coincides with the boundary between MIS 3 and MIS 4, which has an age of 57 ka (Lisiecki & Raymo, 2005). Vicalvi (1999) dated the last disappearance of *Pulleniatina obliquiloculata*, which marks the boundary of biozones Y2 and Y1 (datum YP.3), between 42 and 45 ka. In this study, the Y2/Y1 boundary was dated as 46.1 ka BP (range 47.1-45.18 ka), around the middle of MIS 3.

The Last Glacial Maximum (LGM) is usually associated with the last positive peak of δ¹⁸O, but this pattern undergoes some local variations, since the isotopic ratio largely reflects ice volume and is not necessarily in phase with climatic change (Imbrie & Kipp, 1971). The LGM is defined here as the chronological interval spanning 19-23 ka (within the time of the most recent maximum global ice-volume), during which global climate was reasonably stable (Mix *et al.*, 2001). There are two indications of the LGM in sample 12 (108 cm): a positive peak in δ¹⁸O, and an absolute dating of 20.965 ka BP (21.2-20.76 ka). This point correlates with the MIS 2 peak. According to the biostratigraphic interpretation of Sanjinés *et al.* (2007), the Y/Z limit corresponds to the Pleistocene/Holocene boundary. However, the age of the Pleistocene/Holocene boundary is currently considered to have been at 11.7 ka (Stratigraphic Chart 2015/01; Cohen *et al.*, 2013), and in the age model the last sample of the Pleistocene is dated as 12.56 ka BP (12.625 to 12.43 ka), and the first sample of the Holocene has an estimated age of 10.6 ka. The latter sample, however, is within Biozone Y. These results demonstrate that the Y/Z and the Pleistocene/Holocene boundaries are not synchronous, as observed by Pivel *et al.* (2013) and Broecker & Pena (2014), the Y/Z boundary occurring within the Holocene.

### Faunal census and paleotemperatures

Thirty-two species of planktonic foraminifera were identified, four of which are constituted by two different morphotypes/chromotypes. We thus recognized 36 taxonomic groups (see supplementary material in www.pangaea.de). The taxon *Globigerinoides ruber* (white) is the most abundant in all but three of the 60 samples analyzed, ranging from 18.71-62.17% of total recovery. *Globigerina bulloides* (up to 31.7%) dominated the remaining three samples, and was the second most abundant species, with >10% in 1/3 of the samples, especially at the base of the core. The taxon *Globigerinoides ruber* (pink) is the third most abundant taxon, comprising 1.2-18.5%. Other species that occur in abundances >10% in some samples are *Globigerinita glutinata* (up to 28.9%), *Globigerinoides ruber* (up to 28.7%), *Globorotalia crassaformis* (up to 16.2%), *Globorotalia inflata* (up to 13.6%), *Globorotalia truncatulinoides* (right-coiling; up to 10.0%) (Figure 5; data available as supplementary material in www.pangaea.de).

Figure 2. Schematic diagram of core GL-77 and correlation of sedimentary facies, biostratigraphy based on the presence/absence of *Globorotalia menardii*, *Globorotalia inflata* and *Pulleniatina obliquiloculata* (see Ericson & Wollin, 1968), with respective ages of biohorizons; the Marine Isotope Stage (MIS); and distribution of samples by depth. Black arrows show the AMS ¹⁴C dating (modified from Sanjinés, 2006). Abbreviations: MG, well bioturbated marl, yellowish to olive-gray; LR, bioturbated carbonate-rich mud, gray-olive and with oxidized levels; LL, bioturbated carbonate-poor mud, dark greenish-gray with lighter parts; (A), Broecker *et al.* (1980); (B), Damuth (1975); (C), Kohl *et al.* (2004).
Table 1. Ages obtained by AMS ¹⁴C dating.

<table>
<thead>
<tr>
<th>Core GL-77 sample number</th>
<th>Depth (cm)</th>
<th>Lab code</th>
<th>Measured radiocarbon age (ka BP)</th>
<th>Error (ka)</th>
<th>¹³C/¹²C ratio (‰)</th>
<th>Conventional radiocarbon age (ka)</th>
<th>Calibrated age (ka B.P.)</th>
<th>2σ range (cal ka BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>Beta-331995</td>
<td>1.51</td>
<td>0.03</td>
<td>-1.1</td>
<td>1.900</td>
<td>1.520</td>
<td>1.620 - 1.385</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>Beta-331996</td>
<td>6.65</td>
<td>0.04</td>
<td>+0.5</td>
<td>7.070</td>
<td>7.595</td>
<td>7.690 - 7.505</td>
</tr>
<tr>
<td>9</td>
<td>70</td>
<td>Beta-331997</td>
<td>10.54</td>
<td>0.05</td>
<td>-2.1</td>
<td>10.920</td>
<td>12.560</td>
<td>12.625 - 12.430</td>
</tr>
<tr>
<td>12</td>
<td>108</td>
<td>Beta-331998</td>
<td>17.32</td>
<td>0.07</td>
<td>-0.1</td>
<td>17.730</td>
<td>20.965</td>
<td>21.200 - 20.760</td>
</tr>
<tr>
<td>14</td>
<td>137</td>
<td>Beta-331999</td>
<td>21.83</td>
<td>0.09</td>
<td>-0.6</td>
<td>22.230</td>
<td>26.070</td>
<td>26.240 - 25.935</td>
</tr>
<tr>
<td>21</td>
<td>280</td>
<td>Beta-332000</td>
<td>42.86</td>
<td>0.55</td>
<td>-1.1</td>
<td>43.250</td>
<td>46.055</td>
<td>47.150 - 45.185</td>
</tr>
</tbody>
</table>

Figure 3. Correlation between δ¹⁸O in Globigerinoides ruber (white) and the LR04 reference curve (Lisiecki & Raymo, 2005). Vertical bars represent the correlation between the samples dated by ¹⁴C and biostratigraphic datum, with the respective ages.

Figure 4. Diagram showing the correlation (depending on age) between MISs, biozones, (A) δ¹⁸O, (B) summer, winter, and annual SSTs and (C) relative abundance of Globorotalia menardii. Black arrows show the AMS ¹⁴C dating.
Figure 5. Foraminiferal frequency of core GL-77. Black arrows show the AMS^{14}C dating.
estimates (Figure 4B). The SST oscillation pattern is similar in the three curves (mean summer, mean winter and mean annual estimates) (Figure 4B). However, the temperature range obtained for summer estimates was smaller than for winter SSTs throughout the core. Mean annual SSTs were lower during glacial times mainly as a consequence of lower winter SSTs. The contrast between summer and winter SST estimates suggests a broader temperature range during glacial intervals than during interglacials. During glacials, simply represented by Biozone Y, the SST range was larger than during interglacials (Biozones X and Z). This greater temperature range during glacial times may have been a consequence of the compression of climate belts due to the expansion of polar ice sheets. Compressed climatic belts would in turn lead to a change from tropical to more subtropical climate conditions with a wider temperature range.

Comparing the present and last interglacials, we find higher relative abundances of G. menardii in the last interglacial, in agreement with Ferreira et al. (2014) and Portilho-Ramos et al. (2014a) who analyzed cores from Santos Basin, immediately south of Campos Basin. Iwai (2010) and Portilho-Ramos et al. (2014a) interpreted the higher relative abundance of menardiiforms during the last interglacial as evidence of higher temperatures compared to the Holocene. Indeed, many studies indicate higher global temperatures for the last interglacial compared to the pre-industrial Holocene, with recent estimates based on proxy data ranging from 0.7 ± 0.6°C (McKay et al., 2011) to ~1.9°C (Turney & Jones, 2010).

The distribution of data compiled by Turney & Jones (2010) and McKay et al. (2011) highlight the lack of information for the western South Atlantic. Other areas of the South Atlantic for which there are data available indicate variable temperature trends during the last interglacial sensu stricto, i.e., during MIS 5e. Compared to the Holocene, these estimates range from warmer temperatures in the eastern, cooler waters in the equatorial region and no significant difference in the central part of the basin (see data compilation by Otto-Bliesner et al., 2013). Thus, higher global temperatures do not necessarily imply higher temperatures in our study area. In fact, despite the higher Globorotalia menardii relative abundances, our ANN results indicate only slight temperature differences between the Holocene and the last interglacial. When comparing the samples within the interval between 130-116 ka., corresponding to MIS 5e (n=6), with all the Holocene samples after the last reappearance of G. menardii (n=7), it was observed that summer, winter and annual mean SSTs were warmer for the latter. Our results indicate slightly cooler SSTs during MIS 5e compared to the Holocene. Annual mean, summer and winter SST were respectively 25.3, 26.5 and 24.5°C for MIS 5e, while values obtained for the Holocene were respectively 26.0, 27.3, and 25.1°C (Figure 6; Table 2). To investigate the presumed relationship between the relative abundance of G. menardii and SST, we compared both variables throughout the whole of MIS 5. This comparison suggests a strong correlation, with higher SSTs in periods of higher G. menardii abundances. However, the proportional abundances of G. menardii were highest during MIS 5b-c, while during MIS 5e they were similar to Holocene values. The same pattern was observed by Portilho-Ramos et al. (2014b) in another core retrieved at the slope of Campos Basin.

Figure 6. Comparison between Menardiiform plexus and Globorotalia menardii fauna and mean annual, summer and winter paleotemperatures estimates between the last interglacial (MIS 5) and the Holocene.
During the glacial period, three peaks of low SST occur, around 70, 50-45 and 20 ka. The peak of low SST at 20 ka corresponds to the LGM. During glacial times, especially during the LGM, the Intertropical Convergence Zone is displaced southwards, resulting in enhanced NE trade winds (e.g. Chiang et al., 2003). However, all the low SST peaks apparently coincide with the periods of enhanced SE trade winds proposed by Shi et al. (2001) based on records from the eastern South Atlantic. Strengthened SE trade winds would lead to enhanced heat transport to the northern hemisphere through a strengthened South Equatorial Current (Kim & Schneider, 2003). More records should be analyzed to provide additional information for the understanding of the real meaning of these glacial SST changes.

Between 30-20 ka Globigerinina glutinata stands out among the most abundant species (Figure 5). This species reaches abundances >25%, with a maximum of 29% at the LMG. We do not have data from other cores to verify whether this could be a local datum, since this species is not considered in biostratigraphic studies. However, given the high abundances and the ease of the identification of this species, we suggest it should be included in future biostratigraphic analyses of this area.

**Paleoproductivity**

Sea-surface temperature undoubtedly constitutes the main environmental factor controlling the distribution and abundance of planktonic foraminifera (e.g. Morey et al., 2005). However, nutrient availability may also exert an important control over species abundances and distribution, particularly in the tropics (e.g. Ravelo et al., 1990; Andreassen & Ravelo, 1997). Globigerina bulloides (Conan et al., 2002), the right coiling morphotype of Globorotalia truncatulinoides (Renaud & Schmidt, 2003), and Neogloboquadrina dutertrei (Hilbrecht, 1997) have been linked to productivity changes. Higher relative abundances of N. dutertrei have also been attributed to low salinity conditions (e.g. Cita et al., 1977; Cullen, 1981), although low salinity is frequently a consequence of increased continental runoff, which brings nutrients and thus enhances productivity. In fact, the interrelation between the environmental factors that determine the relative abundances of planktonic foraminifera hinders a straightforward and unequivocal interpretation of the record. Indeed, although G. bulloides, G. truncatulinoides (right coiling), and N. dutertrei have been related to increased productivity, in our study they present different along-core abundances.

The relative abundance records of Globorotalia truncatulinoides (right coiling) and Neogloboquadrina dutertrei present some similarities. Generally speaking, their records suggest low paleoproductivities at the base of the interval, with peaks in paleoproductivity around 90 ka (end of Biozone X), between 50-30 ka, and around 15 ka (between the LGM and the Pleistocene/Holocene boundary), although the peaks in both curves do not coincide precisely. For the Holocene, both species suggest low paleoproductivities (Figure 5). These results are in agreement with Leonhardt et al. (2013) who found low productivity during MIS 5e, increasing towards 100 ka. Higher productivity during the deglaciation compared to the LGM and the Holocene were also found by Leonhardt et al. (2013) and Toledo et al. (2007b). On the other hand, the relative abundance of Globigerina bulloides suggests higher paleoproductivities at the base of the interval, followed by a reduction of productivity towards the top (Figure 5).

Several factors explain the disagreement among the different paleoproductivity proxies based on relative abundances of planktonic foraminifera. First, these indicators are not totally independent, and may suffer influence from other environmental factors. Second, the relative abundance of species is a critical point, since high percentages of one species may actually be a consequence of the low abundance of another. Finally, the information obtained from faunal abundances integrates signals from different seasons, due to the seasonal succession of species. Thus, the abundances of different species may independently reflect changes from specific times of the year.

Given the dependence of benthic foraminifera on the organic matter flux from the surface, their relative abundance (relative to all foraminifera) may also be considered a proxy of paleoproductivity (Gooday, 2002). Van der Zwaan et al. (1999), however, demonstrate that this dependence is not true if the dissolved oxygen concentration becomes a limiting factor. The relative abundance of benthic foraminifera (P/B) suggests higher productivities towards the end of Biozone X and around 70 ka. However, the P/B ratio at slope depths may also be an indicator of dissolution (Nguyen & Speijer, 2014). Another factor that affects the relative amounts of benthic and planktonic foraminifera is bathymetry (Hemleben et al., 1989). Usually, the relative amount of planktonics tends to increase farther from the coast, where water depth increases. The benthic foraminiferal record shows lower values towards the Holocene, but the highest
abundances of benthic foraminifera do not correspond to the lowest sea levels.

**FINAL REMARKS**

The paleoceanographic record of core GL-77 provides new and valuable information for the understanding of paleoceanographic changes that have occurred in the western South Atlantic since the last interglacial. From our age model, we conclude that the Y/Z and Pleistocene/Holocene boundaries are not necessarily synchronous, with the beginning of the Holocene being prior to Biozone Z. The last interglacial period was characterized by higher relative abundances of G. menardii compared to the Holocene. Faunal differences, however, did not translate into significant SST changes. Contradicting previous studies, our estimates suggest slightly warmer summer, winter and mean annual SSTs during the Holocene than during the MIS 5e peak. Higher global temperatures during MIS 5e do not necessarily translate into higher temperatures in our study area. Despite the general agreement between SSTs and Globorotalia menardii abundances, more quantitative approaches should be followed when estimating SSTs, based on either total faunal assemblages or Mg/Ca ratios.

The local datum Globorotalia crassaformis optimum event was identified between 84-71 ka, which reinforces its relevance as a local bistostrigraphic marker. During MIS 4 to 2, the SST range was intensified. Three peaks of low SST detected around 70, 50-45 and 20 ka coincided with periods of enhanced SE trade winds. SST estimates suggest larger differences between summer and winter during the glacial intervals than during interglacials.

The relative abundances of the different species usually linked to high productivity fluctuated independently through time. Despite some similarities, it is not possible to provide a clear picture of past changes in paleoproductivity for the past 130 ka at the Campos Basin.

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