The coupling of *Orbulina universa* diameter with the warming and cooling events in the Arabian Sea over the past 40,000 years

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A 40 ky record of variations in the average diameter of *Orbulina universa* from a 5.4 m core (SK-322) in the Arabian Sea, off Goa, India has been analysed in this study. The chronology of the upper 1.00 m of the core was documented by AMS radiocarbon dates. Fifty specimens of *O. universa* were hand-picked from each of the 50 subsamples. In all, 2500 specimens were measured for their diameter. Downcore variations in the average diameter of *O. universa* were in excellent agreement with the curve representing the Iberian Margin temperature index, with the peak representing the Bølling–Allerød transition and the troughs reflecting Heinrich Event I and Younger Dryas. The lower part of the core examined in this study (between 58 and 100 cm), which is the equivalent of 30,000–40,000 years BP, is marked by closely spaced peaks and troughs that are interpreted as representing the Dansgaard–Oeschger cycles that were dominant in the Northern Hemisphere between 60,000 and 30,000 years BP.

Keywords: Average diameter, *Orbulina universa*, Palaeoclimate, planktic foraminifera.

ORBULINA UNIVERSA was first described from the South Pacific[1]. It is a spinose planktic foraminifer in which the ultimate chamber completely encloses the preceding chambers[2]. Its perfect spherical test is an indication of the mature specimen; thus, there is no confusion with juvenile forms. The species undergoes two growth stages and this character makes it unique among the planktic foraminifera. It is trochospiral in its juvenile stage and later, in its adult stage, is fully enclosed by a spherical chamber[3].

Different planktic foraminiferal species prefer various water column depths. Pioneering work on bathymetric preferences of different planktic foraminiferal species dates back to early 1970s and 1980s (refs 4, 5). These studies observed the abundance of *O. universa* in the mixed layer and, occasionally, in the thermocline. Nearly ubiquitous in transitional, subtropical and tropical waters, its peak in total abundance is in the surface layers near continental margins, especially where there are strong currents and upwelling[6].

In tropical areas, the mean test diameter is large and pores are numerous, while reduced mean test diameter and test porosity are characteristics of subtropical and sub-Antarctic waters[3]. There is latitudinal variation in the test diameter of *O. universa*. Tests from tropical–subtropical waters have a diameter range 600–800 μm; in the transition zone, intermediate-sized tests dominate with a diameter range 450–550 μm and smaller tests prevail in sub-Antarctic waters in a size range <450 μm (ref. 3).

Using multivariate cluster analysis of such morphological parameters as shell diameter and porosity of *O. universa* populations from the Indian Ocean, two major groups were reported to be distributed over the equatorial and central water masses[7]. This species was observed to be a good indicator of palaeoceanographic conditions in the Indian Ocean. Sea surface temperature (SST) and salinity are the two parameters which influence the mean test diameter of *O. universa* in the northern Indian Ocean[8]. A study on the Late Pleistocene samples from the Gulf of Mexico, however, showed no significant relationship between the size of *O. universa* and palaeoclimatic changes[9].

Fluctuations in the subtropical convergence zone were recorded during the examination of two cores from the Indian Ocean[10]. Stable oxygen isotope ratios, microfaunal analysis and variations in the average size of *O. universa* were used as proxies in this study. The palaeoceanographic value of this species in the Red Sea has been discussed in detail[11]. It is, therefore, obvious that the species can be considered as a reliable indicator of palaeoclimatic variations in the Indian Ocean region.

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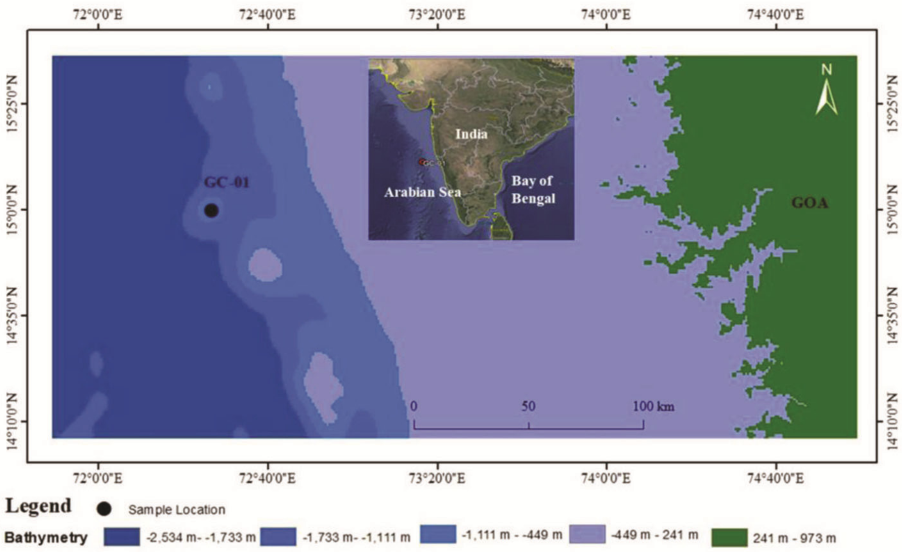

Figure 1. Map showing location of the core.

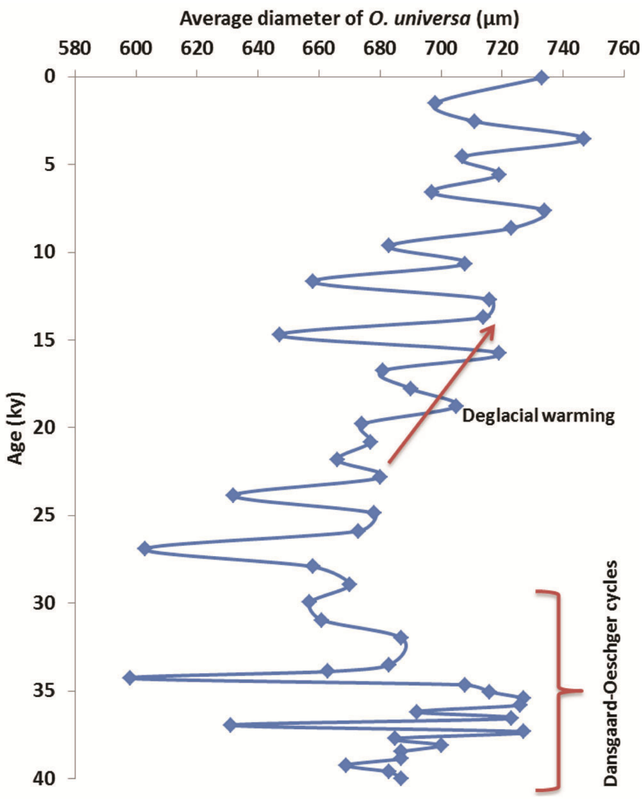

Figure 2. Downcore variations in the average diameter of *Orbulina univera*.

Table 1. Details of the core

	Geographical coordinates		
Water depth (m)	Latitude	Longitude	Core length (m)
517	15°00′18.93″N	72°26′34.48″E	5.4

Mean test size variations in planktic foraminiferal species such as *Globigerinoides ruber*, *Globigerinita glutinata*, *Globigerina bulloides* and *Neogloboquadrina dutertrei* were used to identify episodes of more intense and less intense upwelling in the last 19 kyr (ref. 12). Review of the literature, however, shows that there is lack of information regarding variations in the mean test diameter of *O. universa* and their implications on climate with regard to the Arabian Sea region. The present core, collected from the Arabian Sea, dates back to the Pleistocene and it will help to understand the Pleistocene–Holocene climatic variations in this region. Since there are variations in the results of average diameter of *O. universa* from different oceans and seas, the present study aims to establish whether such variations can be used as an effective tool to interpret palaeoclimatic changes in the Arabian Sea region.

Materials and methods

A 40 kyr record of the variations in the average diameter of *O. universa* from a 5.4 m core (SK-322) in the Arabian Sea, off Goa, India has been analysed in this study (Figure 1 and Table 1). The subsampling was done on-board and the core was sliced at an interval of 2 cm for the first 3 m and at 5 cm for the remaining part. This article presents the results obtained in the upper 1.0 m of the core. The chronology of the core was documented by accelerator mass spectrometer radiocarbon dates[13]. The sub-samples were soaked in distilled water overnight and the overlying water carefully decanted before washing through a 63 µm sieve (ASTM 230) to remove the mud contents. The sand fractions retained on the sieve were oven-dried at 50°C. Fifty specimens of *O. universa* were

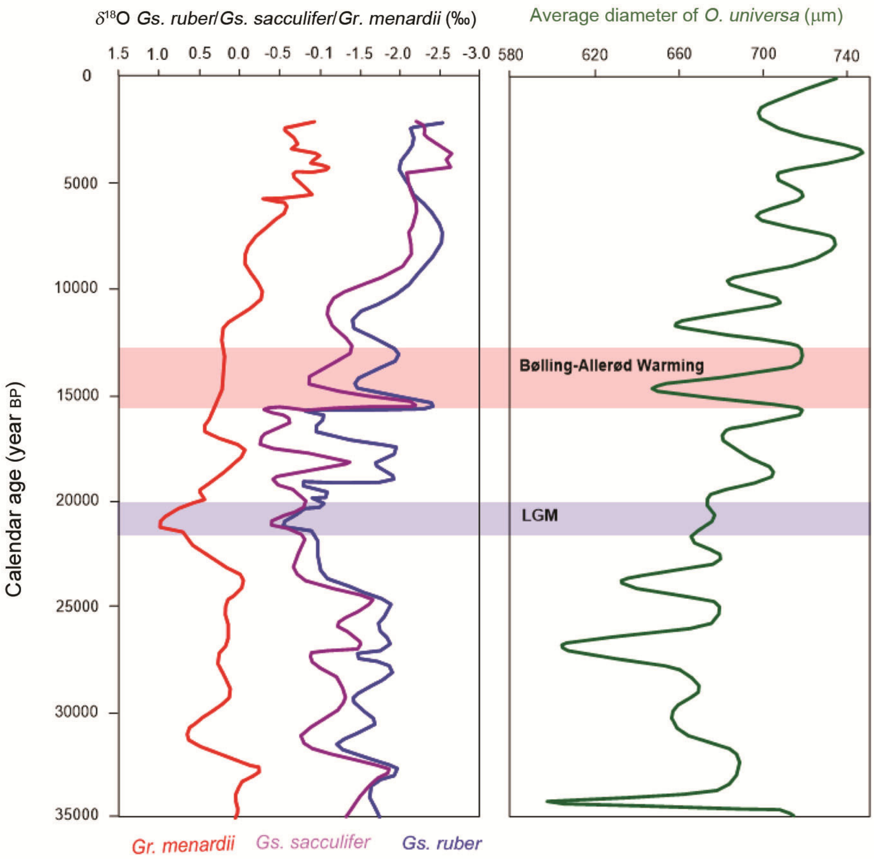

Figure 3. Comparison of *O. universa* diameter with δ^{18}O data of Tiwari *et al.*[16].

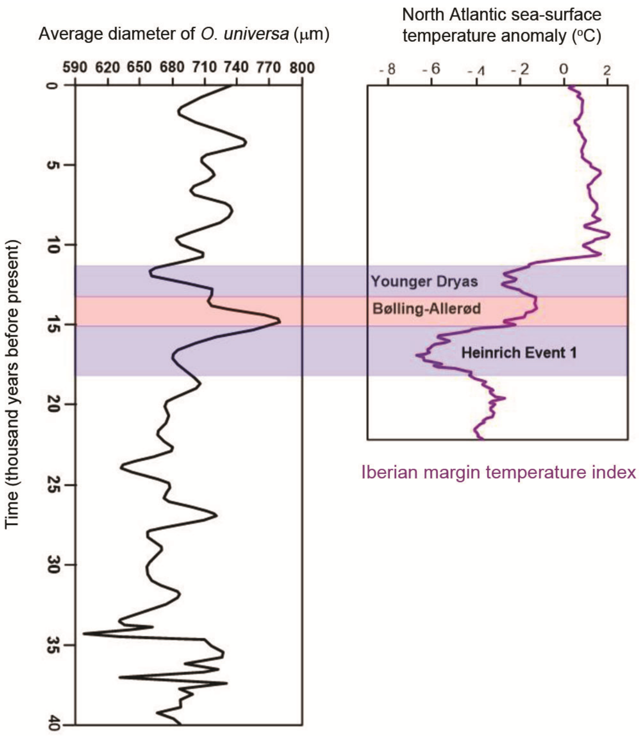

Figure 4. Comparison of *O. universa* data with those of Timmermann and Menviel[15].

hand-picked from each subsample; and in all, 2500 specimens were measured for their diameter in the Department of Geology, University of Madras, Chennai with the help of Nikon SMZ25 microscope using NIS Elements D software.

Results and discussion

Between 22 and 15 ky BP, there was a period of deglacial warming[14]. This was confirmed by results with the help of stable oxygen isotopic data based on a significant shift of δ^{18}O values. The average diameter of *O. universa* in the core examined also showed a gradual increase from 22 to ~15 ky BP, attaining the maximum around 14.7 ky BP (Figure 2), after which a decline was observed in the mean diameter. These results are concordant with earlier observations[14,15] and also support the results of a previous study which showed that the diameter of *O. universa* is positively correlated with temperature[8].

The δ^{18}O values of three planktic foraminiferal species, *Globigerinoides sacculifer*, *Gs. ruber* and *Globorotalia menardii* were in agreement with the onset of the deglacial period ~15,000 ^{14}C years ago or 18,000 calendar years ago compared to the present[16]. It is evident from the present study that there is a slight increase in the

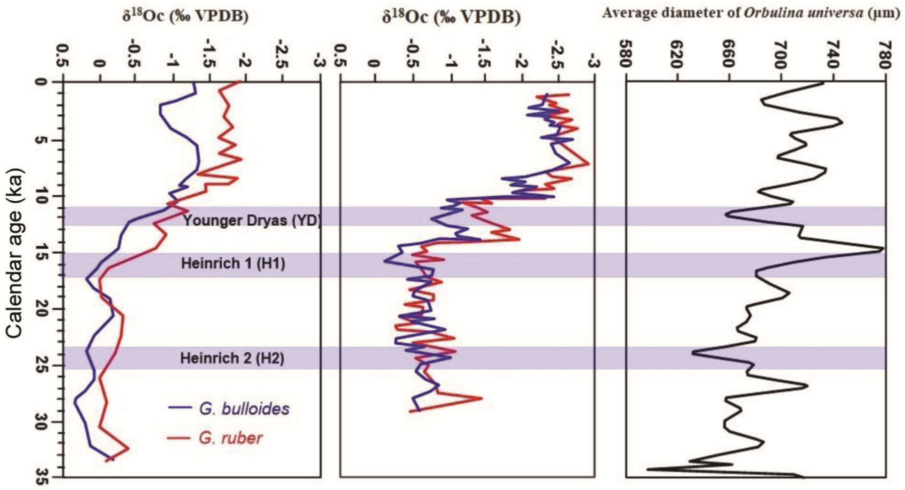

Figure 5. Comparison of *O. universa* data with those of Anand *et al.*[27].

average diameter of *O. universa* at 18,780 years ago, which might be related to this phenomenon. The average diameter variations of *O. universa* are in good concurrence with the δ^{18}O data for the last 35,000 years (Figure 3). The decrease in the average diameter of this species coincides with the shift of δ^{18}O towards higher values during the last glacial maximum, i.e. 21,000 years BP (ref. 16).

The last glacial period witnessed variable climate typified by millennial-scale warmer and colder episodes, commonly referred to as interstadial and stadial Dansgaard–Oeschger (DO) oscillations respectively, which were characteristic of the climate in the Northern Hemisphere between 60,000 and 30,000 years ago[17–19]. It has been documented that some of these colder episodes coincide with abnormal instances of ice-rafted detritus (IRD) in the North Atlantic sediments, and have been referred to as the Heinrich events[20,21]. Both interstadials and stadials have also been reflected in the climate records from the Indo-Asian region[22,23]. Two cooling episodes (Heinrich Event I and Younger Dryas) with a warming episode between them (Bølling–Allerød transition) have been well documented to have occurred in the last 20,000 years[15]. Downcore variations in the average diameter of *O. universa* are in excellent agreement with the curve representing the Iberian Margin temperature index[15], with the peaks representing the Bølling–Allerød transition and the troughs reflecting Heinrich Event I and Younger Dryas (Figure 4).

The lower part of the core examined in this study (between 58 and 100 cm), which is the equivalent of 30,000–40,000 years BP, is marked by closely spaced peaks and troughs in the downcore variations in the mean diameter of *O. universa*. We interpret these relatively short-term variations to be linked with the Dansgaard–Oeschger cycles that were dominant in the Northern Hemisphere between 60,000 and 30,000 years BP (ref. 15). A preliminary stratigraphic study revealed that the interstadials had a time duration of 500–2000 years[24], and the *O. universa* record amply reflects this. That these Dansgaard–Oeschger cycles have been documented in the Arabian Sea is well established[25,26].

Study of the past SST and δ^{18}O in the eastern and western Arabian Sea using two planktonic foraminiferal species, *G. ruber* and *G. bulloides* recorded three points which are characterized by high $\delta^{18}O_w$ ice volume free (IVF) values centred at 23 ky, 16 ky and 11 ky respectively[27]. The eastern Arabian Sea showed high values of $\delta^{18}O_w$ IVF during the Younger Dryas and Heinrich events. The reason may be due to the reduction in southwest monsoon rainfall and run-off from the Western Ghats. The present study aimed to compare the results of Anand *et al.*[27] with the present core and found a perfect match (Figure 5).

It is, therefore, obvious that variations in the mean diameter of *O. universa* can be effectively used to interpret palaeoclimatic changes in the last 40 kyr with great accuracy. Studies on longer cores, in conjunction with δ^{18}O values could throw more light on these climatic variations over a longer period of time.

Conclusion

Downcore variations in the average diameter of *O. universa* are in excellent agreement with the curve representing the Iberian Margin temperature index, clearly reflecting the Heinrich Event I, Bølling–Allerød transition as well as the Younger Dryas. The relatively short-term variations in the lower part of the core are interpreted to be linked with the Dansgaard–Oeschger cycles that were dominant in the Northern Hemisphere between 60,000 and 30,000 years BP. It is, therefore, evident that variations in the mean diameter of *O. universa* can be effectively utilized to interpret palaeoclimatic changes.

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