Palaeoclimatic implication of size variation in *Orbulina universa* in a core from the North Indian Ocean

Rajiv Nigam
National Institute of Oceanography, Dona Paula, Goa 403 004, India

Sea temperature and salinity influence mean diameter of the external shell of the planktonic foraminiferal species *Orbulina universa* d'Orbigny. Using these relationships, and data from samples in a sediment core from the Indian Ocean, it may be inferred that marine transgression events occurred at about 8800, 5500 and 2200 years BP.

THE planktonic foraminiferal species *Orbulina universa* d'Orbigny is a common and widely studied species in all the oceans. Be *et al.*[1] and Hecht *et al.*[2] studied the variation in mean diameter of the spherical test (external shell) of this species in surface sediment samples from the Indian Ocean and found that a direct correlation can be demonstrated between mean test diameter of *O. universa* and surface water temperature. Recently, Haenel[3] reanalysed the Be *et al.*[1] data statistically and showed that mean diameter of this species is (i) directly proportional to temperature ($r = 0.90$), and (ii) inversely proportional to salinity ($r = -0.46$) and density ($r = -0.93$).

Attempts have been made to utilize these ecological relationships to study palaeoclimates in various regions. Malmgren and Williams[4] studied the Gulf of Mexico and noticed that inconsistencies in results preclude the use of mean size of *O. universa* as a palaeoclimatic index in Late Quaternary sequences in that region. However, Be and Duplessy[5] have shown that mean size of the test closely follows palaeoclimatic trends (oxygen isotope ratios) in Late Quaternary deep-sea cores from temperate areas of the southern Indian Ocean (31–32°S). Haenel also noticed the utility of this species in the study of palaeoclimates of the Red Sea. From the above two studies it is apparent that at least in the Indian Ocean region this species can be used to study palaeoclimatic fluctuations.

The objective of the present study is to determine the Holocene palaeoclimatic variations in the northern Indian Ocean using data on mean diameter of *O. universa*.

During the twelfth cruise of *ORV Sagar Kanya* in the Arabian Sea, one 5 m long box core (SK 12/1) was collected from the eastern flank of the Carlesberg Ridge at a water depth of 3869 m (Figure 1). This core has been subsampled at every 5 cm interval up to a depth of 1 m. All the samples were washed through a >125 μm mesh and tests of *O. universa* were picked from the +125 fraction. A total of 1115 specimens from 21 samples were used to calculate mean size of the tests. Measurements were made using a microscope with a graduated eyepiece at a magnification of 40.

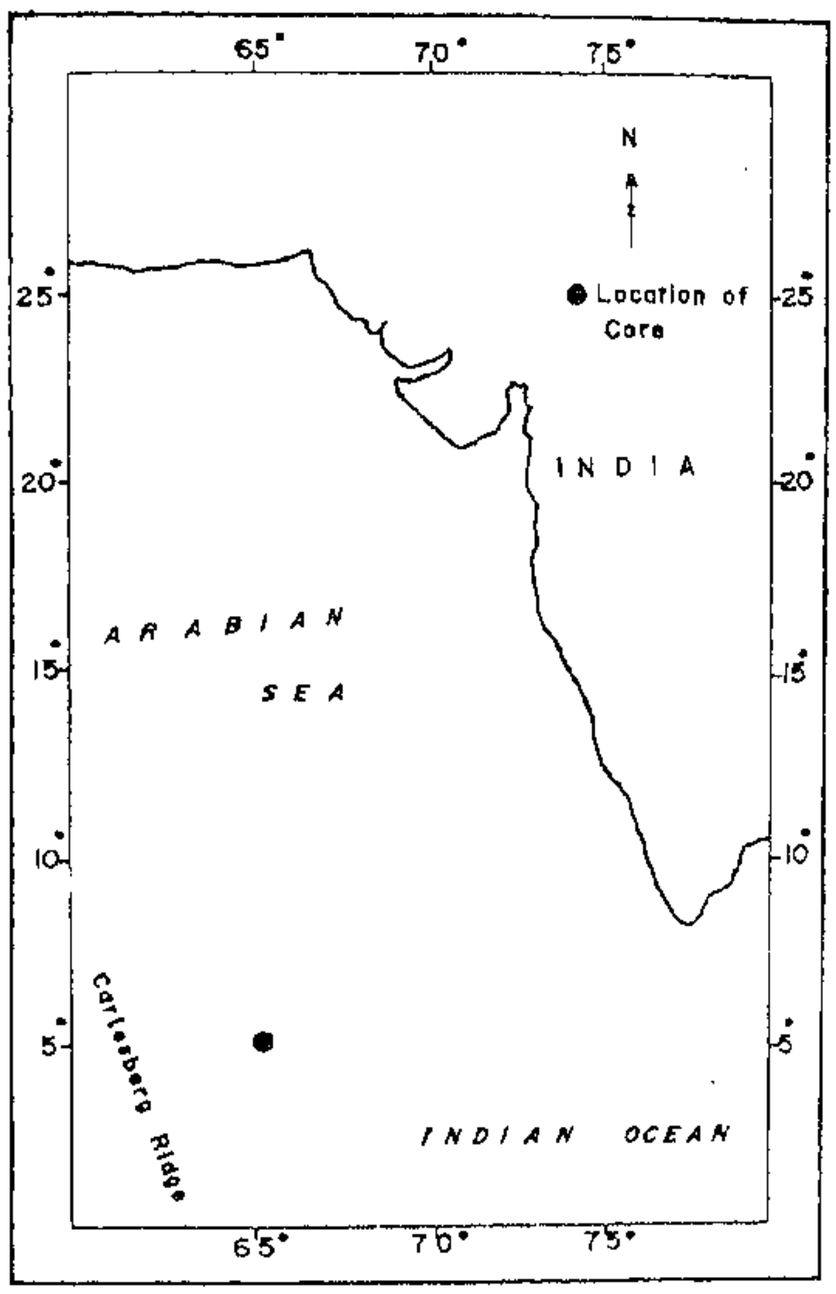

Figure 1. Map showing location from which core SK 12/1 was obtained.

Abundance of total planktonic foraminifera was used to obtain a time standard (Figure 2*a*). Several workers[6–9] have proposed that the number of planktonic foraminifera may be used to fix the Pleistocene/Holocene boundary (i.e. 11,000 yr BP). It was suggested that the top of the aplanktonic zone corresponds to the isotopic stage 1/2 boundary[7,10]. Locke and Thunell[9] found that isotopic stage 1 is characterized by abundant planktonic foraminifera, whereas stage 2a is characterized by low abundance or absence of planktonic foraminifera and corresponds to the interval 20,000 to 11,000 yr BP. In core SK 12/1, although foraminifera do not completely disappear, they show a prominent low (778 in 1 g) at 50 cm depth, above which again there is a sharp increase (peak 6562). Therefore the boundary can be fixed at around 50 cm depth in core SK 12/1. This observation is further supported by the *O. universa* abundance curve, which also shows a trough at 50 cm depth (Figure 2*b*). Earlier, Haenel[3] showed, on the basis of Reiss' data, that the 11,000 yr BP boundary coincides with the rare/absent portion of a curve showing abundance of *O. universa*. In view of the foregoing it is concluded that the upper 50 cm of the core encompasses a time span of about 11,000 years (i.e. the last interglacial).

Figure 2*c* shows the down-core variation in mean diameter of *O. universa*. The mean varies from 0.47 to

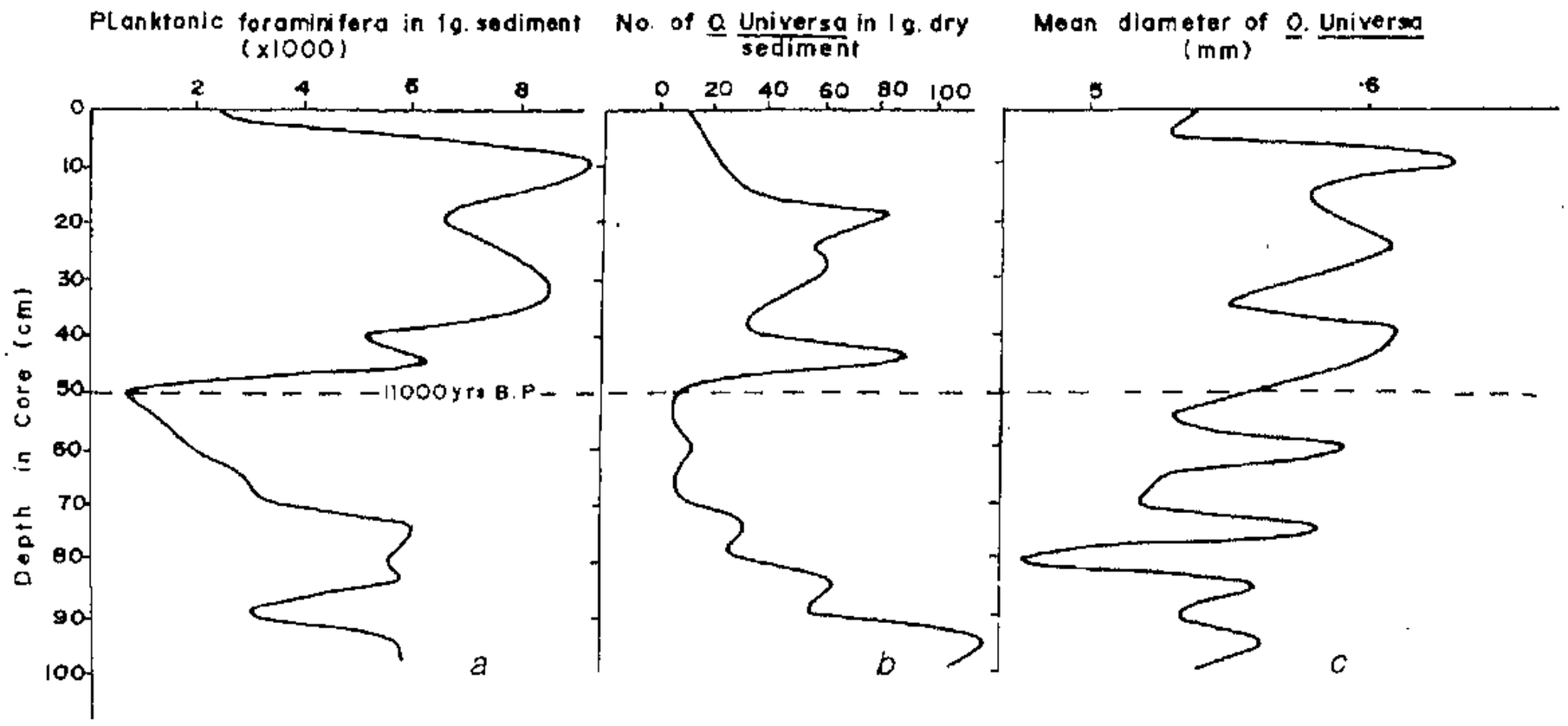

Figure 2. *a*, Variation in number of planktonic foraminifera in 1 g of dry sediments. *b*, Variation in number of *Orbulina universa* in 1 g of dry sediments. *c*, Variation in mean diameter of *Orbulina universa*.

0.63 mm. However, the minimum diameter was 0.225 mm (at st. no. 75–80 cm) and maximum diameter 1.19 mm (at st. no. 20–25 cm). The mean diameter curve shows three peaks, at 10, 25 and 40 cm, in the portion of the core deposited during the last interglacial. As discussed earlier[1-3], since mean diameter of *O. universa* is inversely proportional to salinity and directly proportional to temperature, it may be concluded that, during the Holocene, high temperature and low salinity conditions prevailed at about 8800, 5500 and 2200 yr BP and climatic fluctuations occurred. Since, in the Holocene, high temperature and low salinity conditions were coupled with rise in sea level due to melting of polar ice caps, it is further proposed that the above three dates may indicate episodes of marine transgression.

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Fossil flowers from Kasauli Formation near Barog, Himachal Pradesh

S. Mehra, V. P. Mishra and Anil K. Mathur
Geological Survey of India, Sector E, Aliganj, Lucknow 226 020, India

Well-preserved fossil flowers were found in the Kasauli Formation, which is part of the Lower Tertiary sedimentary sequence in the Himalayan region. These records are significant as fossil flowers are very rare in the Tertiaries of the Himalaya.

THE Dagshai and Kasauli formations represent part of the Lower Tertiary sedimentary sequence between the marine Subathu and freshwater molasse Siwalik Group. The Kasauli Formation represents well-established terrestrial conditions supported by the presence of unionids and fragmentary plant remains[1-3]. Well-preserved fossil flowers, inflorescence and bud have been discovered in this formation and are recorded here. These were found in the greenish-grey siltstones exposed along the Kalka–Shimla road (Figure 1), 1.2 km NNW of Barog (30°53'53"N, 77°04'15"E; altitude 1725 m).

The Kasauli Formation in this section consists mainly of massive grey sandstones and greenish-grey silty shales and siltstones. In addition to the flowers, well-preserved dicot and monocot leaf impressions are also present in this formation and have been collected from several localities in this section. The discovery of flowers is significant as they are of rare occurrence and almost unknown from the Tertiaries of the Himalaya.

The fossil plants reported earlier from the Kasauli Formation include form genera *Poacites*, *Palmophyllum* and *Dicotylophyllum*[4,5] and a single natural taxon *Sabal*