# Oxygen isotope composition of planktonic foraminiferal shells over the Indian Ocean: calibration to modern oceanographic data

O. Cayre CEREGE, BP-80, 13345 Aix en Provence, France

F. Bassinot Centre des Faibles Radioactivités, Laboratoire mixte CNRS/CEA, 91198 Gif sur Yvette Cedex, France

New $\delta^{18}O$ values were obtained on *Globigerinoides ruber*, *Globigerina bulloides* and *Neogloboquadrina dutertrei* picked in narrow size-fractions from 37 core-tops over the Indian Ocean. $\delta^{18}O$ equilibrium values with respect to ambient seawater were calculated using recent temperature and salinity data from the Levitus Atlas and based on regional salinity-$\delta^{18}O$ relationships established recently from measurements of water samples from the Arabian Sea and the Bay of Bengal. Equilibrium $\delta^{18}O$ values are also calculated with annual temperature and salinity weighted by primary productivity derived from chlorophyll satellite imagery.

## Globigerinoides ruber

The lowest $\delta^{18}O$ values were obtained in the Bay of Bengal reflecting the low salinity and low $\delta^{18}O$ of surface waters. In the Arabian Sea, the east-west gradient of increasing $\delta^{18}O$ values results from the westward decrease of surface temperatures associated with the development of upwelling cells on the western margin of the Arabian Sea during the summer monsoon. The comparison of our data from this species with those obtained by Duplessy (1982) indicates that in several cases differences exist which are not inside the estimated error bar. We suspect that size effect on the oxygen isotopic composition could be responsible of the discrepancy between our results obtained on *G. ruber* picked in a narrow size range (250–300 mm) and those of Duplessy (1982) which were obtained in *G. ruber* >150 μm. To confirm this hypothesis, we measured the $\delta^{18}O$ values in *G. ruber* from different size-fractions (160–250; 250–315 and 315–355 μm). Our results indicate that the $\delta^{18}O$ values of *G. ruber* decrease by about 0.3‰ when the size increases by about 100 μm. Our data are in agreement with recent results obtained from Panama Basin sediments (Kroon and Darling, 1995) but are surprisingly opposite to those of Berger *et al.* (1978) obtained from sediments in the western equatorial Pacific.

In order to estimate precisely the shift from equilibrium of $\delta^{18}O$ from *G. ruber*, we compared $\delta^{18}O$ values measured in our core-tops with calculated $\delta^{18}O$ equilibrium values. As *G. ruber* is known to be a surface dwelling planktonic species which calcifies mostly in surface waters, we calculated equilibrium values at 10 m. As explained above, equilibrium $\delta^{18}O$ values were calculated according to two different procedures: (1) using annual mean values of temperature and salinity; or (2) using annual mean oceanographic conditions weighed with productivity data. The comparison between measured values and calculated equilibrium values indicates that for the Bay of Bengal, for the Arabian Sea and for the South-Eastern African Coast, the measured values are generally lighter than calculated equilibrium values. The offset from equilibrium is +0.23 ‰ with the annual mean temperature and salinity and +0.26 ‰ with the oceanographic conditions weighted by the productivity. These values for the shift of *G. ruber* are in agreement with previous studies on this species from plankton tows.

## Globigerina bulloides

The $\delta^{18}O$ values measured from *G. bulloides* are generally 0.1 to 0.4 ‰ heavier than those measured from *Globigerinoides ruber*. As for *G. ruber*, the lightest values reflect the low salinities of the Bay of Bengal and the heaviest values in the Western Arabian Sea reflect the low surface temperature induced by monsoon during upwelling.

*Globigerina bulloides* is a subpolar species living in the transitional waters at high and mid latitudes. However, this species also exists in tropical oceans linked with upwelling areas. In these areas, its abundance is maximum in surface waters during the upwelling period whereas it lives in subsurface water before and after the upwelling season (Sautter and Thunell, 1991b). We compared $\delta^{18}O$ values measured in this study with the equilibrium $\delta^{18}O$

values calculated for annual mean (T,S) conditions at 10, 50, 75 and 100 m. For these four depths, the offsets from equilibrium are equal to +0.02 ‰, +0.40 ‰, +0.81 ‰ and +1.85 ‰, respectively. The use of the weighted approach results in an increase of the shift in the order of 0.05 ‰. Spero and Lea (1996) studying the oxygen isotopic composition of *G. bulloides* cultured in laboratory, showed that the shift from equilibrium is related to the ontogenic stage of the foraminiferal life with a decrease of incorporation of metabolic compound with an increase in shell size. They calculated a set of empirically derived correction factors in function of shell size. Following their equation, we calculated the shell equilibrium $\delta^{18}O$ corrections for shells between 250 and 300 µm for warm temperatures (>22°C). The corrections are +0.95 to 1.02 ‰ and correspond to the shift from equilibrium calculated with (T,S) data at 75 m. While many of our core-tops come from upwelling areas, our ?$^{18}$O measurements indicate that *G. bulloides* live in subsurface waters. The use of the weighted $\delta^{18}O$ equilibrium values does not change this result. A second possibility could be found: *G. bulloides* would calcify in surface waters with a shift of about 1 ‰ but its $\delta^{18}O$ signal would be disturbed by a dissolution effect as suggested by Sautter and Thunell (1991b) or by the addition of heavy calcite in deep waters during final ontogenic stages. Additional calcification is still poorly known for *G. bulloides* and the $\delta^{18}O$ shift from equilibrium in our study does not seem to be affected by dissolution and we conclude that *G. bulloides* in the northern Indian Ocean live at 75 m of water depth.

## Neogloboquadrina dutertrei

$\delta^{18}O$ values measured from *N. dutertrei* are generally 0.8 to 1.0 ‰ heavier than those measured from *G. ruber*. Surface distribution of $\delta^{18}O$ values reflects thermal and salinity gradients existing in the northern Indian Ocean. *Neogloboquadrina dutertrei* is not a surface-dwelling species but its depth habitat is still debated in recent studies. Our measured $\delta^{18}O$ values are compared with calculated equilibrium $\delta^{18}O$ values at 10, 50, 75 and 100 m. The offsets from equilibrium are respectively equal to −0.71, −0.33, +0.11 and +0.67‰. The use of the weighted equilibrium $\delta^{18}O$ values changes the shift values by about +0.05 ‰. Previous studies established that *N. dutertrei* calcifies with a shift between −0.30 ‰ and +0.11 ‰. According to these results, *N. dutertrei* from our core top sediments appears to have calcified at around 50−75 m in the water column. In the northern Indian Ocean, the temperature gradient occurring between 30 and 75 m indicates that 50 m is about the depth of the thermocline. Our results indicate therefore that *N. dutertrei* calcifies within the thermocline. The first detailed study on *N. dutertrei* in the Indian Ocean was made by Curry and Matthews (1981a). These authors suggested that this species adapts its depth in order to calcifies at constant temperature (near 22° and 24°C). They found two different explanations: (1) these temperatures correspond to the optimum conditions for the calcification and reproduction of *N. dutertrei*; or (2) the isotherms of 22° to 24° correspond to the depth of greatest food abundance. In our study, there is no significant difference in the pattern of *N. dutertrei* between the Arabian Sea and the Bay of Bengal whereas temperature profiles are strongly different. In both areas the species seems to calcify between 50 and 75 m whereas in the Bay of Bengal at these depths the temperature is between 24.5 and 27.5°C. Therefore our results tend to favour the hypothesis that *N. dutertrei* adapts its depth as a function of the nutrient supply and not as a function of water temperature.

## References


Berger W.H., Killingley J.S. and Vincent E. (1978) *Oceanologica Acta*, **1**, 203−16.

Curry, W.B. and Matthews, R.K. (1981) *Palaeogeo., Palaeoclim., Palaeoecol.*, **33**, 173−91.

Duplessy, J.C. (1982) *Nature*, **295**, 494−8.

Kroon, D. and Darling, K. (1995) *J. Foraminiferal Res.*, **25**, 39−52.

Sautter, L.R. and Thunell, R.C. (1991) *Paleoceanogr.*, **6**, 307−34.

Spero, H.J. and Lea, D.W. (1996) *Marine Micropal.*, **28**, 231−46.