

# Effect of Temperature and Salinity on Stable Isotopic Composition of Shallow Water Benthic Foraminifera: A Laboratory Culture Study

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**Abstract :** Quantitative estimation of past climatic parameters from stable isotopic composition of foraminifera relies on estimating the precise relationship between stable isotopic composition of the species analyzed and the physico-chemical factors of the seawater. This relationship can be established either on species collected from surface sediments or in plankton tows. Another method to establish such relationships is by subjecting the foraminiferal species to known physico-chemical parameters in the laboratory. In the present work, shallow water benthic foraminiferal species, *Rosalina* sp. and *Pararotalia nipponica* were subjected to different combinations of seawater temperature (25°C to 35°C) and salinity (25 psu to 37 psu) in the laboratory to assess their stable oxygen isotopic composition and its applicability in determining seawater temperature and salinity. The stable isotopic ratio of the species shows no consistent relationship with salinity. The relationship between  $\delta^{18}\text{O}$  foraminifera and seawater temperature is more consistent for *P. nipponica* than for *Rosalina* sp. Salinity appears to have less control on  $\delta^{18}\text{O}$  foraminifera as compared to the seawater temperature, within the studied salinity and temperature range. The study shows that the changes in  $\delta^{18}\text{O}$  of *P. nipponica* can be used effectively to infer past seawater temperature changes.

**Keywords:** Culture, Benthic foraminifera, *Pararotalia nipponica*, *Rosalina* sp., Salinity, Temperature, Isotopes.

## INTRODUCTION

The near shore shallow marine waters close to river mouths experience wide seasonal salinity changes due to fresh water influx. The changes depend on seasonal variations in monsoon intensity accompanied by differential input of terrestrial sediments by the river into the oceans. These locations are ideally suited to study the past changes in monsoon intensity. Benthic foraminifera are abundant in shallow water regions (Boltovskoy & Wright, 1976; Murray, 1991) and temporal changes in their abundance, diversity and morphology have been used to infer past monsoon changes (Zwaan *et al.*, 1999; Nigam, 2005). More precise estimate of past monsoon changes can be obtained from the study of temporal variation in the stable oxygen isotopic ratio of the selected benthic foraminiferal species.

The application of benthic foraminiferal stable oxygen isotopic ratio to infer past monsoon changes, however, requires a precise estimation of the influence of various physico-chemical factors on foraminiferal stable oxygen isotopic ratio. Previously, based on field and laboratory culture studies, it has been inferred that the seawater temperature, salinity, pH,

$\text{CO}_3^{2-}$  ion concentration, etc., affect the stable oxygen isotopic ratio of foraminifera (Bé *et al.*, 1977; Erez and Luz, 1983; Bouvier-Soumagnac and Duplessy, 1985; Bouvier-Soumagnac *et al.*, 1986; Spero and Lea, 1996; Spero *et al.*, 1997; Bemis *et al.*, 1998; Bijma *et al.*, 1999). These studies further indicated that the relationship between oxygen isotopic composition and seawater parameters is species specific. Such studies on benthic foraminifera, however are limited (Chandler *et al.*, 1996; Wilson-Finelli *et al.*, 1998; McCorkle *et al.*, 2008; Baras *et al.*, 2010; Phillipson *et al.*, 2010). Considering the short life span, possibility of seasonal isotopic bias is more in planktic foraminifera, when compared to benthic foraminifera, having longer life spans.

A few recent studies, however, have shown that some benthic foraminiferal species secrete their test preferentially during particular seasons which brings in significant isotopic bias (Cage and Austin, 2008). Additionally, the life-span of a few benthic foraminiferal species is of the order of a few weeks to a few months, which will lead to a clear seasonal bias in its isotopic composition. Therefore, a proper understanding of the effect of various factors on the oxygen isotopic ratio of benthic foraminifers with short life span, is required to get

reliable seasonal paleoclimatic signatures. In the present study, we have subjected two shallow water benthic foraminiferal species, viz., *Rosalina* sp. (d'Orbigny, 1826) and *Pararotalia nipponica* (Asano, 1936) to a different combination of seawater salinity and temperature to understand the effect of these parameters on its stable oxygen isotopic ratio.

## METHODOLOGY

### Study area and Field collection

Material for picking live foraminifera (seaweed and surface sediment samples) for the study was collected through skin diving in shallow areas or on-board research vessels off Goa (15° 27' N; 73° 48' E). The samples (seaweed/sediments) were then brought to the shore with the seawater and sieved through 1000 µm (to remove large unwanted material) and 63 µm sieves in order to concentrate the foraminifera. The plus 63 µm and <1000 µm material was transferred to glass containers with seawater and brought to the laboratory. Seawater was also collected from the sampling site, filtered through the muslin mesh and was used for further processing of the material and for the experiment. In the laboratory, the field material was scanned for live benthic foraminifera, under the reflected light stereo-zoom microscope; the isolated live specimens were kept under observation in multiwell culture dishes. The live nature of the specimens was further confirmed by their movement, collection of food material or extended pseudopodia, noticed under the inverted microscope. Once confirmed to be alive, specimens were maintained in laboratory till they reproduced. The juvenile specimens with initial 2-3 chambers (in order to ensure that bulk of the carbonate was secreted under controlled laboratory culture conditions) were subjected to the experiment.

### EXPERIMENTAL SET-UP

The juvenile specimens of *Rosalina* sp. were subjected to 25°C, 30°C and 35°C temperature and 25 psu, 30 psu and 35 psu salinity, whereas *P. nipponica* specimens were subjected to 25°C, 27°C and 30°C temperature and 30 psu, 35 psu and 37 psu salinity. Therefore, nine combinations of temperature and salinity were used for the experiment. The experiment was carried out in replicate, such that two sets of specimens were subjected to similar salinity-temperature combination, so as to assess any experimental variability. To begin with, all the specimens were subjected to 25°C temperature and 35 psu salinity, as this was the temperature and salinity at the time of sampling. After three days, one set was left at the temperature and salinity reported from the field, while the temperature and salinity in other sets were changed according to the desired

combination. The schematic diagrams (Fig. 1 and Fig. 2) show the experimental set-up. The salinity and temperature were changed gradually, in order to prevent a sudden experimental shock, which the organisms could experience if they were transferred directly to the respective intended salinity and temperature.

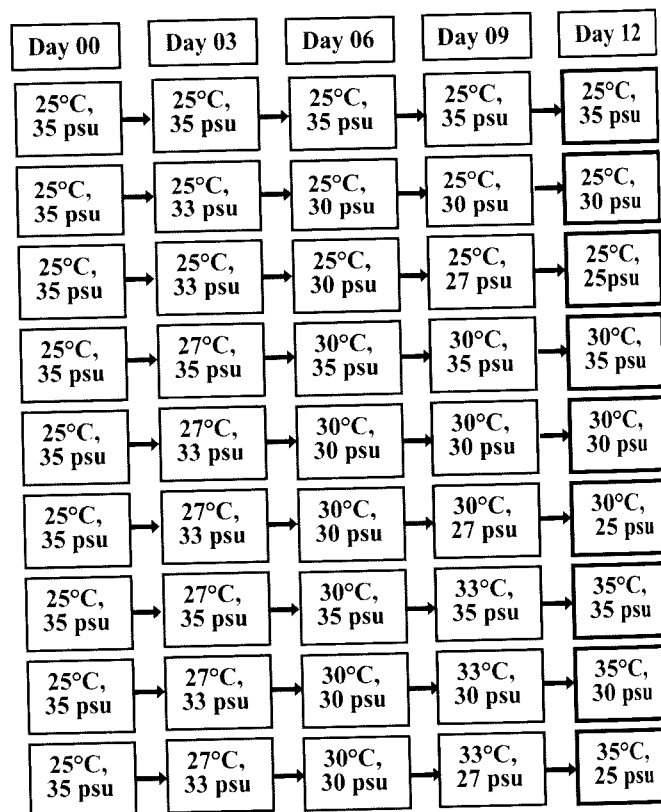


Fig. 1. Schematic showing the gradual change in the salinity and temperature combinations to which juvenile specimens of benthic foraminifera *Rosalina* sp. were subjected during the experiment. Specimens were subjected to nine different combinations of temperature (25°C, 30°C and 35°C) and salinity (25 psu, 30 psu and 35 psu).

At the onset of the experiment, number of chambers and maximum diameter for all the specimens were noted. The seawater with salinity lower than that from the field was prepared by diluting the normal seawater with less saline seawater. The higher salinity water was prepared by controlled evaporation at 45°C temperature. The seawater with different salinity was prepared in bulk, in the beginning of the experiment which was used throughout the experiment, to avoid any change in the oxygen isotopic composition of the seawater. The culture dishes were wrapped in poly-films to prevent evaporation. The salinity of the seawater was measured every time just before changing the media. The salinity of the

Day 00	Day 03	Day 06	Day 09	Day 12
27°C, 35 psu	25°C, 37 psu	25°C, 37 psu	25°C, 37 psu	25°C, 37 psu
27°C, 35 psu	25°C, 35 psu	25°C, 35 psu	25°C, 35 psu	25°C, 35 psu
27°C, 35 psu	25°C, 33 psu	25°C, 30 psu	25°C, 30 psu	25°C, 30 psu
27°C, 35 psu	27°C, 37 psu	27°C, 37 psu	27°C, 37 psu	27°C, 37 psu
27°C, 35 psu	27°C, 35 psu	27°C, 35 psu	27°C, 35 psu	27°C, 35 psu
27°C, 35 psu	27°C, 33 psu	27°C, 30 psu	27°C, 30 psu	27°C, 30 psu
27°C, 35 psu	30°C, 37 psu	30°C, 37 psu	30°C, 37 psu	30°C, 37 psu
27°C, 35 psu	30°C, 35 psu	30°C, 35 psu	30°C, 35 psu	30°C, 35 psu
27°C, 35 psu	30°C, 33 psu	30°C, 30 psu	30°C, 30 psu	30°C, 30 psu

Fig. 2. Schematic showing the gradual change in the salinity and temperature combinations to which juvenile specimens of benthic foraminifera *P. nipponica* were subjected during the experiment. Specimens were subjected to nine different combinations of temperature (25°C, 27°C and 30°C) and salinity (30 psu, 35 psu and 37 psu).

used media was also measured in order to check for any evaporation. Equal amount of food in the form of mixed diatom culture was added in each culture dish, every time the media was changed. All the observations on the experimental specimens were made with the help of Nikon inverted microscope. The experiment was discontinued when specimens stopped responding. The specimens were then washed in distilled water and preserved for isotopic analysis.

### ISOTOPIC ANALYSIS

Once the experiment was over, the specimens were thoroughly cleaned to get rid of any material sticking to the test and were subsequently stored in micropaleontological slides. The isotopic analysis was done at Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, Kiel University, Germany on Finnigan MAT 251 mass spectrometer. The precision of  $\delta^{18}\text{O}$  based on analysis of internal standard was  $\pm 0.07\%$ . The stable oxygen isotopic values are expressed with VPDB.

### RESULTS AND DISCUSSION

The weight of the calcite precipitated prior to being subjected to respective temperature-salinity combination was negligible compared with the weight of the mature tests. Thus the stable oxygen isotopic ratio of the foraminiferal tests at different temperature-salinity combinations can be considered as indicative of that condition. The  $\delta^{18}\text{O}$  *Rosalina* sp. is relatively depleted than that of the *P. nipponica*. At 25 psu salinity, no relationship is noted between  $\delta^{18}\text{O}$  *Rosalina* sp. and seawater temperature (Fig. 3). At 30 psu salinity,  $\delta^{18}\text{O}$  *Rosalina* sp. has a strong negative correlation (0.97) with seawater temperature, whereas at 35 psu salinity the relationship between  $\delta^{18}\text{O}$  *Rosalina* sp. and seawater temperature is highly positively correlated (0.96). In case of *P. nipponica* a poor correlation is noted between  $\delta^{18}\text{O}$  and seawater temperature at 30 psu salinity, whereas at 35 psu and 37 psu salinity, the  $\delta^{18}\text{O}$  *P. nipponica* and seawater temperature have a strong positive correlation (0.96 and 0.93, respectively) (Fig. 4).

At constant seawater temperatures,  $\delta^{18}\text{O}$  *Rosalina* sp. is poorly correlated with the seawater salinity at 25°C and 30°C seawater temperatures. The  $\delta^{18}\text{O}$  *Rosalina* sp. is, however, strongly positively correlated with seawater salinity at 35°C temperature (Fig. 5). In case of *P. nipponica*, a poor correlation is noted between  $\delta^{18}\text{O}$  and seawater salinity at 30°C seawater temperature. Whereas at 25°C and 27°C seawater temperatures,  $\delta^{18}\text{O}$  *P. nipponica* is negatively correlated with seawater salinity (0.72 and 0.89, respectively) (Fig. 6). A positive correlation means increasingly depleted  $\delta^{18}\text{O}$  with increasing seawater salinity whereas a negative correlation means increasingly enriched  $\delta^{18}\text{O}$  with increasing seawater salinity or temperature. A strong positive correlation between  $\delta^{18}\text{O}$  *Rosalina* sp. and seawater salinity at 35°C temperature suggests that in regions with consistently warm waters  $\delta^{18}\text{O}$  values of *Rosalina* sp. can be used to infer seawater salinity and thus past monsoon intensity. As compared to *Rosalina* sp.,  $\delta^{18}\text{O}$  *P. nipponica* is better correlated with salinity in relatively cooler waters and thus it can help understand salinity changes from comparatively cooler regions. The  $\delta^{18}\text{O}$  of none of the species, however, has a consistent relationship with seawater salinity, thus requiring additional work to assess applicability of its stable oxygen isotopic ratio to infer paleomonsoon.

Although no consistent relationship is observed between seawater temperature and  $\delta^{18}\text{O}$  in case of *Rosalina* sp.,  $\delta^{18}\text{O}$  *P. nipponica* decreases with increasing seawater temperature at all the studied salinities. The relationship between  $\delta^{18}\text{O}$  *P. nipponica* and seawater temperature is in line with that observed in case of several deep water benthic and planktic foraminiferal species (Bijma *et al.*, 1999; Filipsson *et al.*, 2010).

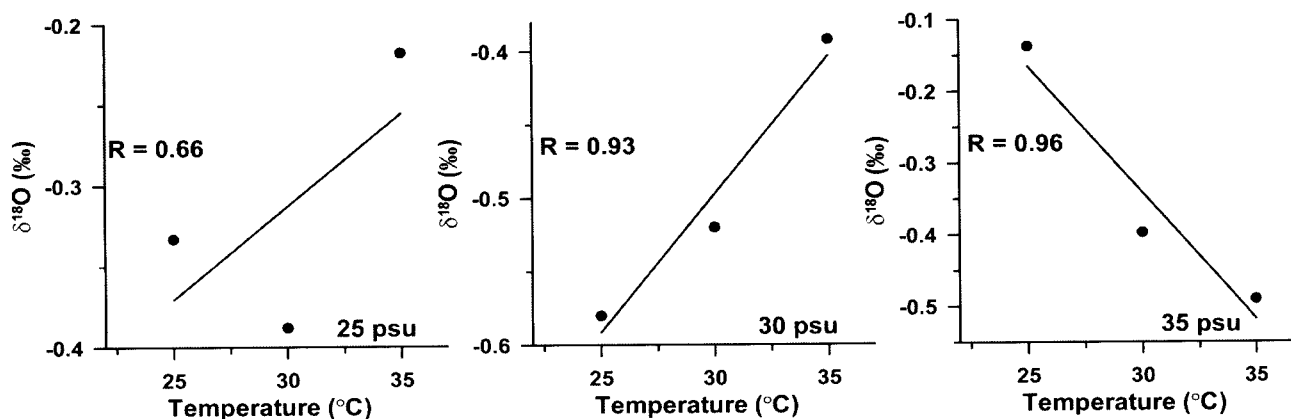


Fig. 3. The relationship between seawater temperature and  $\delta^{18}\text{O}$  *Rosalina* sp. at three different salinities. The  $\delta^{18}\text{O}$  *Rosalina* sp. is positively correlated with seawater temperature at 35 psu salinity, whereas at 30 psu salinity, it is negatively correlated. Interestingly, no apparent relationship is noted between seawater temperature and  $\delta^{18}\text{O}$  *Rosalina* sp. subjected to 25 psu salinity.

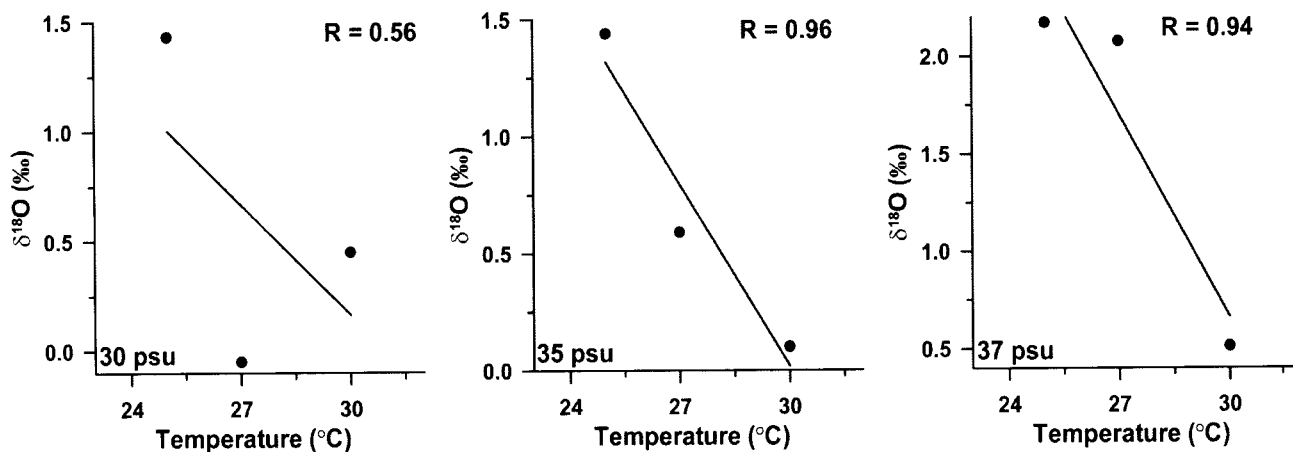


Fig. 4. The relationship between seawater temperature and  $\delta^{18}\text{O}$  *P. nipponica* at three different salinities. A strong positive correlation between seawater temperature and  $\delta^{18}\text{O}$  *P. nipponica* is observed at 35 psu and 37 psu salinity, whereas poor correlation is noted between  $\delta^{18}\text{O}$  *P. nipponica* and seawater temperature at 30 psu salinity.

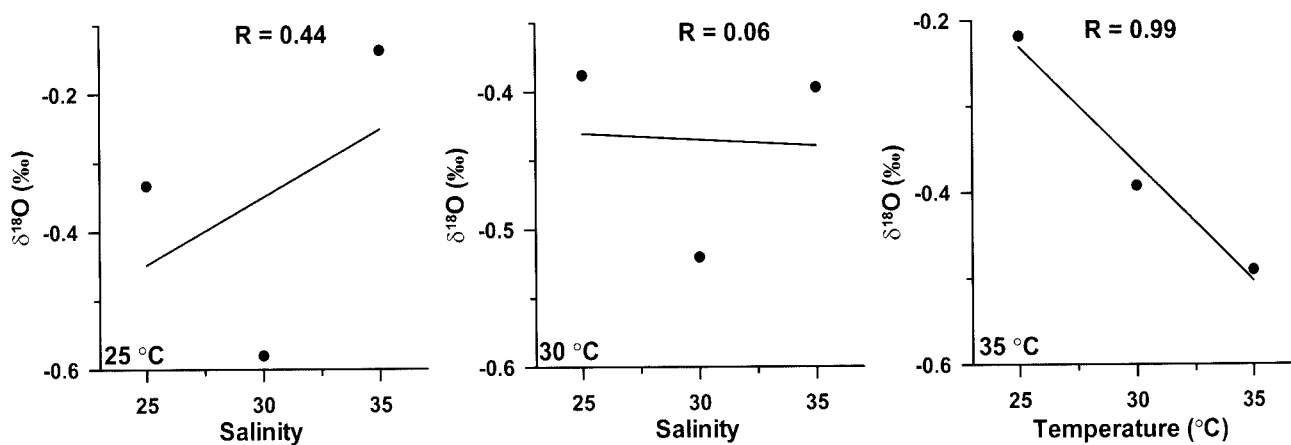


Fig. 5. Graph showing the relationship between seawater salinity and  $\delta^{18}\text{O}$  *Rosalina* sp. at three different temperatures. It is observed that the  $\delta^{18}\text{O}$  *Rosalina* sp. is positively correlated with seawater salinity at 35°C temperature, but at 25°C and 30°C seawater temperatures,  $\delta^{18}\text{O}$  *Rosalina* sp. is poorly correlated with the seawater salinity.

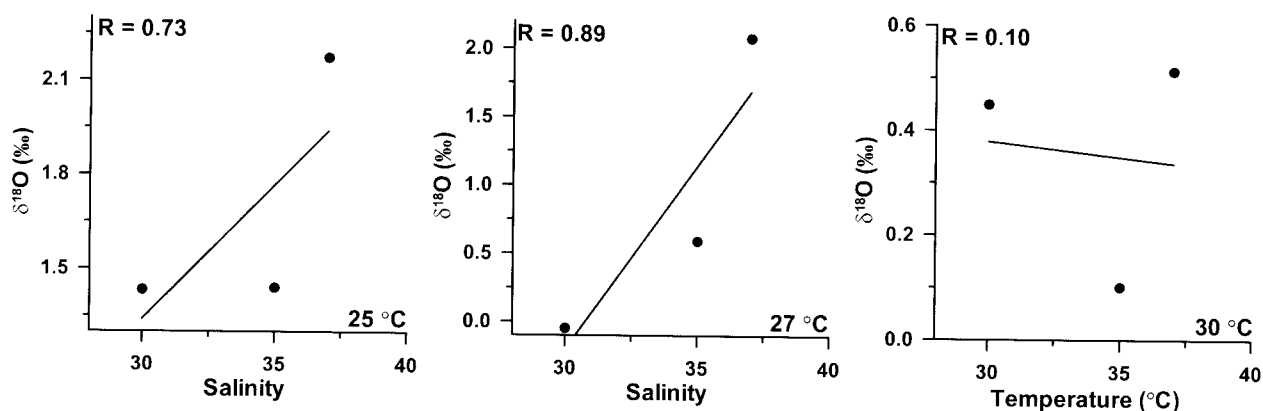


Fig. 6. Graph showing the relationship between seawater salinity and  $\delta^{18}\text{O}$  *P. nipponica* at three different temperatures. Poor correlation is noted between  $\delta^{18}\text{O}$  *P. nipponica* and seawater salinity at 30°C seawater temperature, whereas at 25°C and 27°C seawater temperatures,  $\delta^{18}\text{O}$  *P. nipponica* is negatively correlated with seawater salinity.

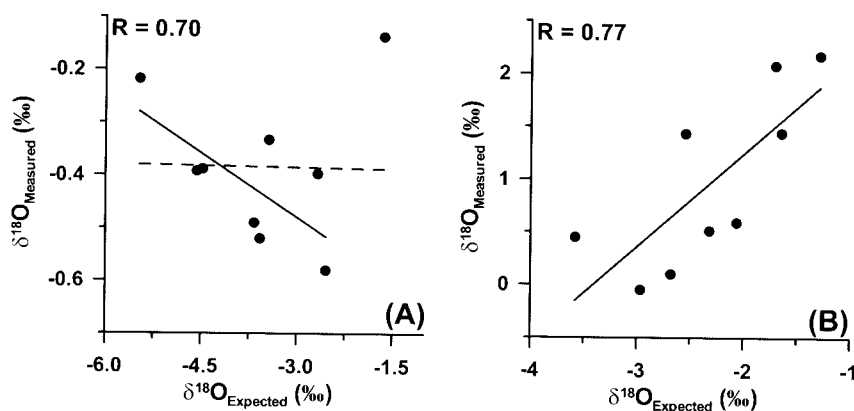


Fig. 7. The plot of expected versus measured  $\delta^{18}\text{O}$  for *Rosalina* sp. (A) and *P. nipponica* (B). The correlation values are also given. For *Rosalina* sp., the dotted trend line is based on all the data points, while the solid trend line is based on all data points except one (-0.14, -1.38) corresponding to 25°C temperature and 35 psu salinity.

The slope of the best fit line describing the relationship between  $\delta^{18}\text{O}$  *P. nipponica* and seawater temperature, however, varies with seawater salinity.

Similarly, the relationship between seawater salinity and  $\delta^{18}\text{O}$  also does not remain constant at different seawater temperatures. Only at 35°C temperature, very strong positive correlation (0.98) is noted between  $\delta^{18}\text{O}$  *Rosalina* sp. and seawater salinity, whereas in case of *P. nipponica*,  $\delta^{18}\text{O}$  and salinity show a strong negative correlation (0.89) at 27°C temperature. Interestingly, the seawater salinity does not result in any significant change in  $\delta^{18}\text{O}$  in both *P. nipponica* and *Rosalina* sp. at 25°C and 30°C.

To assess the offset of measured  $\delta^{18}\text{O}_{\text{foraminifera}}$  from the expected values,  $\delta^{18}\text{O}_{\text{calcite}}$  was also calculated. A paleotemperature equation was used to estimate  $\delta^{18}\text{O}_{\text{calcite}}$  at different temperatures (Shackleton, 1974; Bemis *et al.*, 1998).

$$\text{Temperature} = 16.5 - 4.80 * (\delta^{18}\text{O}_{\text{calcite}}(\text{VPDB}) - (\delta^{18}\text{O}_{\text{seawater}}(\text{SMOW}) - 0.27))$$

The relationship between seawater salinity and its  $\delta^{18}\text{O}$  given by Delague *et al* (2001) for the surface water samples collected from the Bay of Bengal was used to calculate  $\delta^{18}\text{O}_{\text{seawater}}$ , which is required to estimate  $\delta^{18}\text{O}_{\text{calcite}}$ . This equation was chosen as it is based on a number of low salinity data points. Here we would like to point out that though the choice of equation relating  $\delta^{18}\text{O}_{\text{seawater}}$  with salinity will affect the estimated  $\delta^{18}\text{O}_{\text{calcite}}$ , it will result in a constant offset in all the values as it is linearly related. Thus the choice of equation relating  $\delta^{18}\text{O}_{\text{sw}}$  with salinity will not affect the correlation value between  $\delta^{18}\text{O}_{\text{foraminifera}}$  and  $\delta^{18}\text{O}_{\text{calcite}}$ .

The plot of expected versus measured  $\delta^{18}\text{O}$  values is too scattered for *Rosalina* sp. with a very poor correlation (0.02). The correlation improves significantly (0.70), however, just by removing one data point (25°C, 35 psu) (Fig. 7A). This seawater temperature and salinity combination is at the extreme to which *Rosalina* sp. was subjected in this experiment. The extreme salinity and temperature combination might have led

to some adverse effect on the normal physiology of *Rosalina* sp. Changes in physiology under extreme physico-chemical conditions might affect the metabolic rate of the foraminifera. A change in the metabolic rate will affect its isotopic composition as confirmed by a difference in the  $\delta^{18}\text{O}$  of juvenile and mature specimens of the same species of foraminifera (Bijma *et al.*, 1999; Schmiedl *et al.*, 2004; McCorkle *et al.*, 2008; Filipsson *et al.*, 2010). The difference in the  $\delta^{18}\text{O}$  of juvenile and mature specimens of the same species is attributed to the difference in the rate of secretion of calcite by the juveniles and mature specimens. A similar anomalous offset was also noted in *Bulimina* subjected to very low temperature (4°C) (Filipsson *et al.*, 2010). Additionally, this anomalous value can also be attributed to dissolution of foraminiferal calcite as it has been reported that the foraminiferal calcite starts dissolving when subjected to low salinity (Nigam *et al.*, 2006; Kurtarkar *et al.*, 2011). Dissolution of foraminiferal tests leads to differential removal of different isotopes of oxygen leading to alteration of  $\delta^{18}\text{O}$  (Sexton *et al.*, 2006, Williams *et al.*, 2007; dos Anjas-Zerfass *et al.*, 2011).

The measured  $\delta^{18}\text{O}$  *P. nipponica* values are also significantly offset from the expected  $\delta^{18}\text{O}$  values. But the correlation between expected and measured  $\delta^{18}\text{O}$  for *P. nipponica* is much better (0.77) than that for *Rosalina* sp., with all data points plotted. Interestingly, the measured  $\delta^{18}\text{O}$  *Rosalina* sp. values become progressively enriched when it is expected to be more depleted. The measured  $\delta^{18}\text{O}$  *P. nipponica* values are directly related with the expected values, but with an offset. The average offset of  $\delta^{18}\text{O}$  *P. nipponica* from the expected  $\delta^{18}\text{O}$  is -3.28 ‰ with a standard deviation of 0.58 ‰. A constant offset of measured  $\delta^{18}\text{O}$  foraminifera from the expected  $\delta^{18}\text{O}$  has previously been reported for a number of benthic foraminiferal species (Shackleton and Opdyke, 1973; Duplessy *et al.*, 1984). It indicates that the relationship between  $\delta^{18}\text{O}$  *P. nipponica*, seawater salinity and temperature is different than that of the previous species. Additional data points with

several combinations of seawater salinity and temperatures are, however required to precisely estimate the paleotemperature equation for *P. nipponica*. The offset of measured  $\delta^{18}\text{O}$  *Rosalina* sp. from expected (-3.18 ‰) is comparable with that of *P. nipponica*. A very large standard deviation (1.18 ‰) in the offset (-3.18 ‰) of expected minus measured  $\delta^{18}\text{O}$  values for *Rosalina* sp., however indicates that the oxygen isotopic composition of this species is not very reliable for estimating seawater temperature and salinity.

## CONCLUSION

Based on the laboratory culture study of two shallow water benthic foraminiferal species, namely *Rosalina* sp. and *P. nipponica* subjected to different combinations of seawater salinity and temperatures, we conclude that the stable isotopic ratio of the studied species shows no consistent relationship with seawater salinity. Compared to the seawater temperature, salinity appears to have little control on  $\delta^{18}\text{O}$  foraminifera within the studied salinity and temperature range. The relationship between  $\delta^{18}\text{O}$  foraminifera and seawater temperature is more consistent for *P. nipponica* than for *Rosalina* sp. The study shows the changes in  $\delta^{18}\text{O}$  of *P. nipponica* can be used to infer past seawater temperature changes.

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## References

- ASANO, K. (1936) Fossil foraminifera from Muraoka-mura, Kamakura-gori, Kanagawa Prefecture. Geol. Soc. Japan Jour., v. 43, pp. 603-615.
- BARRAS, C., DUPLESSY, J.-C., GESLIN, E., MICHEL, E., and JORISSEN, F. J. (2010) Calibration of  $\delta^{18}\text{O}$  of cultured benthic foraminiferal calcite as a function of temperature. Biogeosciences, v. 7, pp. 1349-1356.
- BÉ A.W.H., HEMLEBEN, C., ANDERSON, O.R., SPINDLER, M., HACUNDA, J. and TUNTIVATE-CHOY, S. (1977) Laboratory and field observations of living planktonic foraminifera. Micropaleontology, v. 23(2), pp. 155-179.
- BEMIS, B. E., SPERO, H. J., BIJMA, J. and LEA, D.W. (1998) Reevaluation of the oxygen isotopic composition of planktonic foraminifera: Experimental results and revised paleotemperature equations. Paleoceanography, v. 13, pp. 150-160.
- BIJMA, J., SPERO, H.J. and LEA, D.W. (1999) Reassessing foraminiferal stable isotope geochemistry: Impact of the oceanic carbonate system (experimental results). In Fisher, G. and Wefer, G., (Eds.). Use of proxies in paleoceanography: examples from the south Atlantic, Springer-verlag Berlin Heidelberg, pp. 489-512.
- BOLTOVSKOY, E. and WRIGHT, R., (1976) *Recent Foraminifera*. Dr. W. Junk b.v., Publishers, The Hague.
- BOUVIER-SOUMAGNAC, Y. and DUPLESSY, J.-C. (1985) Carbon and oxygen isotopic composition of planktonic foraminifera from

- laboratory culture, plankton tows and recent sediment: implications for the reconstruction of paleoclimatic conditions and of the global carbon cycle. *Jour. Foramin. Res.*, v. 15, pp. 302-320.
- BOUVIER-SOUMAGNAC, Y., DUPLESSY, J.-C. and BÉ, A. W. H. (1986) Isotopic composition of a laboratory cultured planktonic foraminifer *O. universa*, Implications for paleoclimatic reconstructions. *Oceanol. Acta.*, v. 9, pp.519-522.
- CAGE, A.G. and AUSTIN, W.E.N. (2008) Seasonal dynamics of the coastal water masses in a Scottish fjord and their potential influence on benthic foraminiferal shell geochemistry. In Austin, W. E. N. and James, R. H., (Eds.) *Biogeochemical Controls on Palaeoceanographic Environmental Proxies*, Geological Society, London, Special Publication, pp. 155-172.
- CHANDLER, G. T., WILLIAMS, D. F., SPERO, H. J. and XIAODONG, G., (1996) Sediment microhabitat effects on carbon stable isotopic signatures of microcosm-cultured benthic foraminifera. *Limnol. Oceanogr.*, v. 41, pp. 680-688.
- D'ORBIGNY, A. (1826) *Tableau methodique de la classe des Cephalopodes*, *Annales des Sciences Naturelles*, v. 7, pp. 245-315.
- DOS ANJOS-ZERFASS, G.S., CHEMALE, F. JR., and MOURA, C.A.V. (2011) Post-depositional effects on the microstructure and stable isotopes composition of planktic foraminiferal tests from the Miocene of the Pelotas Basin, south Brazilian continental margin. *Rev. Mexi. Cien. Geol.*, v. 28, p. 92-104.
- DUPLESSY, J.-C., SHACKLETON, N. J., MATTHEWS, R.K., PRELL, W., RUDDIMAN, W.F., CARALP, M. and HENDY, C.H. (1984)  $^{13}\text{C}$  Record of benthic foraminifera in the last interglacial ocean: Implications for the carbon cycle and the global deep water circulation. *Quarter. Res.*, v. 21, pp. 225-243.
- EREZ, J. and LUZ, B. (1983) Experimental paleotemperature equation from planktonic foraminifera. *Geochim. Cosmochim. Acta.*, v. 47, pp. 1025-1031.
- FILLIPSON, H.L., BERHARD, J.M., LINCOLN, S.A. and McCORKLE, D.C. (2010) A culture based calibration of benthic foraminiferal paleotemperature proxies:  $\delta^{18}\text{O}$  and Mg/Ca results. *Biogeosciences*, v. 7, pp. 1335-1347.
- KURTARKAR R. S., NIGAM R., SARASWAT R. and LINSHY V. N. (2011) Regeneration and abnormality in benthic foraminifer *Rosalina leei*: implications in reconstructing past salinity changes. *Riv. Ital. Paleontol. Stratigr.*, v. 117, pp. 189-196.
- McCORKLE, D. C., BERNHARD, J. M., HINTZ, C. J., BLANKS, J. K., CHANDLER, G. T. and SHAW, T. J. (2008) The carbon and oxygen stable isotopic composition of cultured benthic foraminifera. In Austin, W. E. N. and James, R. H., (Eds.) *Biogeochemical controls on palaeoceanographic environmental proxies*, Geological Society, London, pp. 135-154.
- MURRAY, J.W. (1991) *Ecology and Paleocology of Benthic Foraminifera*. John Wiley, New York and Longman Scientific and Technical, Harlow, U.K., p. 397.
- NIGAM, R., (2005) Addressing environmental issues through foraminifera: Case studies from the Arabian Sea. *Jour. Paleontol. Soc. India.*, v. 50, pp. 25-36.
- NIGAM, R. SARASWAT R. and KURTARKAR R. S., (2006) Laboratory Experiment to study the effect of salinity variations on benthic foraminiferal species – *Pararotalia nipponica* (Asano). *Jour. Geol. Soc. India.*, v. 67, pp. 41-46.
- DELAGUE, G., BARD, E., ROLLION, C., JOUZEL, J., STEVENARD, M., DUPLESSY, J.-C. and GANSEN, G. (2001) Oxygen isotope/salinity relationship in the northern Indian Ocean. *Jour. Geophys. Res.*, v. 106, pp.4565-4574.
- SCHMIEDL, G., PFEILSTICKER, M., HEMLEBEN, C., and MACKENSEN, A., (2004) Environmental and biological effects on the stable isotope composition of recent deep-sea benthic foraminifera from the western Mediterranean Sea. *Mar. Micropaleontol.*, 51,129-152.
- SEXTON, P. F., WILSON, P. A., and PEARSON P. N., (2006) Microstructural and geochemical perspectives on planktic foraminiferal preservation: "glassy" versus "frosty". *Geochem., Geophys., Geosyst.*, v. 7, p. 1-29.
- SHACKLETON, N. J. (1974) Attainment of isotopic equilibrium between ocean water and the benthonic foraminifera genus *Uvigerina*: isotopic changes in the ocean during the last glacial. *CNRS, Colloques Internationaux*, v. 219, pp. 203-209.
- SHACKLETON, N. J. and OPDYKE, N. D. (1973) Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 105 and 106 year scale. *Quater. Res.*, v. 3, pp. 9-55.
- SPERO, H. J. and LEA, D. W. (1996) Experimental determination of stable isotope variability in *Globigerina bulloides*: implications for paleoceanographic reconstructions. *Mar. Micropaleontol.*, v. 28, pp. 231-246.
- SPERO, H.J., BIJMA, J., LEA, D.W. and BEMIS, B.E. (1997) Effect of seawater carbonate concentration on foraminiferal carbon and oxygen isotopes. *Nature*, v. 390, pp. 497-500.
- WILLIAMS, M., ALAN M. HAYWOOD, MARYLINE VAUTRAVERS, BRUCE W. SELLWOOD, CLAUS-DIETER HILLENBRAND, IAN P. WILKINSON, and C. GILES MILLER (2007) Relative effect of taphonomy on calcification temperature estimates from fossil planktonic foraminifera. *Geobios*, v. 40, pp. 861-874.
- WILSON-FINELLI, A., CHANDLER, G. T. and SPERO, H. J. (1998) Stable isotope behavior in paleoceanographically important benthic foraminifera: Results from microcosm culture experiments. *Jour. Foramin. Res.*, v. 28, pp. 312-320.
- ZWAAN, G. J. V., DUIJNSTEE, I. A. P., DEN DULK, M., ERNST, S. R., JANNINK, N. T. and KOUWENHOVEN, T. J. (1999) Benthic foraminifera: Proxies or problems? A review of Pleocological concepts. *Earth Sci. Rev.*, v. 46, pp. 213-236.