J. Ind. Geophys. Union (April 2007)
Vol.11, No.2, pp.73-78

On the intriguing relationship between seawater salinity and δ^{18}O of *Globigerina bulloides* at higher latitudes

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ABSTRACT

The δ^{18}O variation in planktic foraminifera *Globigerina bulloides* from nineteen surface sediment samples, collected onboard *ORV Sagar Kanya* between 1.92°S and 55.01°S latitude in the Indian Ocean sector of Southern Ocean, have been analyzed to understand the relationship between oxygen isotopic fractionation and near surface seawater salinity. The initial intriguing results indicate that up to ~31°S latitude, salinity may influence the oxygen isotopic composition of the foraminiferal tests. However, beyond 31°S (further south) latitude, salinity does not appear to influence the *G. bulloides* oxygen isotopic composition significantly.

INTRODUCTION

The monitoring of the impact of various physico-chemical processes on the stable isotopic composition of different water masses in the ocean is significant (Mackensen 2001). Different isotopic signatures of the water masses have the potential to be differentiated in fossil carbonates as well (Mackensen et al., 1996). Major isotopic fractionation in foraminiferal shells is caused by equilibrium/kinetic effects associated with the hydrologic cycle (freezing, evaporation, precipitation). These effects in turn also change the seawater salinity. Therefore, δ^{18}O variations of foraminiferal tests could possibly be an important tool to understand salinity-linked variation in different water masses in modern marine environment.

An oceanic transect from low latitude to higher latitude encompasses a variety of regimes, each having its own distinct water mass characteristics (Orsi, Whitworth & Nowlin 1995). One among such significant hydrographical boundaries is Sub Tropical Convergence (STC) or Sub Tropical Front (STF) (Deacon 1933, 1937; Clifford 1983; Hofmann 1985). The adjoining region of this STF witnesses a number of oceanic frontal systems having their own physical properties (currents, salinity, temperature, density, nutrient contents etc). Having realized the significance of the above-mentioned region, the Indian pilot expedition to Southern Ocean (PESO) was launched in January 2004 with an aim to understand various oceanographic processes in different water regime and their effects and changes both in space and time. Accordingly a number of surface and sub surface sediment samples were collected along a north-south transect between 80° E and 40° E longitude.

In order to assess the intriguing relationship between isotopic composition of planktic foraminifera and the changes that occur across this transect in the gradient of sea surface salinity, we particularly explore the trends in the latitudinal distribution of δ^{18}O *Globigerina bulloides* and near sea surface salinity.

MATERIALS AND METHODS

A total of nineteen surface sediment samples were collected onboard ORV *Sagar Kanya* between 1.92° N and 55.01° S latitude in the Indian Ocean sector of Southern Ocean (Fig.1). Since, all the sediment samples were collected from above the calcium carbonate compensation depth (CCD) and foraminiferal lysocline (4,400-4,700 m water depth; Banakar et al., 1998), therefore, the dissolution effect on the samples may be ruled out. Immediately all the sediment samples (top 1 cm of the sediment core/grab) were stained with Rose Bengal and preserved in 10% formalin to differentiate living specimens of benthic foraminifera. The presence of living benthic foraminiferal specimen at all the stations indicates presence and recovery of surface sediment samples. Accordingly the surface hydrographic properties were considered for inter-comparison assuming that the surface sediment samples are the representative of the modern time. All the sediment samples were processed as per standard procedure. An appropriate

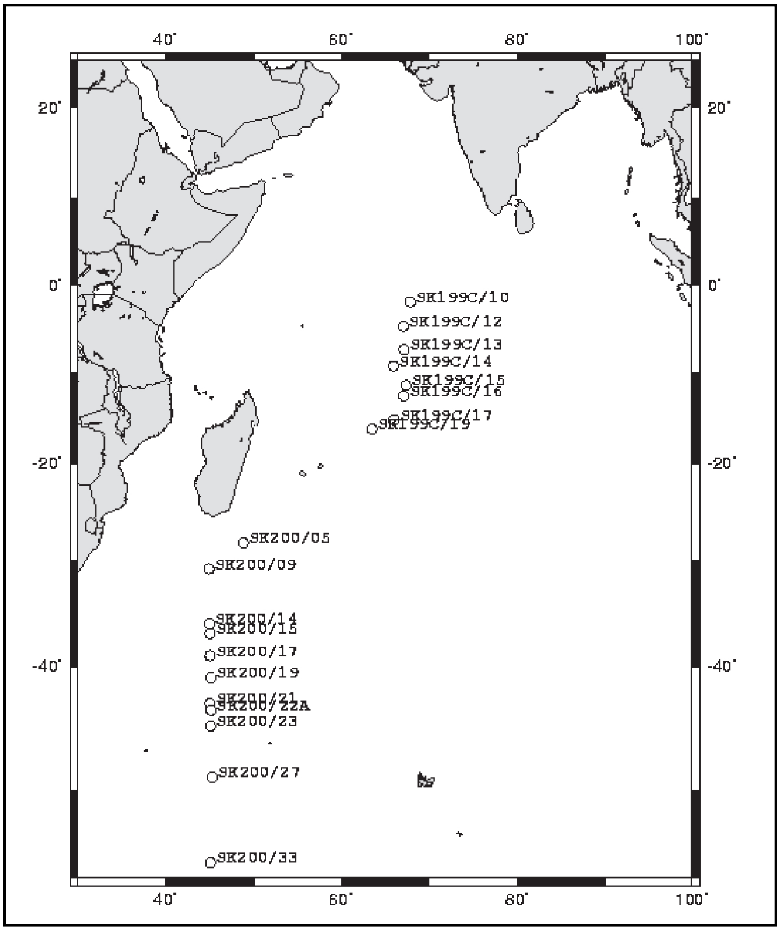

Figure 1. Locations of grab and Piston corer samples. (**o** = geographical location of the sampling station).

amount of sediment from each sample was dried overnight at 45°C. The sediments were sieved through 63μm sieve. Plus 63μm fraction was dried and transferred to plastic vials. From the dried $>63\mu$m fraction, a representative aliquot was taken by quartering and coning, to pick 10-12 mature specimens of *G. bulloides* for stable isotopic (oxygen) analyses. *G. bulloides* species was selected for the isotopic analysis because of its ubiquitous presence in all the samples. To determine oxygen isotope ratios of *G. bulloides*, the properly cleaned specimen were analysed through a Finnigan MAT 251 isotope ratio gas mass spectrometer coupled to an automatic carbonate preparation device (Kiel I) and calibrated via NBS 19 to the PDB scale at the Alfred Wegener Institute for Polar and Marine Research, Germany. The values are given in d-notation versus VPDB (Vienna Pee Dee Belemnite). Precision of oxygen measurements based on repeated analyses of a laboratory standard over a one-year-period was better than 0.09‰ for oxygen. Since planktic foraminifera in recent sediment in general have $^{18}O/^{16}O$ ratios consistent with growth in isotopic equilibrium with sea water at or near the sea surface (Woodruff, Savin & Douglas 1980; Curry & Mathews 1981), the near sea surface salinity was measured using CTD all along the transect at designated station for inter comparison. The correlation coefficient of these two parameters in different latitudinal zones was calculated and plotted using Excel software.

RESULTS AND DISCUSSION

Fig.2a shows that the minimum value of $\delta^{18}O$ is -1.53 ‰, recorded at station SK 199C/14, whereas it reaches to the maximum (3.138 ‰) at station SK 200/33. Similarly the minimum near sea surface salinity recorded in this transect is 33.7 (at station SK200/21) whereas maximum salinity (35.7) was recorded at station SK200/14 (Fig.2 b). It is also evident from figs. 2 a-b that both these parameters are apparently showing peculiar trends in two distinct latitudinal regime which has been categorized here as Zone- A (between 1.02° S and 31.00° S latitude) and Zone- B

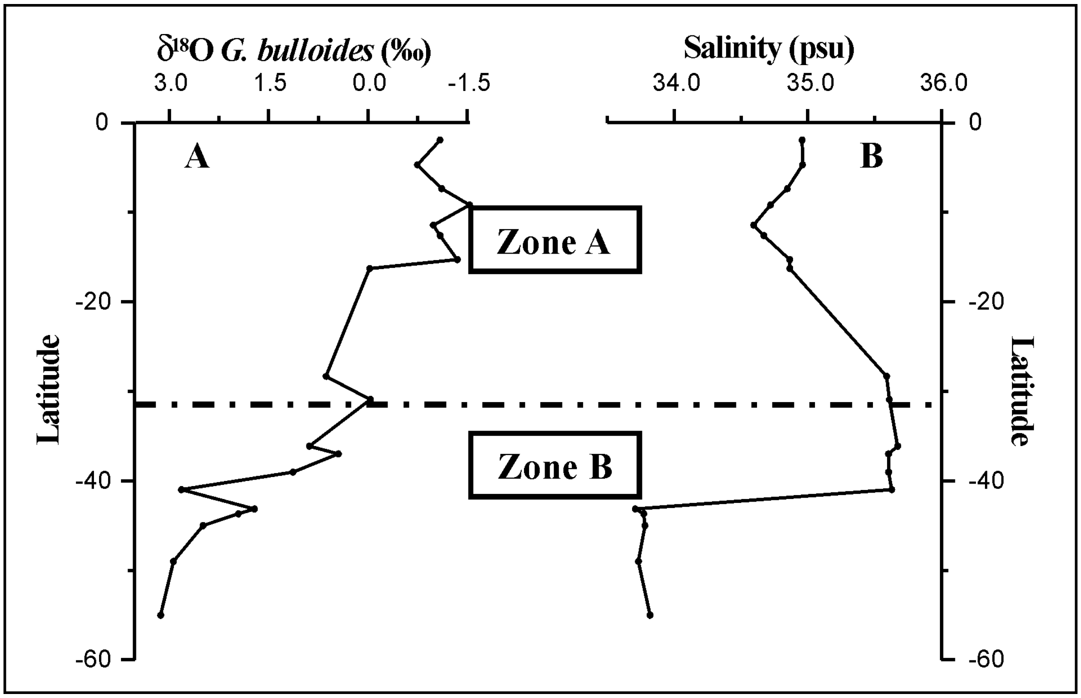

Figure 2. Latitudinal changes of $d^{18}O$ in *Globigerina bulloides* (A), and salinity of near sea surface water (B). The horizontal dotted line marks the zones A and B with different relationship between salinity and $d^{18}O$ in *Globigerina bulloides*.

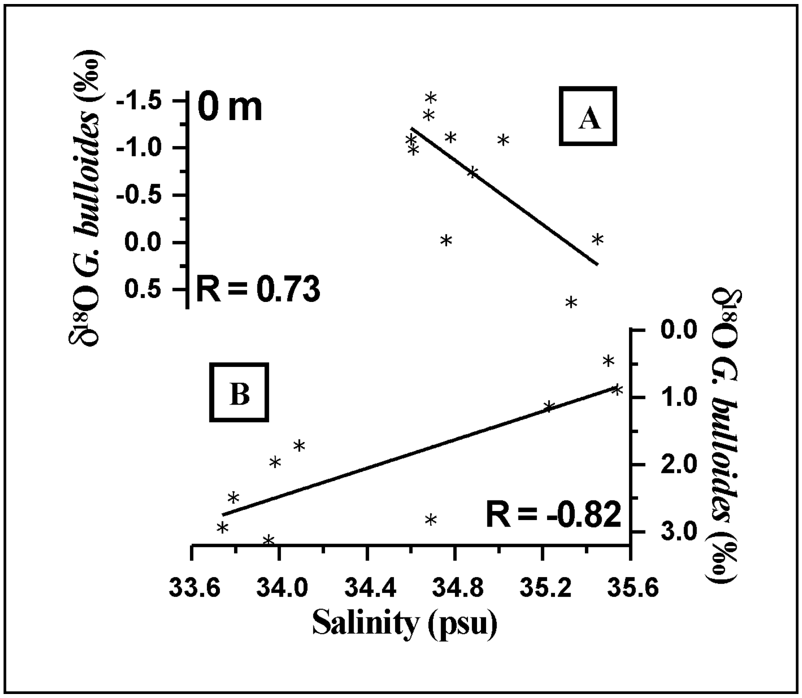

Figure 3. Graph shows the relationship between seawater oxygen isotopic composition and salinity in the southwestern Indian Ocean. Figure 3A shows the direct relationship between $d^{18}O$ and near sea surface salinity (R = +0.73) in Zone- A, whereas Figure 3B shows the inverse relationship between $d^{18}O$ and near sea surface salinity (R = -0.82) in Zone- B.

(between 31.00° S and 55.00° S latitude) (Fig. 2). It can be seen in figures 2A-B that in Zone- A, $\delta^{18}O$ values fluctuate between -1.53 and -0.77‰ and follow a trend similar to that of salinity variations. The direct correlation between these two parameters (R = +0.73) is reasonably good (Fig. 3A). On the contrary, it is interesting to note that in Zone- B (further south of around 31° S latitude) the salinity profile shows a drastic fall followed by a marginally increasing trend but the $\delta^{18}O$ values continues to maintain an increasing trend, thereby suggesting a rather inverse relationship. The correlation coefficient of the two parameters (salinity vs $\delta^{18}O$) in Zone- B (R = -0.82) further confirms such an inverse relationship between the two. (Fig.3B). The latitudinal change in relationship between salinity and oxygen isotopic composition of *G. bulloides* probably shows the complex influence of various environmental factors on the oxygen isotopic composition of the seawater, a measure of seawater salinity (Peros et al., 2007).

A general progressive increase (from lower to higher latitude in southern hemisphere) in $\delta^{18}O$ values in tandem with salinity variation up to around 31°S latitude in the study area could probably arise because of gradual aging (resulting in increase in salinity) of the Indian Central Water (ICW) and Australasian Mediterranean Water (AAMW) that occupies the thermocline and larger part of the water above thermocline in the Indian Ocean (Wyrtki 1971).

Fig.2 further shows that the salinity values after a sharp decline fluctuate in a narrow range, while $\delta^{18}O$ values show a continued increasing trend further south of 31°S latitude. Does it imply that as we move towards higher latitude (further south of 31°S latitude) the salinity does not hold much control on the $d^{18}O$ fractionation in the foraminiferal tests? Perhaps the change in the salinity of the surface waters seems to be underestimated by $\delta^{18}O$ values of *G. bulloides*. Does it further imply that $\delta^{18}O$ of planktic foraminifera *G. bulloides* may not incorporate the changes in seawater characteristics as a result of sea ice formation and melting? It appears that while these processes affect the sea surface salinity and other oceanographic conditions of higher latitude regions, they do not necessarily change the $\delta^{18}O$ of sea water as much as evaporation and precipitation (Craig & Gordon 1965; Matsumoto, Lynch & Anderson 2001).

According to Craig & Gordon (1965), the processes affecting the relationship between salinity and water isotopes in principle are evaporation and precipitation that differ according to oceanographic region and latitude. It was further opined that in higher latitudes, by freezing of ocean surface water, sea ice releases brines and increases salinity of the water. Due to a very small isotopic fractionation between water and ice no depletion of water $\delta^{18}O$ accompanies the salinity increase. This results in an essentially zero slope in $\delta^{18}O$ versus salinity plot (Craig & Gordon 1965). Probably a combination of such peculiar processes leads to the change in relationship between salinity and $\delta^{18}O$ *G. bulloides* towards higher southern latitudes in the study area.

Based on the data discussed here, it appears that perhaps salinity does not play a direct and governing role in influencing the $\delta^{18}O$ of *G. bulloides* tests in higher latitude regions. The preliminary inferences drawn in this study are at tandem with the findings of earlier studies which pointed out that the $\delta^{18}O$ of foraminiferal calcite near the Antarctica is not related to density in a straight forward way, as it is in the warm waters of the world ocean (Lynch-Stieglitz, Curry & Slowey 1999).

CONCLUSIONS

Based on this study carried out to understand the relationship between near-surface seawater salinity and $\delta^{18}O$ *G. bulloides* it is observed that in the southwestern Indian Ocean, upto around 31° S latitude $\delta^{18}O$ *G. bulloides* becomes progressively heavier with increasing salinity of the ambient water mass, whereas beyond 31° S (further south) latitude, *G. bulloides* oxygen isotopic composition becomes heavier with decrease in seawater salinity. However, to further understand the intriguing interrelationship of oxygen isotopic fractionation and sea salinity in higher latitudes and to augment this study further, a number of transects in and around the study area (different sector of Southern Ocean) are proposed for similar investigations. In order to further augment our inferences it is proposed to calculate seawater salinity from the *G. bulloides* oxygen isotopic ratio and sea water temperature and compare the estimated values with the physical data of salinity.

ACKNOWLEDGEMENTS

We are grateful to Dr. P.S. Goel, Secretary, MoES and Shri Rasik Ravindra, Director, NCAOR for their kind support and encouragement to publish the results. Prof. A. Mackensen and Laboratory staff at Alfred Wegener Institute for Polar and Marine Research Bremerhaven, Germany are thankfully acknowledged for providing facilities for oxygen isotope analyses. Fellow PESO members, Master, officers and crew of ORV *Sagar Kanya* are acknowledged for providing logistics support during the collection of the samples.

REFERENCES

Banakar, V.K., Parthiban, G., Pattan, J.N. & Jauhari, P., 1998. Chemistry of surface sediment along a north south transect across the equator in the central Indian basin: an assessment of biogenic and detrital influences on elemental burial of the sea floor, Chem. Geo., 147, 217-232.

Clifford, M.A., 1983. A descriptive study of the zonation of the Antarctic Circumpolar Current and its relation to wind stress and ice cover, 93 pp. Unpublished MS thesis, Texas A&M University.

Craig, H. & Gordon, L., 1965. Deuterium and oxygen – 18 variations in the oceans and marine atmosphere, In Tongiorgi, E (ed), Stable Isotopes in Oceanographic studies and Pleotemperatures. SPOLETO, CNR, Pisa, p. 1-122.

Curry, W.B. & Mathews, R.K., 1981. Paleo-oceanographic utility of oxygen isotopic measurements on planktonic foraminifera: Indian Ocean core top evidence, Paleogeo. Paleoclimat. Paleoeco., 33, 173-181.

Deacon, G.E.R., 1933. A general account of the hydrology of the Southern Atlantic Ocean, Discovery Rep., 7, 171-238.

Deacon, G.E.R., 1937. The hydrology of the Southern Ocean, Discovery Rep., 15, 1-24.

Hofmann, E.E., 1985. The large-scale horizontal structure of the Antarctic circumpolar current from FGGE drifters, Jour. of Geophy. Res., 90, 7087-7097.

Lynch-Stieglitz, J., Curry, W.B. & Slowey, N.C., 1999. A geostrophic transport estimate for the Florida Current from the oxygen isotope composition of benthic foraminifera, Paleoceanography, 14, 360-373.

Mackensen, A., Hubberten, H.W., Scheele, N. & Schlitza, R., 1996. Decoupling of $\delta^{13}C$ CO_2 and phosphate in Recent Weddell Sea Deep and Bottom Water: Implications for glacial Southern Ocean paleoceanography, Palaeoceanography, 1, 203-215.

Mackensen, A., 2001. Oxygen and carbon stable isotopes tracers of Weddel Sea water masses: New data and some paleoceanographic implications, Deep Sea Res., 1, 1401-1422.

Matsumoto, K., Lynch-Stieglitz, J. & Anderson, R.F., 2001. Similar glacial and Holocene Southern Ocean hydrography, Paleoceanography, 16, 1-10.

Orsi, A.H., Whitworth, T. & Nowlin Jr., W.D., 1995. On the meriodinal extent and fronts of the Antarctic Circumpolar Current, Deep Sea Res., 42, 641-673.

Peros, M.C., Reinhardt, E.G., Schwarcz, H.P. & Davis, A.M., 2007. High-resolution paleosalinity reconstruction from Laguna de la Leche, north coastal Cuba, using Sr, O, and C isotopes. Palaeogeogr., Palaeoclimatol., Palaeoecol., 245, 535-550.

Woodruff, F., Savin, S.M. & Douglas, R.G., 1980. Biological fractionations of Oxygen and Carbon isotopes by recent benthic foraminifera, Mar. Micropal., 5, 3-11.

Wyrtki, K., 1971. Oceanographic Atlas of the International Indian Ocean Expedition, Natl. Sci. Found., Washington D.C., p. 531.

(Accepted 2007 May 4. Received 2007 March 15; in original form 2007 January 29)

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