Cosmopolitanism of the planktic foraminiferal species *Globigerinita glutinata* – A testimony by Q-mode cluster analysis

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***Abstract*–**Planktic foraminifera species *Globigerinita glutinata* (Egger, 1895) was analyzed from 22 surface sediment samples from 9.69° N to 55.01° S north-south stretch along the Indian Ocean. Different morphological parameters; *viz.* average size, mean proloculus size, number of chamber and coiling direction of *G. glutinata* were measured and this data were analyzed using a Q-mode cluster analysis. Samples were differentiated into two main clusters, and eventually five sub-clusters. Despite these clusters are defined by particular morphological characters of the species, there is no ecological control for the morphological variations. The study suggests that the ecological parameters does not have any major role on the morphological variations of planktic foraminiferal species *G. glutinata*. This signifies the cosmopolitanism of this species.

Keywords*–Globigerinita glutinata*, morphological parameters, ecological parameters, cosmopolitan species

I. INTRODUCTION

UNDERSTANDING the distribution pattern of planktic foraminifera, in assemblage or specific species and its morphological variations in present environments helps to interpret the fossil assemblages to decipher the paleoclimate. The distributional patterns and morphology of planktic foraminifera are controlled by the hydrological parameters, *viz.* temperature, salinity, nutrients, concentration of dissolved oxygen etc., those are dependable on the latitudinal changes [1], [2].

Morphological variations of some planktic foraminifers are well recorded from the modern sediments as a function of biogeography, as well as from the fossil record, as evolution through time [3]. It was proved that such morphological changes can be attributed to either spatial or temporal environmental variations, which have been shown to influence the direction and rate of evolution within a single species or lineage [4].

Along a long stretch of oceanic transect witnessing varied oceanographic conditions and distinct water-masses, one can postulate an influences of physico-chemical properties of ambient water masses on the various morphological features of planktic foraminifera [1], [2].

Keeping the above points in mind, in the present study we have tried to notice the morphological variability in the calcareous shell of planktic foraminiferal species *Globigerinita glutinata* in surface sediments along a North-South transect in South-western Indian Ocean. Though reference [5] classified this species as subpolar one, but later this species was considered as cosmopolitan one spreading within a wide range of temperature and salinity [6], [7]. For this reason, this species evoke a great interest for paleoclimatic studies over a wide range of water masses all over the world [8]-[13].

This study attempts to understand the relation between morphological features of planktic foraminiferal species *Globigerinita glutinata* and various hydrological parameters of ambient water masses encountered along north-south transect in Indian Ocean considered for the present study by applying Q-mode cluster analyses to the data generated on morphological characteristics to arrive at broader groups (clusters) which could be classified on the basis of external morphological features of the tests.

II. THE STUDY AREA

THE sampling stations for the present study represent different latitudinal belt, which can be divided into several zoogeographic provinces which are primarily influenced by ecology and climate, *viz.* tropical, subtropical, transitional and sub Antarctic [6], [14]-[17]. Southern Ocean remains an important study area for global climate research and can be divided into three zones based on the dominant dynamics: The Western Boundary Current (WBC) zone (35°-45° S), the Antarctic Circumpolar Current (ACC) zone (45°-60° S) and the Seasonal Sea Ice (SSI) zone (60°-75° S). The WBC zone contains a number of energetic western boundary currents, such as the Agulhas Current, the Brazil/Malvinas Current and the East Australia Current. Hydrographic conditions in Southern Ocean (SO) are modulated by an eastward flowing Antarctic Circumpolar

Current (ACC) which is embedded with numerous circumpolar fronts [18], [19].

However, the western part of the Southern Indian Ocean which gets heat largely from the warm western boundary current has greater importance to largest air-sea heat exchange in the Southern Ocean [20]. The hydrological fronts and freshwater input along 62° E and 30° E meridional sections were computed [21] which emphasized that the areas west of the Crozet Plateau and east of the Kerguelen–Amsterdam passage are the key regions where the fronts confluence and split again. The frontal systems distinguish the different regimes of cold Antarctic waters from the warmer and saltier waters of the subtropical regime. Solar insolation warms the upper ocean and the winds provide momentum to help maintain the large-scale ocean circulation and control cooling by evaporation. Typical XBT survey shows that the seasonal thermocline extended from 40 to 150 m in (31-39º S) subtropical waters [19]. Agulhas Return Front (ARF), Southern Subtropical Front (SSTF) and Northern Subantarctic Front (NSAF) were identified as a merged front between 40°15′ and 43° S suggesting that isotherms representing the merged frontal system (ARF+SSTF+SAF1) exhibited temperature variation from 19 to 10° C while the isohalines demarcated the merged frontal system with a salinity drop from 35.54–34.11 across ~3° latitude [19] which was located to the north of the Crozet Plateau as the triple frontal system.

The position of Southern Sub Antarctic Front was identified between 47° and 48° S (between 6 and 7° C isotherms). The Polar Front (PF1) was identified between 49° and 50° S (isotherms varied from 5 to 4° C) and at the northern limit of 2° C isotherm below 200 m. Southern Polar Front (PF2) was identified between 52° and 54° S (temperature range 3-2° C). The water depth of Antarctica Intermediate Water (AAIW) is about ~1150 and ~1200 m and this water mass can be identified by its properties such as, temperature ~4.4º C, salinity (minimum) ~34.42, having density about 27.24 kg m^{-3} in the northern front of subtropical zone [18].

Circumpolar Deep Water in the study area is identified with its characteristic features such as temperature ~2° C; salinity ~34.77, and density ~27.8 kg m^{-3}. It occupies the depth range between 2000-3800 m north of 45° S and rises sharply to shallower depths south of the frontal zone. North Atlantic Deep Water (NADW) with higher salinities (~34.8) transported from the South Atlantic to the southwestern corner of the Indian Ocean, is assumed to be strongly blocked from reaching east of about 45° E, by the Madagascar ridge [22]. Below the CDW, the decreased temperature and salinity is assumed to indicate the influence of Antarctica Bottom Water (AABW). AABW at the depth of 4100 to 4700 m with a temperature of ~ −0.165 to −0.62° C, salinity ~34.67 to 34.65 and density ~27.85 to 27.86 kg m^{-3} is noticed between 49° to 56° S[23] [19]. The barotropic Antarctic Circumpolar Current (ACC) reaches the ocean floor and is able to mix efficiently the North Atlantic Deep Water (NADW) and deep waters from Indian and Pacific Oceans. The mixture of these deep waters, the Circumpolar Deep Waters (CDW), then spreads back in to other oceans basins.

It is well known that Antarctica Bottom Water and Circumpolar Deep Water (CDW) enter the Indian Ocean in the west off Madagascar and East Africa, and in the east along the Ninety East Ridge [23], [24]. Furthermore, deep upwelling across the area north of 18° S with an intensity of about 4 x 10^{-7} m/s, about three times larger than estimated for the Pacific and Atlantic Oceans has been noticed earlier [24]. A very strong, deep, meridional overturning cell, consisting of an inflow of 27±10 Sv below about 1800 m near 32º S and outflow above that depth was augmented by an Indonesian Throughflow of 6.6 Sv has also been noticed [22]. The overturning circulation carries layers of warm near-surface water and cold deep water in alternate directions thereby, transporting heat along with allied properties. The Southern Ocean plays a unique role in the global scale overturning circulation as well due to the circumpolar connection in the Southern Ocean. Water found at intermediate and abyssal depths at low latitudes rises towards the surface in the Southern Ocean. Deep water that upwells closer to Antarctica is cooled by the cold air blowing off the continent and its salinity is increased by brine released during sea ice formation. The dense water produced in this way sinks near the continental margin of Antarctica and returns to the north in deep currents flowing along the sea floor.

III. MATERIALS AND METHODS

SEDIMENT samples along a north-south transect between 9.69° N to 55.01° S latitude and 80° E to 40° E longitude, in the Indian Ocean Sector of the Southern Ocean were collected, during Pilot expedition to Southern Ocean (PESO), onboard ORV *Sagar Kanya* (the 199C and 200^{th} cruises). A total of twenty two surface sediment samples was selected for using in the present study (Figure 1).

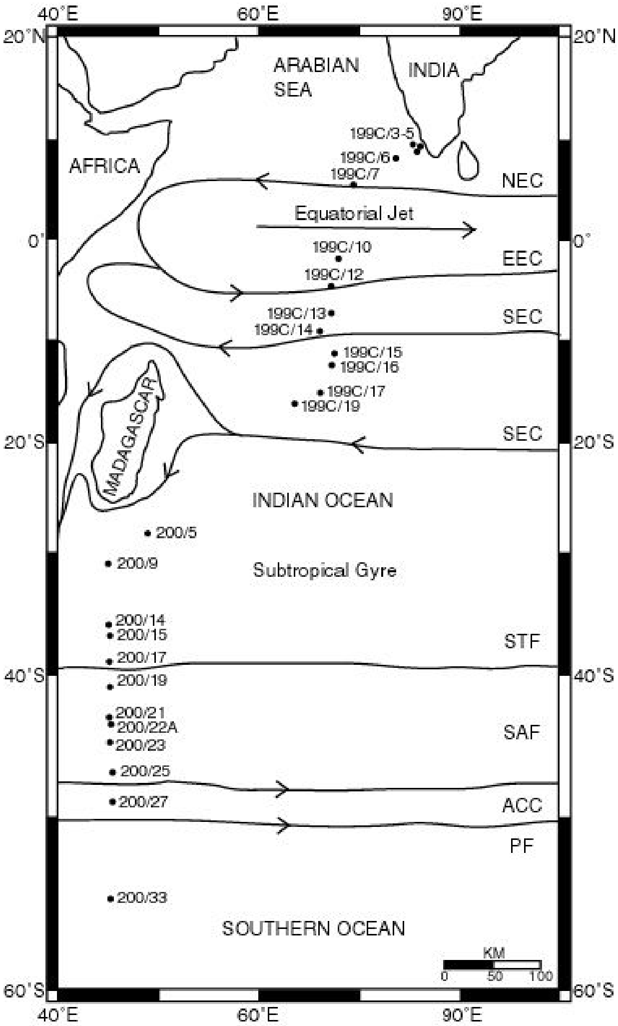

Fig. 1 Locations of sampling stations along North-South transect in South-western Indian Ocean

All the twenty two sediment samples were processed following the standard procedure. Approximately 2-3 gm of sediment from each sample was dried overnight at 45° C. Dried sediment samples were soaked in water and subsequently treated with sodium hexa-metaphosphate in order to dissociate clay lumps. The treated sediments were sieved over 63 µm sieve with a special care to avoid the breakage of foraminifera test. Plus 63 µm fraction was dried and transferred to plastic vials. The plus 63 µm fraction was dry sieved over 125 µm sieve and an aliquot was taken by quartering and coning from this plus 125 µm, to pick an average of 40 specimens of planktic foraminiferal species *Globigerinita glutinata* (Egger, 1895). The morphological features, longest length of the test (test size), longest length of the first chamber (mean proloculus size), total number of chambers, coiling direction of the this species was observed and measured under a stereo zoom microscope using a calibrated scale with divisions of 14 µ. The data thus obtained was subjected to Q-mode cluster analysis, using the software STATISTICA for windows, version 5.0. The tree-clustering analysis was performed using weighted pair group averaging method. The total number of morphological parameters was chosen as the variables to increase the precision for the analysis. The results of cluster analysis were plotted in the form of a two-dimensional hierarchy dendrogram wherein locations were presented along X-axis while similarity level is plotted on Y-axis.

IV. RESULTS

THE Q-mode cluster analysis classified the samples into two homogeneous clusters (A & B) under the linkage distance 50 (Figure 2). Clusters A and B were in turn subdivided into sub-clusters A_1 & A_2 and B_1, B_2 & B_3 respectively under the linkage distance 30.

Cluster A comprises total 5 samples; three among them fall between the latitudes 9.4051°N and 9.179°S (tropical zone) while rest two are within the latitudes 40.9813°S and 47.1048°S (towards sub-polar zone). This cluster shows average test size of 228.94 µm (range 205.12-247.5 µm), average mean proloculus size of 10.34 µm (range 9.53-11.37 µm), average number of chambers of 11.79 (range 10.8-13.5) and average dextrality of 22.67% (range 0-50%). In ecological parameters, the sea surface temperature and sea surface salinity shows the range of the values with 23.71-4.56°C (average 16.46°C) and 33.9-35.17 psu (average 34.74 psu) respectively. On the other hand, the nitrate content ranges from 0.31 µmol to 4.86 µmol with an average of 1.91 µmol; while phosphate content shows a range of 1.57 µmol to 8.42 µmol with an average of 3.14 µmol; and total nutrients show a range of 2.01 µmol to 11.22 µmol with an average of 5.05 µmol. The dissolved oxygen ranges from 4.43 mg/l to 7.1 mg/l with an average 5.33 mg/l. Cluster A is further subdivided into two sub-clusters, namely A_1 and A_2.

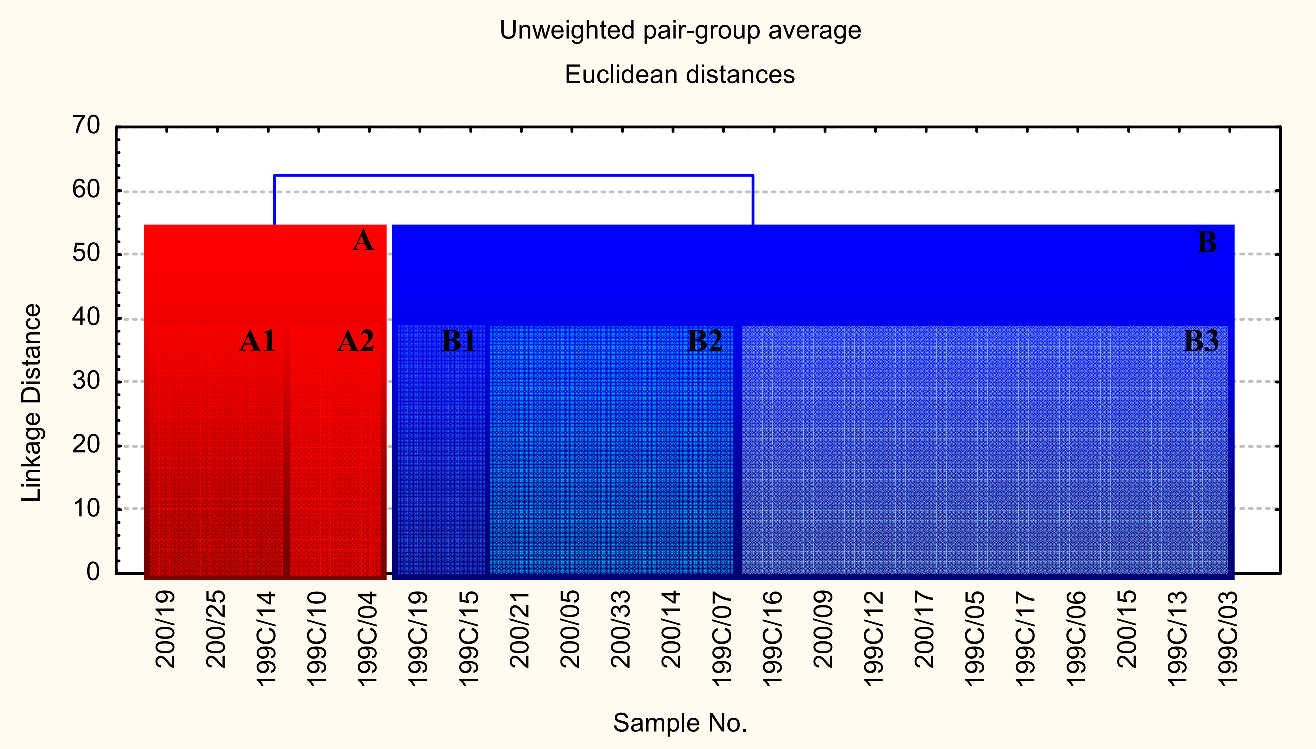

Fig. 2 Cluster analysis of four parameters (Coiling Direction, MPS, Average Test Size and Number of Chamber) of *N. glutinata*

located within equatorial zone (9.179°S latitude) and other two located within sub-polar area (40.9813°S and 47.1048°S latitudes). This sub-cluster shows the average test size ranged between 235.03 and 247.50 µm with an average of 241.26 µm and mean proloculus size ranges from 9.53 to 9.90 µm with an average 9.78 µm. Number of chamber varies between 10.80 and 13.50 with an average of 12.10, while dextrality falls within 30.00 and 50.00% with an average of 37.78%. In case of ecological parameters, this cluster shows a range of sea surface temperature and sea surface salinity within 4.56°C and 19.93°C (average 12.38°C), and within 33.90 psu and 34.93 psu (average 34.53 psu), respectively. The values of nitrate and phosphate vary from 0.38 to 2.80 µmol (average 1.47 µmol) and from 1.57 to 8.42 µmol (average 3.88 µmol), respectively, which collectively range from 2.01 to 11.22 µmol (average 5.34 µmol). Dissolved oxygen ranged from 4.54 mg/l to 7.10 mg/l, with an average of 5.90 mg/l.

Sub-cluster A_2, represented by only two samples is located within equatorial region (latitudes 9.4051°N and 1.923°S). This sub-cluster shows average test size ranging from 205.12 µm to 215.8 µm, with an average of 210.46 µm; mean proloculus size ranging from 11.00 µm to11.37 µm, with an average of 11.18 µm); number of chamber ranging from 11.00 to 11.67, with an average of 11.33 and dextrality falling 0%. In case of ecological parameters, the sea surface temperature and salinity shows a range of 21.45°C-23.71°C and 34.95-35.17 psu, respectively, with an average 22.58°C and 35.06 psu, respectively. The dissolved oxygen shows a range of value with 4.43-4.53 mg/l (average 4.48 mg/l). In case of nutrients, this sub-cluster shows a range of 2.33-6.90 µmol, average 4.62 µmol); nitrate ranges from

Cluster B comprises of 17 samples spread over a broader range of the study area (9.5045°N to 55.0065°S latitudes). This cluster shows variations of average test size between 188.03 µm and 247.24 µm with an average of 207.33 µm, mean proloculus size between 8.8 µm and 12.19 µm with an average of 10.4 µm, number of chamber between 9.5 and 12 with an average of 10.79 and dextral coiling between 35.71% and 100% with an average of 77.07%. The ecological parameters sea surface temperature ranges from 1.14°C to 24.23°C with an average of 18.83°C and sea surface salinity ranges from 33.53 psu to 35.51 psu with an average of 34.96 psu. The total nutrient values varied between 1.85 µmol and 11.58 µmol (average 4.95 µmol), while the dissolved oxygen ranged from 4.43 mg/l to 7.73 mg/l (average 5.11 mg/l). The nitrate values ranged from 0.3 µmol to 9.11 µmol (average 2.85 µmol), while phosphate values varied from 1.17 µmol to 5.95 µmol (average 2.28 µmol). Cluster B is further subdivided into three sub-clusters, namely B_1, B_2 and B_3.

Sub-cluster B1 consists of two samples, located at the latitudes of 11.4243°S and 16.2677°S. This sub-cluster shows the average test size ranged between 232.90 and 247.24 µm with an average of 240.07 µm and mean proloculus size ranges from 10.27 to 11.88 µm with an average 11.07 µm. Number of chamber varies between 9.8 and 11.17 with an average of 10.48, while dextrality falls within 80.00 and 83.33% with an average of 81.67%. In case of ecological parameters, this cluster shows a range of sea surface temperature and sea surface salinity within 21.18°C and 22.76°C (average 21.97°C), and within 34.88 psu and 35.01 psu (average 34.95 psu), respectively. The values of nitrate and phosphate vary from 0.37 to 0.41 µmol (average 0.39 µmol) and from 1.44 to 1.57 µmol (average 1.50 µmol), respectively, which collectively range from 1.85 to 1.94 µmol (average

1.89 μmol). Dissolved oxygen ranged from 4.55 mg/l to 4.7 mg/l, with an average of 4.63 mg/l.

Sub-cluster B_2, represented by five samples is distributed mainly between latitudes 28.3215°S and 55.0065°S, except one sample that falls at 5.5121°N. This sub-cluster shows average test size ranging between 192.3 and 214.74 μm, with an average of 203.29 μm and mean proloculus size ranging from 8.80 and 11.00 μm, with an average of 9.94 μm). On the other hand it shows number of chamber ranging from 95 to 11.5, with an average of 10.92 and dextrality ranging between 95% and 100%, with an average of 99%). In case of ecological parameters, the sea surface temperature and salinity shows a range of 1.14°C-23.85°C and 34.06-35.50 psu, respectively with an average 14.13°C and 34.93 psu, respectively. The dissolved oxygen show a range of value of 4.43-7.73 mg/l, with an average of 5.82 mg/l. In case of nutrients, this sub-cluster shows range of 2.08-11.55 μmol, with an average of 5.58 μmol; nitrate shows values with the range of 0.3-7.81 μmol and an average of 3.44 μmol, while phosphate shows values with the range of 1.17-3.74 μmol and an average of 2.14 μmol.

Sub-cluster B_3 consists of ten samples, located within a wide range of the latitudes of 9.5045°N and 39.0285°S. This sub-cluster is characterized by a range of average test size of 188.03-223.28 μm (average 202.81 μm) and dextrality with the range of 35.71%-80.00% (average 58.38%). It also shows a range of number of chambers with the range of 9.80-12.00, with an average of 10.79 and mean proloculus size with the range of 9.46-12.19 μm, with an average of 10.49 μm. In case of ecological parameters, this cluster shows a range of sea surface salinity from 33.53 psu to 35.51 psu (average 34.97 psu) and a range of sea surface temperature between 15.63°C and 24.23°C (average 20.55°C). The values of nitrate varies from 0.3 to 9.11 μmol (average 3.09 μmol), while phosphate shows a range of 1.42-5.95 μmol (average 2.54 μmol), and collectively nutrients show a range of values from 1.86 to 11.58 μmol (average 5.28 μmol). Dissolved oxygen shows a range of values of 4.47 mg/l to 5.61 mg/l (average 4.82 mg/l).

V. Discussion

BESIDES the ecological distributional study, foraminiferal data were used extensively in statistical analysis for envrionmental studies [25]; e.g. biofacies analysis [26], [27], evaluation of fossil assemblages [28], taxonomy [29], diversity and abundance [30] and marine environmental analysis [31]-[35]. More precisely, the cluster analysis of planktonic foraminifera was also used to classify them with different water masses [36]-[40]. Following these paths, the present study dealt with the cluster analysis applied on the morphological data of planktic foraminifera *Globigerinita glutinata*.

Globigerinita glutinata is considered as a cosmopolitan species spreading over a wide range of temperatures and salinities [6], [7], [41]. *Globigerinita glutinata*'s wide latitudinal distribution riches its maxima at high latitudes and also in upwelling regions at low latitudes [7], [42]. In contrast, reference [43] noted that in the subpolar eastern North Atlantic, *G. glutinata* shows more subtle changes that do not appear to be related to the large-scale fluctuations associated with other foraminiferal species.

Previously it has observed that the temperature and salinity are the most important influencing factors for the size variation in test of the planktic foraminifers [44]-[47]. But reference [48] stated that shell-mass accumulation rates and the mean size of *G. glutinata* are related to upwelling intensity in the Arabian Sea.

Proloculus (the first chamber) of foraminifers has a large influence on the final size as it has a direct relation with geometry of the size of the proloculus [49]-[50]. The coiling directions in foraminifera are the widely studied morphological parameters [51]-[57] and are proposed to be used as indicators of thermal condition of the ambient water. Generally coiling direction varies from species to species [58]; sometimes even same species may exhibit different response in different geographical locations [52], [59]-[61], [36].The Q-mode cluster analysis on the samples from the north-south stretch in southern Indian Ocean shows that the morphological characters of *G. glutinata* do not exhibit any relation with different ecological parameters in different regions. Two clusters and subsequent five sub-clusters show no definite ecological control over any cluster or sub-cluster. Cluster A spreads over a wide latitudinal range from 9.4051°N to 47.1048°S, exhibiting a wide variety of temperature ranged from 23.71°C (in SK 199C/4) to 4.56°C (in SK 200/25) as well as salinity ranged from 35.17 psu (in SK 199C/10) to 33.90 psu (in SK 200/25).

VI. Conclusions

THE results of present study indicate that the ecological parameters, such as sea surface temperature, sea surface salinity, dissolved oxygen and nutrients does not play any role to control the morphological characteristics of planktic foraminiferal species *G. glutinata*. In order to further augment our findings a number of transects from geographically distinct regions are required to be investigated for similar aspects.

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