Journal of Climate Change, Vol. 2, No. 2 (2016), pp. 99–110.
DOI 10.3233/JCC-160021

Significance of *Globigerina Bulloides* D'orbigny: A Foraminiferal Proxy for Palaeomonsoon and Past Upwelling Records

Ankush Shrivastav[1], Ashutosh Kumar Singh[1], Devesh K. Sinha[1]*, Tushar Kaushik[2], Vikram Pratap Singh[3] and Kirtiranjan Mallick[4]

[1]Department of Geology, University of Delhi, Delhi – 110007
[2]Agharkar Research Institute, Gopal Ganesh Agarkar Road, Pune – 411004, Maharashtra
[3]Department of Geology, Indira Gandhi National Tribal University, Amarkantak, MP
[4]Department of Geology, Utkal University, Vani Vihar, Bhubaneshwar, Odisha
✉ deeveshksinha@yahoo.com

Received May 3, 2016; revised and accepted June 1, 2016

Abstract: The planktic foraminiferal species *Globigerina bulloides* is an important proxy for inferring past upwelling intensity and related monsoonal variability. Besides its relative abundance, the stable isotopic composition of its test has been extensively used for surface water temperature estimation and paleoproductivity changes. Enough confusion still remains regarding identification of this taxon due to wide range of variation in morphological parameters. Due to this, several species have been erected including *Globigerina quadrilatera*, *Globigerina megastoma, Globigerina bermudezi, Globigerina cariacoensis* and *Globigerina riveroe*. Some are considered to be phenotypic variants by various authors whilst separate species by others. Considering this, we strongly favour picking up of single morphotype of *Globigerina bulloides* for isotopic analyses and advocate for a detailed genetic study of various morphotypes to get enlightened picture of the species concept.

Keywords: *Globigerina bulloides*, Phenotypic variant, Paleoproductivity, Isotopic analysis, Upwelling.

Introduction

The optimal paleoceanographic and paleoclimatic use of any taxon depends on its accurate identification and inclusion of the specimens that do not confirm to the established limits of that taxon and that may adversely affect its use (Cifeli and Scott, 1986). The last few decades have witnessed tremendous progress in the taxonomic studies of Neogene planktic foraminifera (Lamb and Beared, 1972; Stainforth et al., 1975; Blow, 1979; Saito et al., 1976; Kennett & Srinivasan, 1983; Bolli and Saunders, 1985). The cores recovered by the Deep Sea Drilling Project and its successor Ocean Drilling Program have provided excellent opportunities to examine evolutionary trends in Neogene planktic foraminifera at high resolution. Additionally, the surface ultrastructural studies using the Scanning Electron Microscope have helped in a great way to further refine the taxonomy as the surface ultrastructures have been considered by a number of workers to represent conservative morphologic features within related species or genera (Parker, 1962; Lipps, 1966; Collen and Wella, 1973; Fleisher, 1974; Saito et al., 1976; Huang, 1981; Kennett and Srinivasan, 1983). The floating nature of the planktic foraminifera in surface ocean currents is an advantage to the

*Corresponding Author

paleoceanographers because their distribution in the oceanic sediments is like a snap-shot of the prevailing surface ocean circulation patterns. Planktic foraminifera as proxy for surface water paleoceanography has been further enhanced with the ambitious programme of Joint Global Ocean Flux Study which has enabled to verify the relationship between water mass properties, processes occurring in the oceans and related changes in the assemblages and abundances of certain planktic foraminifera (Thunell and Sautter, 1992; Curry et al., 1992). However, the basic prerequisite for using any planktic foraminiferal species for paleoceanographic or paleoclimatic interpretation is objectivity in taxonomy for comparison as the abundance and isotopic records generated by various workers to be compared to understand any causative factors for paleoceanographic and paleoclimatic changes.

Darling et al. (2006), based on genetic studies of left and right coiled varieties of *Neogloboquadrina pachyderma*, advocated separation of the two coiling varieties as separate species. This warrants a serious reconsideration of employing planktic foraminiferal abundance, stable isotopic data and other chemical proxies for paleoceanographic and paleoclimatic interpretations. Despite several studies devoted towards solving taxonomic problems related with planktic foraminifera, there is still enough confusion on the identity of some of the key planktic foraminiferal species for example *Globigerina bulloides* d'Orbigny, which is an important proxy for paleoceanographic and paleoclimatic changes. Lamb and Beard (1972) stated that *G. bulloides* was "a simple *Globigerine* much confused in the literature and because its simple morphology is commonly duplicated through homeomorphy, the species name has become a wastebasket taxon". In this paper we address the problem arising from the use of several variants of *Globigerina bulloides* by different authors, particularly in the light of extensive use of relative abundance of *Globigerina bulloides* and stable isotopic analyses of its test as proxy indicator of paleomonsoon (Anderson et al., 2002; Gupta et al., 2003). The taxonomy of *Globigerina bulloides* and its phenotypic variants have been discussed in this paper.

Globigerina bulloides as a Paleoceanographic and Paleoclimatic Proxy

Several studies have been carried out to observe the variation in palaeomonsoonal intensity by using relative abundance and isotopic analyses of planktic foraminiferal species *G. bulloides* d'Orbigny (Malmgren and Kennett, 1978; Naidu and Malmgren, 1996; Kroon and Darling, 1995). *G. bulloides* dominates planktic foraminiferal assemblages in the tropical upwelling regions of the Arabian Sea (Prell and Curry, 1981; Naidu et al., 1992) and in the Atlantic Ocean (Peterson et al., 1991). Thus, changes in the relative abundance and fluxes of *G. bulloides* in sediments have been used to infer past variations in upwelling and associated summer monsoon intensity in the Arabian Sea (Prell, 1984; Anderson and Prell, 1993; Naidu and Malmgren, 1996). *G. bulloides* is most abundant in water masses at high southern latitudes and has a distinct maximum in high northern latitudes and low latitude upwelling regions (Thiede and Junger, 1992). Its geographical distribution and associated data suggest a preference for productive environments (Brock et al., 1992; Duplessy et al., 1981; Hemleben et al., 1989; Kipp, 1976; Thiede, 1983; van Leeuwen, 1989; Zhang, 1985) where *G. bulloides* may be related to the phytoplankton bloom succession (Hilbrecht, 1996). The distribution and abundance of *G. bulloides* may be directly related to food availability rather than to a specific temperature range (Reynolds and Thunnel, 1985).

G. bulloides seems to be quite opportunistic occurring in local, nutrient-rich mixing zones and episodic phytoplankton blooms (Shulz et al., 1995). In addition to its abundance in upwelling regions, *G. bulloides* is a typical transitional to polar species and occurs in high abundances in these regions and is found mainly in, and above, thermoclines and its maximum in abundance is in the surface layers of the ocean exclusively in the euphotic zone (Hembleben et al., 1989; Hembleben and Bijma, 1994). Not only has the relative abundance of *G. bulloides* been established as an indicator of monsoonal upwelling, but also the larger abundance of the individuals with greater mean size indicates more fertile and upwelled surface waters (Malmgren and Kennett, 1978). In a typical coastal upwelling region western Arabian Sea, its relative abundance exceeds 60% (Anderson et al*.,* 2002) of the total planktic foraminiferal fauna. A good correlation is found between the maxima of *G. bulloides* and the highest concentration of organic material in the surface waters (Thiede and Junger, 1992). *G. bulloides* is more abundant in central upwelling zones and areas of high productivity (Brock et al., 1992). *G. bulloides* feeds on algal prey (Lee et al., 1966). This feeding strategy may explain why *Gg. bulloides* abundances are related to productive environments probably related to the phytoplankton dinoflagellates bloom occupying the centre of upwelling zones. This is also indicated in the biogeographical maps of Bé and Hutson (1977) in the area of upwelling in the Arabian Sea offshore from Somalia.

Important studies were made on the relationship between abundance of this species and Holocene monsoonal record (Prell and van Campo, 1986; Clemens et al., 1991; Anderson et al., 2002; Gupta et al., 2003). Sediment trap data from the western Arabian Sea show that the production of *G. bulloides* is highest during southwest monsoon season (Curry et al., 1992). Recently, Anderson et al. (2002) and Gupta et al. (2003) used *G. bulloides* counts from the Arabian Sea and interpreted increase in the Asian SW Monsoon during the past four centuries and linked the Holocene variations of the Southwest Monsoon with climatic changes in the North Atlantic. At a longer time scale Kroon et al. (1991) and Prell and Kutabach (1992) noted a marked increase in the percentage abundance of *G. bulloides* at 8.5 Ma in the Arabian Sea. These workers suggested that monsoon strengthened at 8.5 Ma at least in Southeast Asia. This finally led to serious thinking about the climate-tectonics relationship due to concomitant upliftment of the Tibetan plateau (Zhisheng et al., 2001) and its effect on Indian Monsoon. Thus the planktic foraminiferal species *Globigerina bulloides* has become very much significant and relevant in understanding causative factors for long and short term climatic change in general and monsoon in particular.

Problem with Identity of *Globigerina bulloides* and Related Species

The great variability found in *Globigerina bulloides* resulting from morphological variation (Plate 1) may make the delineation of this species difficult. The central form on which identification of a taxon depends has to be the primary type and comparison of the individuals with the type specimen (Cifeli and Scott, 1986). The degree of variability around the central type allowed in a taxon varies from one worker to another and thus much subjectivity is involved in assigning individuals to different species (Cifelli and Scott, 1986). The variation is triggered by environmental change and the course of variation, the resulting morphotypes will depend on the inherent genetic factors as well as external factor (Cifeli and Scott, 1986).

Phenotypic variation within a species of planktic foraminifera ought to be controlled by surface water oceanographic changes. Though *G. bulloides* has been used widely by paleoceanographers and paleoclimatologists world over, there are problems involved in identification of this species as it is morphologically very close to a number of other planktic foraminifera species including *Globigerina falconensis* Blow, *Globigerina umbilicata* Orr & Zaitzeff and *Globigerinella obesa* (Bolli). Besides, a number of species resembling *Gg. bulloides* have been erected from time to time by different workers including *Globigerina quadrilatera* Galloway & Wisseler (1927) (Pleistocene, California); *Globigerina megastoma* Earland (1934) (Late Pliocene to Recent, cool subtropical to subpolar, southern hemisphere); *Globigerina bermudezi* Seigle (1963) (Late Pleistocene to Recent Cariaco Basin and Caribean); *Globigerina cariacoensis* Rogl and Bolli (1973) (Late Pleistocene to Recent, Tropical Atlantic) and *Globigerina riveroe*, Bolli & Bermudez (1965) (Pliocene, Venezuela).

All these forms were considered by Kennett and Srinivasan (1983) to be phenotypic variants of *Globigerina* (*Globigerina*) *bulloides*. All these forms show a wide range of variations in the position and size of the aperture, the shape of the last chamber of the final whorl and height of the spire and there is no general agreement amongst various authors on including all in one species i.e. *Globigerina bulloides.* However, for a paleoceanographers employing the tests of *G. bulloides* for stable isotopic analyses, it is essential to pick up a population which consists of a single morphotype/ species to have reliable data. The need to generate vast amount of isotopic data by non-taxonomists, mostly utilizing foraminiferal tests for isotopic analyses, may lead to picking up of several variants of *Gg. bulloides* (considered by Kennett and Srinivasan, 1983) or several species of *Globigerina* (see Bolli and Saunders, 1985 for *Globigerina bermudezi*; Iaccarino, 1985 for *Globigerina megastoma*, *Globigerina riveroae*, and *Globigerina cariacoensis* resembling *G. bulloides*) for stable isotopic analyses. Two types of errors are possible. One is that mixed population of various morphotypes from the same sample are picked up for isotopic analyses and the other is with changing age of the sample certain morphotypes may dominate making the data further complicated. For example, *Globigerina cariacoensis* considered by Kennett and Srinivasan (1983) to be a phenotypic variant of *Gg bulloides* has been considered as separate species of *Globigerina* by Rögl and Bolli (1973), Selli et al. (1977), Colalongo and Sartoni (1979) and Iaccarino (1985).

The appearance of *Globigerina cariacoensis* was inferred to be an important stratigraphic event in recognizing the Pliocene-Pleistocene boundary (Poore and Berggren, 1975). In fact, the first occurrence of *Gg. cariacoensis* is the event which most closely approximates the Pliocene-Plesitocene boundary in Vrica Stratotype section in Calabria (Iaccarino, 1985). Another example is *Globigerina bermudezi* considered by Kennett and Srinivasan (1983) as a variant of *Gg. bulloides* but Bolli and Saunders (1985) considered it a separate species and gave its stratigraphic range restricted to Pleistocene. Keeping such stratigraphically younger variants (species?) of *Globigerina bulloides*, the likelihood of picking up a mixed population for isotopic analyses with range of variations cannot be ruled out. Many papers which report isotopic analyses and census data for *Gg. bulloides* do not provide details of variety picked, and the comparison of data generated world over by different workers using *Gg. bulloides* and its variants (species?) becomes convoluted. We have attempted here to provide description of each morphotypes as given in the literature (Table 1).

Problems Arising out of Picking up Mixed Population of Various Morphotypes of *Globigerina bulloides*

Specifically, the disequilibrium in oxygen isotopic ratios of $^{18}O/^{16}O$ derived from tests of different foraminiferal species poses problems when using isotopic ratios derived from two species as a proxy for oceanic temperature or for global ice volume. More problems arise in case of $\delta^{13}C$ values which is more prone to vital effect because of preferential intake of ^{12}C during metabolic process. Thus, if the various morphotypes of *Globigerina bulloides* (as considered by Kennett and Srinivasan, 1983) i.e. *Globigerina quadrilatera*, *Globigerina megastoma, Globigerina bermudezi, Globigerina cariacoensis* and *Globigerina riveroe* are different species as considered by several authors then their isotopic ratios would be different and clumping them together as *Globigerina bulloides* for isotopic analyses may lead to erroneous results. The isotopic disequilibrium in different species was originally attributed to unknown biological reasons. Since then, the term vital effect has evolved into a catch–all phrase in paleoclimatology for biologically mediated processes that are poorly understood (Cronin, 1999).

So far as the grouping of various morphotypes into a single species is concerned as in case of *Globigerina bulloides*, it is good to avoid too many names for little variations provided there is a degree of confidence in assigning various morphotypes as phenotypic variants of a single species. But the problem in paleontology is that the bio-species concept of interbreeding population cannot be verified and we cannot be sure that these all belong to one species or are different unless laboratory culturing techniques are applied or genetic studies are carried out on various morphotypes like those of Darling et al. (2006). This information is essential because the *Globigerina bulloides* test is counted as well as subjected to stable isotopic analyses and if at all these morphotypes are different species, however closely related, the phenomena of vital effect will be operative and the isotopic analyses of a population consisting of mixed population of various morphotypes would not give reliable results. We strongly argue in favour of picking up of one single morphotypes of *Globigerina bulloides* while subjecting the test for isotopic analyses and the paper must provide details of the morphotypes picked up. As the stable isotopic composition of the tests of *Gg. bulloides* as well as its relative abundance forms the central theme of a number of papers dealing with monsoonal upwelling, the correct identification of this species is essential. Keeping this in view we have discussed here the identity of *Globigerina bulloides* d'Orbigny and other planktic foraminiferal species closely resembling *Gg. bulloides* based on our own observation from DSDP sites 593, 594 and ODP sites 763A and 762B together with the previous literature available.

Systematic Description and Discussion on Various Morphotypes and Closely Related Species

Order: FORAMINIFERIDA Eichwald, 1830

Suborder: GLOBIGERININA Delage and Herouard, 1896

Superfamily: GLOBIGERINACEA Carpenter, Parker and Jones, 1862

Family: GLOBIGERINIDAE Carpenter, Parker and Jones, 1862

Subfamily: GLOBIGERININAE Carpenter, Parker and Jones, 1862

Genus: *Globigerina* (*Globigerina*) d'Orbigny, 1826

Type species: *Globigerina bulloides* d'Orbigny, 1826

Kennett and Srinivasan (1983) subdivided the genus *Globigerina* into *Globigerina* (*Globigerina*) and *Globigerina* (*Zeaglobigerina*) acknowledging *Globoturborotalita* Hofker to be a senior synonym of their *Zeaglobigerina* subgenus. This subdivision was based on the difference in surface ultrastructure

Table 1: Various morphotypes and species resembling *Globigerina bulloides*

Name of the species/ morphotypes	*Important characters*	*Ref*	*Remarks*
Globigerina bulloides d' Orbigny	Low trochospiral test, umbilical aperture, three to three and half chambers in the final whorl Plate 1, Fig.1.	1	This is the typical *Globigerina bulloides.*
Globigerina bemudezi Seiglie	Last and occasionally also the penultimate chamber is laterally narrower and at the same time extending toward umbilical side partly overhanging the wide umbilical pit. There is a tendency for the final chamber and occasionally also the penultimate one to become partly detached. Such detachment may also extend to the spiral side where irregularly shaped secondary sutures form.	2, 3	This was considered by Kennett and Srinivasan (1983) to be phenotypic variant of *Globigerina bulloides.*
Globigerina cariacoensis Rögl and Bolli	High to very high trochospire, fairly lobate equatorial periphery, loosely arranged globular chambers, last chamber tilted over the umbilicus, large umbilicus nearly quadrangular in outline, wide and low arched aperture. Differs from bermudezi in having high spire and less elongated final chamber.	2, 4	This was considered by Kennett and Srinivasan (1983) to be phenotypic variant of *Globigerina bulloides.* The appearance of *Gg. cariacoensis* is inferred to be an important stratigraphic event in recognizing Pliocene/ Pleistocene boundary in the type section of Vrica, Calabria, Italy.
Globigerina megastoma Earland	Total number of chambers less than *Gg. cariacoensis* and less wide aperture than *Gg. cariacoensis*. Other features same as *Gg. cariacoensis*.	2, 4	This was considered by Kennett and Srinivasan (1983) to be phenotypic variant of *Globigerina bulloides*.
Globigerina quadrilatera Galloway and Wissler	Final chamber is reduced in size and has a delicate wall structure and have smoother appearance. The reduced final chamber no longer follows the normal coiling pattern but is tilted towards the umbilicus.	2	This was considered by Kennett and Srinivasan (1983) to be phenotypic variant of *Globigerina bulloides.*
Globigerina riveroae Bolli and Bermudez	Tendency of the aperture to become extra umbilical. The final chamber is not hemispherical as is typical for *Globigerina bulloides* ss. but slightly compressed tangentially and thus shows sometimes a certain affinity to *Globigerina bermudezi.*	2	This was considered by Kennett and Srinivasan (1983) to be phenotypic variant of *Globigerina bulloides.*
Globigerina umbilicata Orr and Zaitzeff	It differs from Globigerina bulloides in exhibiting one or two more chambers in the final whorl, distinctly incised sutures on the spiral side and more conspicuous umbilicus.	1	Rögl and Bolli (1973) described forms intermediate between *Gg. bulloides* and *Gg. umbilicata*. Kennett and Srinivasan (1983) considered it as separate species.
Globigerina diplostoma Reuss	Differs from *Gg. bulloides* in a slower increase of chamber size. The last chamber is often of the same size or even smaller as compared with the penultimate.	5	Blow (1959) maintained that *Gg. diplostoma* is a different species than *Gg. bulloides*. Restricted to Miocene.

References: [1]Kennett and Srinivasan (1983). [2]Rögl and Bolli (1973). [3]Bolli and Saunders (1985). [4]Iaccarino (1985). [5]Rögl (1985).

of the members of the two groups. It can be observed that this is a brilliant example of the fact that surface ultrastructures are conservative morphological features within evolutionary lineages. *Globigerina* (*Globoturborotalia*) is characterized by a cancellate surface ultrastructure with regular sub-hexagonal pore pits, while *Globigerina* (*Globigerina*) is distinguished by a hispid surface, penetrated by cylindrical pores. This division of *Globigerina* into two subgenera based on surface ultrastructure of naturally group members which are phylogentically related to each other. This is verified by encountering numerous specimens which are morphological intergrades between members of the lineages. *Globigerina bulloides* belongs to the subgenus *Globigerina* (*Globigerina*).

***Globigerina* (*Globigerina*) *bulloides* d'Orbigny**

(Plate 1, Figures 1-17)

1826 *Globigerina bulloides* d'Orbigny; Ann. Sci. Nat. Paris, vol. 1, no. 7, p. 277 (no figure given), (vide Ellis and Messina, 1940 *et. seq*).

1866 *Globigerina bulloides*; Schwager, Novara Exped. Geol. Theil, 2(1), p. 257.

1960 *Globigerina bulloides* Banner and Blow, Cushman Found. Foraminifera Res. Contr. vol. 11, pt. 1, p. 1-41.

1973 *Globigerina bulloides*; Rögl and Bolli, Initial Repts DSDP vol. xv, p 1, fig. 1.

1983 *Globigerina* (*Globigerina*) *bulloides* Kennett and Srinivasan, Hutchinson Ross Pubi. Co. U.S.A., p. 36, pl. 6, figs. 4-6.

1985 *Globigerina bulloides* Rögl, *In*: Plankton Stratigraphy (Eds., Bolli, Saunders and Perch-Nielsen), Cambridge Univ. Press, p. 321, figs. 4.1-2.

Recorded Stratigraphic Range

Blow (1969) recorded *Globigerina* (*Globigerina*) *bulloides* from middle part of zone N16 to N23 whereas Kennett and Srinivasan (1983) gave its range from Middle Miocene to Holocene.

Remarks

Globigerina (*Globigerina*) *bulloides* is distinguished by an umbilically placed aperture with hispid surface and without having a lip (Plate 1, Figure 1). Surface is with circular pores (~2 µm in diameter) with spines with circular cross section in between. *Gg. bulloides* has usually four chambers in the final whorl rapidly increasing in size as added. The first chamber of the final whorl is approximately 50 µm in diameter while the diameter of the last chamber is four times i.e. 200 µm. Ratio of diameter of Final Chamber to First Chamber is 1:4 (Plate 1, Figure 1). Individuals with an additional bulla like chamber having a hispid surface ultrastructure (Plate 1, Figure 2) and those with smoother surface ultrastructure (Plate 1, Figure 3), covering partly the initial chamber of the final whorl are infrequently encountered. The additional chamber may be in the normal plane of coiling as in Plate 1, Figure 2 or deviates from the plane of coiling of the initial chambers of final whorl (Plate 1, Figures 3 and 4). Such individuals can be distinguished from similar looking *Globigerina umbilicata* Orr & Zaitzeff by having less wide aperture. Such forms were considered by Bolli and Bermudez (1965) to represent intermediate stage between *Gg. bulloides* d'Orbigny (Plate 1, Figure 1) and *Gg. bulloides umbilicata* Orr and Zaitzeff. *Gg. bulloides* has been distinguished from a morphologically resembling species *Globigerinella obesa* Bolli (Plate 1, Figure 17) by having a more hispid surface and umbilical aperture. Some of the individuals of *Gg. bulloides* show little change in the shape, height and width of aperture from centrally placed to the one which is slightly shifted towards margin (Plate 1, Figure 5) but not like *Globigerinella obesa.* Such forms of *Gg. bulloides* were named as *Globigerina bulloides riveroae* by Bolli and Bermudez (1965).

Gg. bulloides is distinguished from *Gg. falconensis* Blow (Plate 1, Figure 16) by absence of an apertural lip. Malmgren and Kennett (1977) distinguished between the two species based on biometric analysis and concluded that the two forms exhibit distinct differences in pattern of relative abundance, kummerform chambers, coiling, test size and shape. However, we also observed a difference in the ultrastructure between the two species. There is a considerable reduction in the pore density and pore size in *Globigerina falconensis*; this may thus be taken as additional and reliable criteria to distinguish between the two forms. However, for picking the specimens for isotopic analyses the apertural lip of the falconensis should be looked carefully.

The two forms have been considered as separate species. Rögl and Bolli (1973) gave detailed descriptions of varieties of *Globigerina bulloides.* They distinguished different morphotypes as *Globigerina bulloides bulloides* d'Orbigny (typical) (like Plate 1, Figure 1), *Gg. bulloides* cf. *quadrilatera* Galloway and Wissler (final chamber reduced in size, Table 1); *Globigerina bulloides riveroae* Bolli and Bermudez (large and wide aperture and tendency to become extraumbilical, Table 1). Table 1 gives a comparative account of various species/morphotypes resembling *Globigerina bulloides*.

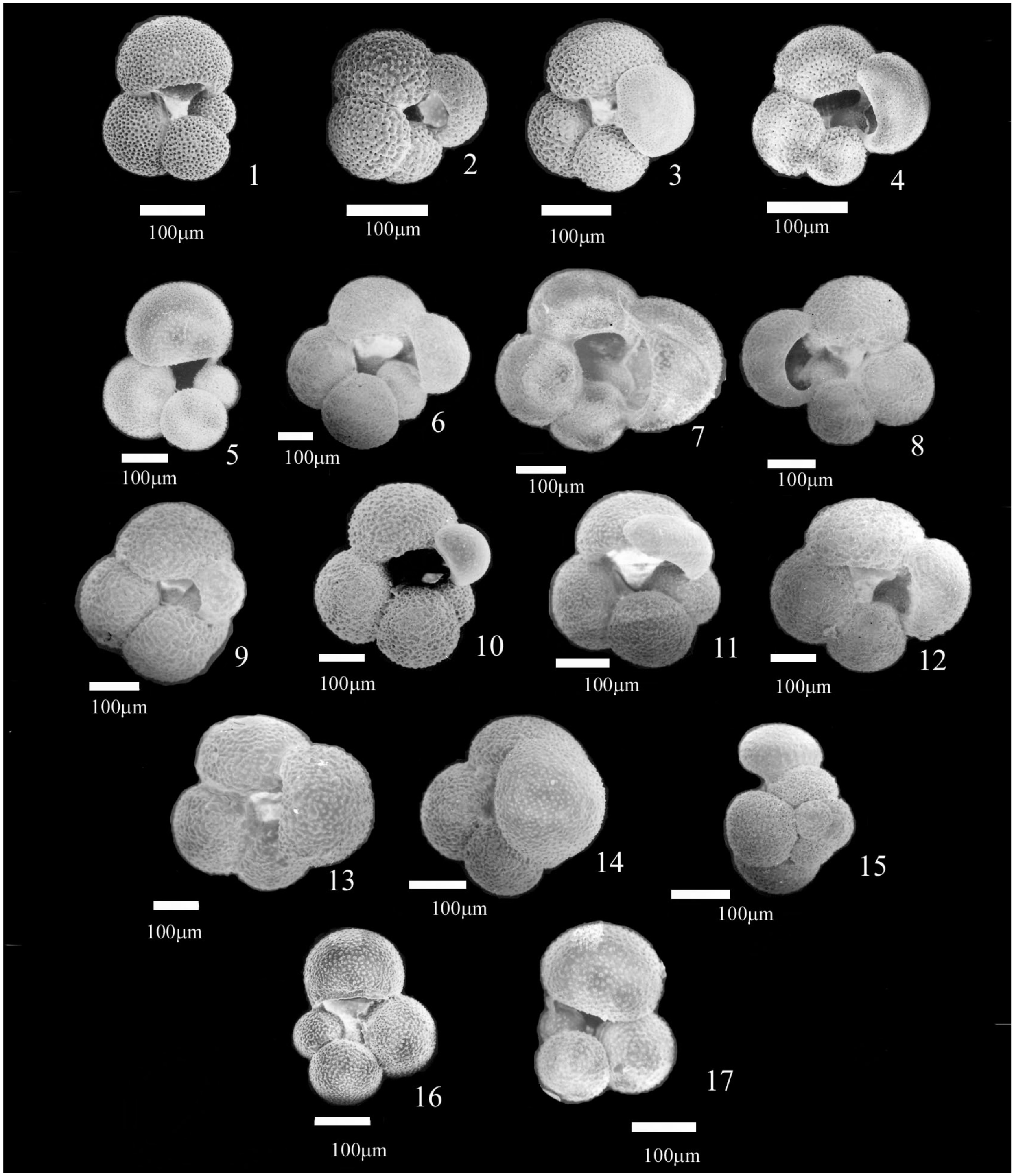

Plate 1: Fig. 1. *Globigerina bulloides* d'Orbigny: Apertural view; having four chambers in the final whorl, Leg-122-763A, 2H-06, 75-77 cm. Fig. 2. *Globigerina bulloides* d'Orbigny: Apertural view; with an additional chamber having same hispid surface and in the same plane of coiling and enveloping first chamber of the last whorl. There are four chambers in the final whorl. Leg-122-763A, 2H-06, 75-77 cm. Fig. 3. *Globigerina bulloides* d'Orbigny: Apertural view; with an additional chamber having smoother surface and in the different plane of coiling; thus enveloping first chamber of the last whorl. Aperture is umbilical and there are four chambers in the final whorl. Leg-122-763A, 2H-06, 75-77 cm. Fig. 4. *Globigerina bulloides* d'Orbigny: Apertural view; it is having an additional smooth chamber in the different plane of coiling enveloping first chamber of the last whorl. Aperture is becoming extra umbilical. The first chamber

(*Contd.*)

Plate 1: (*Contd.*)

of the final whorl is enveloped by the additional chamber because of different plane of coiling. Leg-122-763A, 2H-06, 75-77 cm. Fig. 5. *Globigerina bulloides* d'Orbigny: Apertural view; it is showing a tendency for aperture to become slightly extra umbilical like *Gg. rivorae*. **It is morphologically similar to** *Globigerinella obesa* **which has a smoother surface. Leg-122-763A, 2H-06, 75-77 cm. Fig. 6. *Globigerina bulloides* d'Orbigny: Apertural view. With an additional chamber slightly smaller than penultimate but differs from variety 3 and 4 in having five chambers in the final whorl and this is due to the fact that the additional chamber is in the same plane of coiling and thus does not envelop the first chamber of the final whorl. Umbilicus is wide and aperture is umbilical. Leg-90-593, 1-1,66-68 cm. Fig. 7. *Globigerina bulloides* d'Orbigny: Apertural view. This is showing similarity with Fig. 6, in possessing a wide umbilicus and umbilical aperture and differs in having additional chamber in different plane of coiling and thus enveloping the first chamber of the final whorl. Leg-90-594, 1-1,66-68 cm. Fig. 8. *Globigerina bulloides* d'Orbigny: Apertural view. It is dextral form of above (Fig.7) but the last chamber is having same size as penultimate chamber and enveloped first chamber of the final whorl. Leg-90-593,1-1,66-68 cm. Fig. 9. *Globigerina bulloides* d'Orbigny: Apertural view. It is having a kummerform chamber with same ultrastructure, envelops the first chamber of the final whorl Leg-90-593,1-1,66-68 cm. Fig. 10. *Globigerina bulloides* d'Orbigny: Apertural view. It is also having a kummerform smooth chamber which is not enveloping the first chamber of the final whorl, 90-593, 1-1,66-68 cm, 100 µm. Fig. 11. *Globigerina bulloides* d' Orbigny: Apertural view. It is also having a kummerform smooth elongate chamber which is secreted in different plain of coiling and partly enveloping the aperture. Leg-90-593,1-1,66-68 cm. Fig. 12. *Globigerina bulloides* d'Orbigny: Apertural view. It is having an additional chamber which is smaller than penultimate chamber and covers the first chamber of the final whorl. Leg-90-593,1-1,66-68 cm. Fig. 13. *Globigerina bulloides* d'Orbigny: It is same as Fig. 12 with additional chamber which envelops the first chamber of the final whorl and apertural area. Leg-90-593, 1-1, 66-68 cm. Fig. 14. *Globigerina bulloides* d' Orbigny: Apertural view. It is same as Figs. 12 and 13 with a further large additional chamber covering completely the aperture and this chamber lies in different plane of coiling. Leg-90-594, 1-1, 66-68 cm. Fig. 15. *Globigerina bulloides* d' Orbigny: Side view. It is having high spired test like** *Gg. cariacoensis* **Leg-90-593, 1-1, 66-68 cm. Fig. 16. *Globigerina falconensis* Blow: Apertural view. It differs from** *Gg. bulloides* **by the apertural lip. Leg-122-763A, 6H-01, 75-77 cm. Fig. 17. *Globigerinella obesa* (Bolli): Apertural view. It looks like** *Gg. bulliodes* **but having extra umbilical aperture and smooth surface 122,763A,1H-1, 76-78 cm, 100 µm.**

Most of these morphotypes were considered by Kennett and Srinivasan (1983) to represent phenotypic variants of *Globigerina bulloides*. In addition to the morphotypes described in Table 1, *Gg. bulloides* may show a wide range of variations. Individuals having very wide umbilicus and fifth additional chamber in the final whorl not covering the first chamber (Plate 1, Figure 6) are frequent. Sometimes the additional chamber, larger than the penultimate totally covers the first chamber of the final whorl though in the same plane of coiling (Plate 1, Figures 7 and 8). Specimens with a kummerform chamber covering partly the apertural area are also frequently encountered. This kummerform chamber may be having a hispid surface (Plate 1, Figure 9) or a smooth surface (Plate 1, Figure 10). Sometimes the kummerform chamber may become elongate covering more area of the aperture (Plate 1, Figure 11) similar to *Globigerina bermudezi* Seiglie. The degree and extent to which the additional chamber covers the apertural area also varies from partly covering (Plate 1, Figure 12), to almost half covering (Plate 1, Figure 13) to completely covering due to additional chamber having different plane of coiling (Plate 1, Figure 14). Rare specimens of *Globigerina bulloides* having high spired test are also encountered (Plate 1, Figure 15). Such forms were described as *Gg. cariacoensis* Rögl and Bolli (Table 1) and were considered to mark the Pliocene/Plesitocene boundary in type section of Vrica, Italy.

Thus from the above description and Table 1 it can be observed that much subjectivity is involved in identification of these morphotypes and also one morphotype can have range of variations in their morphology and that will be confusing with the other morphotypes. Some of the key issues which need to be discussed are:

1. Are all these morphotypes to be considered as phenotypic variants of *Globigerina bulloides* as envisaged by Kennett and Srinivasan (1983)?
2. If yes, then there must be surface water oceanographic changes responsible for such range of variations and each morphotype has been triggered by environmental change and the course of variation in the resulting morphotypes will depend on the inherent genetic factors as well as external factor (Cifeli and Scott, 1986).
3. In such cases if we consider vital effect, the isotopic composition of each morphotypes will be different and clumping together these morphotypes

as *Globigerina bulloides* s.s. for stable isotopic analyses would lead to erroneous results. Further with changing age of the sample relative abundance of different morphotypes would change (e.g. appearance of *Gg. caricoensis* in Pleistocene).

4. If these morphotypes are considered as different species even after the publication of Kennett and Srinivasan (1983) (see the various publications of NOAA Satellite and Information Service, National Geophysical Data Centre, Core Data from ODP Legs 101-121, Iacarino, 1985; Bolli and Saunders, 1985), then again because of the inherent vital effect the isotopic equilibrium for each will differ and taking a mixed population as *Globigerina bulloides* for isotopic analyses will not be correct. It is worth mentioning here that large amount of data being generated for isotopic analyses involved picking up of *Gg. bulloides* by non-taxonomists.
5. A careful study involving stable isotopic analyses of various morphotypes is needed to prove or disprove the above assumptions.

Conclusions

Globigerina bulloides d'Orbigny is an important proxy for paleoceanographic and paleoclimatic changes especially for palaeomonsoonal intensity variation. It's census data and stable isotopic compositions are widely utilized for inferring upwelling and sea surface temperature history.

Considerable variations in the morphology of this species has resulted in erection of a number of species which have been considered by some authors to be phenotypic variations of a single species while others have considered them different species.

Wide range of variation is seen within *Gg. bulloides* population in the number of chambers in the final whorl, position and size of the aperture, height of the spire, surface and shape of the kummerform chamber, and coiling plane of the additional chamber.

Considering the state of art regarding identification of *Globigerina bulloides*, single morphotypes must be picked up for stable isotopic analyses in view of inherent vital effect. The study involving use of *Globigerina bulloides* for stable isotopic analyses should mention strictly the morphotypes used for isotopic analyses.

Detail genetic studies are warranted for various morphotypes and similar looking species of *Globigerina bulloides* to get an enlightened species concept.

Acknowledgements

Authors are grateful to the Deep Sea Drilling Project and Ocean Drilling program for providing Deep Sea samples. DKS and AKS are thankful to ISRO GBP and Delhi University for providing financial help. TK, VPS, KRM and AS are thankful to CSIR for providing financial help in the form of JRF and SRF.

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