

1972 21-26

GLOBIGERINA PACHYDERMA (EHRENBERG) IN THE SHELF - SLOPE SEDIMENTS OF NORTHERN INDIAN OCEAN

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ABSTRACT

The occurrence of specimens of *Globigerina pachyderma* (Ehrenberg) which is considered to be a typical bipolar, cooler water species, in the Recent shelf-slope sediments of the northern Indian Ocean as far north as 9, 12, 14, 19 and 23° latitudes in the Arabian Sea and 18° latitude in the Bay of Bengal is considered and compared with similar occurrence from other oceans of the world.

The vertical and spatial distributions have shown that it is both dextrally and sinistrally coiled, regionally distributed, controlled by water masses and the juvenile forms of *G. eggeri*, *G. quadrilatera*, *G. hulloides* and also *G. quinqueloba* appearing as variants of this species are considered as morphologic intergrades. Evidences of periodic drifts of climate are observed as seen in the alternate layers of cold and warm water sediments in cores of Atlantic and the Pacific thus bringing the colder water fauna to lower latitudes. An understanding of the hydrological conditions in the Indian Ocean revealed the Sub-tropical Sub-surface Water mass is traced as far north as Gulf of Aden, and the Indian Ocean Deep Bottom Water originating in the deepest levels of the South Polar region moves northwards and passing through the equator enters the Arabian Sea and the Bay of Bengal; and also the Indian Central Water mass and the Equatorial Water mass having different T-S relationship are responsible in the transport of this species to the middle and low latitudes. Therefore, considering various factors like movement of low salinity, low temperature water masses, mixing and upwelling resulting in the occurrence of this species in the northern Indian Ocean sediments, it is proposed that the forms which occur in the low latitudes (up to 25° N) in the northern Indian Ocean be referred to henceforth as (1) (a) *Globigerina pachyderma* (Ehrenberg) *forma dextralis typica* Setty, n. subsp. (Sensu Stricto) if the species is right-coiled, and (b) *Globigerina pachyderma* (Ehrenberg) *forma sinistralis typica* Setty, n. subsp. (Sensu Stricto) if the species is left-coiled; (3) as *Globigerina pachyderma* (Ehrenberg) *forma dextralis* Setty, n. subsp. (Sensu Stricto) for those which occur in the mid-latitudes; and (4) all those forms which occur in the high latitudes as *Globigerina pachyderma* (Ehrenberg) (Sensu Stricto) where they are typically left coiled.

INTRODUCTION

An investigation of several samples of bottom sediments of the Indian shelf of the Arabian Sea revealed that the planktonic foraminifera increase in their abun-

dance toward the outer shelf and the slope while they are frequent to rare shorewards. Also, they tend to be absent at the mouths of the rivers which may be due to the freshwater influx into the sea and consequent fall in salinity, temperature, organic content, and a continuous sediment inflow into the region (Setty and Gupta, 1972 b).

The characteristic planktonic foraminifera that are encountered in the surface shelf sediments in the five regions of the northern Indian Ocean (four in the Arabian Sea and one in the Bay of Bengal) north of the equator represent a rather unusual mixed assemblage which includes a typical tropical warm water, cold temperate and transitional fauna. Further, it seemed rather intriguing to record the occurrence of undoubted though rare, specimens of *Globigerina pachyderma* (Ehrenberg) in the sediments.

Globigerina pachyderma (Ehrenberg) has been a subject of considerable study in the last few years. As it has been considered to be a typical bipolar, cooler water species, its value as a paleoclimatic indicator has been greatest. Therefore, its occurrence in a sediment assumes greater importance, more so in areas which are known today as tropical regions of the world.

DISCUSSION

While discussing the antecedents and the distribution of *Globigerina pachyderma* (Ehrenberg), in the Southern Pacific, Parker (1962) stated that, 'occasional specimens are seen even at the equator,' though this species is largely confined to the area south of Lat. 25°S. But, it is of interest to note here that *G. pachyderma* is recorded in the shelf and slope sediments of the west coast of India, as far north as 9°N, 12°N, 14°N, 19°N and also 23°N in the Arabian Sea (Setty, 1972, Setty and Gupta 1972, Rao 1972, Narayanan 1974 MS) and nearly 18°N in the Bay of Bengal (Bhatt, 1969); all the locations being beyond the equator and to the north of it.

Though it is a bipolar species, the Arctic form differs considerably from that of the Antarctic. Arctic forms are smaller and thinner, whereas Antarctic forms are thicker and larger, though both types are sinistrally coiled. However, the typical characteristics of *G. pachyderma* as a species, are, in having a square outline, the final chamber being smaller than the penultimate one; the last whorl having 4-5 chambers, the test being fragile in juvenile forms and spinose with a large aperture, while the adult is a robust form showing indistinct chambers due to thickening giving distinctly a pitted appearance; and the aperture being small and placed in the final chamber.

DISTRIBUTION (IN SPACE) AND ENVIRONMENT (PRESENT)

It is stated that, as a rule, *G. pachyderma* is a cold water fauna extending as far south as 25°N in the Northern Hemisphere and again as far north as 25°S in the Southern Hemisphere though a few cold temperate forms penetrate as isolated specimens into the tropical zones. This species is typically left coiled as a cold water fauna in the high latitudes of the South Atlantic where the temperature is about 9°C (Boltovskoy, 1969). Similarly, it is so in the North Atlantic where the isotherm is 7.2°C. This situation however, alters with a decrease in latitude and increase in temperature above 7.2°C (Ericson, 1959) in the North Atlantic, and 9°C in the South Atlantic, when the left coiling direction passes yielding to the right coiling forms. It is these right coiled forms which become thin walled and reduced in size and are encountered occasionally even at the equator. According to Ericson (1959) and Bandy (1960) these are characteristic warm water, mid-latitude fauna sometimes extending to low latitudes. Kennett (1970) pointed out that during the Pleistocene time, the Arctic and Antarctic populations reached the Equator and had a free interchange there, but, in the Indian Ocean, it is the Antarctic fauna alone that is found in the equatorial waters and spreads again further to the north into the Arabian Sea and the Bay of Bengal.

Though the distribution of *G. pachyderma* is considered restricted its occurrence in other low latitudes is observed. In the North Atlantic, *G. pachyderma* is observed between 27°-34°N (from Florida to Cape Hatteras) in the beach, inner, middle, and outer shelf and the slope regions and also along the path of the Gulf Stream (Wilcoxon, 1964). Further it is reported, though as rare

specimens, in the region between Cape Cod to 15°N in Sargasso Sea (a subtropical rather than subtemperate zone) and in the South Equatorial Current at 3°S to 10°N flowing into the Gulf of Mexico (Cifelli, 1967). Similarly, it occurs in very low frequencies in the bottom sediments of the Gulf at 28°N 86°W, a region which is diagnostic of mid-latitudes where the surface temperature is 20°C in February and 29°C in August (Parker, 1954). Incidentally, it may be of interest to note here that d'Orbigny's specimen was originally collected from the vicinity of Cuba; though Ehrenberg's specimen was from 62°40'W and 23°00'W.

Undoubted specimens of *G. pachyderma* occur in the bottom sediments of Kerala (9°N, 76°E), Mangalore (12° 35'N, 74°, 16.5'E), Karwar (14°-22.5'N, 74.15'E), Bombay along Lat. 18° 33'N and Long. 72°22'E and 70°-30'E transect) and off Gujarat coast (in the region between 22°07'N 67° 09'E and 23° 29.2'N 68°29'E). A very few specimens of sinistrally coiled forms are also seen in the Gujarat region. The thin-walled specimen found here are very similar to those figured by Parker (1962). Similar dextrally coiled forms are, however, reported from the Recent sediments off New Zealand (Jenkins, 1967, Kennett, 1967). This is due to an abrupt change that occurs at 52°S which is the Antarctic Convergence region.

G. pachyderma also has a vertical distribution in addition to lateral or spatial distribution. Vilks (1969) has observed that *G. pachyderma* is abundant in the deeper 200 m layer which is a warmer and more saline water of the Atlantic that enters the Arctic through Hazen Strait adjacent to Prince Gustav Adolf Sea. The observation seriously contradicts the notion that the species is indigenous to the Arctic or Antarctic region and thus only confined to cold water. But, this does not apply to the Antarctic water.

Boltovskoy (1969) differentiates *G. pachyderma* based upon its appearance in two categories—(1) *forma superficialis* which is chiefly confined to the upper layer (0-500 m) water but rare in greater depth and sediments and (2) *forma typica* which is characteristic of greater depths (500-2000 m) but never in surface waters. He confirms that *G. pachyderma* is hemipelagic and occurs at depths ranging from 0-500 to 2000 m also and therefore in sediments whose latitude and surface temperature zonation is at variance with the environmental conditions.

at depths even at the equator and beyond it. However, Boltovskoy (1969) has further divided this species into two kinds based upon their direction of coiling—(1) *forma sinistralis*, a typical low temperature and high latitude (25°—65°S and 25°—65°N) fauna and (2) *forma dextralis*, a typical transitional and warm water fauna and (2) *forma dextralis*, a typical transitional and warm fauna (25°N—25°S) which occurs even at the equator.

In the Mediterranean, this species is observed to be associated with *G. quinqueloba*, *G. bulloides*, *Globoquadriina dutertrei* Parker (= *Globigerina eggert* Rumbler) in higher frequencies whereas *G. inflata*, *G. quadrilobata*, *G. acquilateralis* and *Globigerinoides ruber* in low frequencies at a mean minimum temperature of 13°C (Parker, 1954). Thus temperature plays a key role in the lateral and vertical distribution of *G. pachyderma* in the water masses of the oceans, though several known and unknown factors are also responsible. The water temperature affects the absolute size of the tests resulting in either fragile or robust forms. Further, it is the chief factor that is responsible in changing the direction of coiling, however, according to Kennett (1970) it is more so as a result of environmental variation.

It is considered that the juvenile forms of *G. eggert*, (= *Globoquadriina dutertrei* Parker), *G. quadrilobata*, *G. bulloides* are similar to those of *G. pachyderma* and therefore they are considered to be morphologic intergrades (Smith, 1963). Further, this species is also considered as a variant of *G. bulloides* and *G. quinqueloba* (Srinivasan, personal communication). But Boltovskoy (1971) and Kennett (1965) have shown the differences between the two species. However, Be' (1960) has observed that the so called occurrence of *G. bulloides* in the Central Arctic Sea is only a morphological variant and an earlier developmental stage of *G. pachyderma*. Kennett (1970) has shown the distinct differences between the Arctic and Antarctic species. *G. inflata* and *G. pachyderma incompta* (Cifelli) are synonymous with *G. pachyderma* (Ehrenberg).

GEOLOGICAL TIME AND PALEO-OCEANOGRAPHY

Definite and undoubted specimens were recognised from the Mohnian stage (early late Miocene of Kleinpell 1938) of California in the core of the Experimental Mohole Project, wherein it was found that 100% were left coiling (in sample no. 12) forms compared to only 53% in the overlying (sample No. 13) Pliocene sediments

(Parker, 1964). These specimens were found to be warm water or transitional zone species (Parker 1962, p. 630) and their percentage of coiling ratio changed with the change in temperature/environmental conditions of Pliocene time.

According to Friedrichs (1971) the paleotemperature measurements indicate that the late Miocene to Recent interval is not a time of generic extinction but shows a decline in the appearance of new planktonic foraminiferal genera. Whether magnetic reversals since late Miocene time (or for that matter even earlier) has had any effect and if so to what extent is not very clear.

A general lowering of earth's temperature and the resulting Pleistocene glaciation causes climatic changes thus resulting in the extension of the mid-latitude fauna to shift further to lower latitudes. This facilitates this species to extend itself to new areas and thus record its existence in the bottom sediments of the regions of the low latitudes which are today environmentally very different. Evidences of such periodic drifts of climatic changes are observed in the alternate layers of warm water and cold water faunal deep sea sediments in the Atlantic and the Pacific (Arthenius 1952, Ericson and Wollin, 1956 b, Phlegar *et al.*, 1953 and others), in the Gulf of Mexico (Ewing *et al.*, 1958); in the Mediterranean (Phlegar 1947); and also in the Arabian Sea (Stubbings 1937). Thus according to Phlegar (1960) the colder water fauna noticed in the cores from the low latitudes are like those of now living in the mid-latitudes and similarly those from mid-latitudes are like those now living in high latitudes. Whether this view corroborate, with polar wandering concept during the Tertiary time is not known. Therefore, extending or delimiting the range of distribution of any species but particularly *G. pachyderma* to temperature zones as proposed by Vaughan (1947) may not be justifiable, because (1) the classifications are for the surface water masses only, (2) the vertical temperature zonation varies considerably, and (3) *G. pachyderma* is also found to live at depths even upto 2000 m, and (4) the thanatocoenosis of this species in the past differs from that of the present. Further, it is also to be noted that the temperature zones of Vaughan (1940) and others are not free from the influence of currents and water mass movements from the Poles. Therefore, the extension of latitudinal range upto the equator need not be restricted to the condition of

general cooling of oceanic waters during the Pleistocene time (though under such conditions such a situation is further accelerated), but it can be taking place even at present time due to the continuous movement of Antarctic (and Arctic in some parts of the Pacific and the Atlantic) cold currents and water masses at considerable depth.

In the Indian Ocean, the Sub-tropical Sub-surface water mass is traced to move as far north as the Gulf of Aden and the Gulf of Oman, after sinking below the surface at the region of the Sub-tropical Convergence Line. Similarly, the Indian ocean Deep Bottom water—a water mass of low salinity and low temperature originating in the deepest levels of the south polar region moves northwards and passing the equator enters the Arabian Sea through the Laccadive Sea and the Bay of Bengal (Sewell, 1937; Robinson, 1966). Further, the Indian Central Water mass extending between 35° – 40° S and 15° – 20° S has a temperature/salinity relation which falls between $T = 8^{\circ}\text{C}, S = 34.60\text{‰}$ and $T = 15^{\circ}\text{C}, S = 35.50\text{‰}$. The Indian Equatorial Water mass lies to the north of the Central Water mass and the T–S relations at most of the stations north of the equator fall between $T = 4^{\circ}\text{C}, S = 34.90\text{‰}$, $T = 18^{\circ}\text{C}, S = 32.25\text{‰}$ but these relations are intermediate between the Equatorial Water and the Central Water masses (Sverdrup *et al.*, 1962; Fairbridge *et al.*, 1966, p. 387). This indicates that the T–S relationship falls within the tolerance range of the right coiling forms of *G. pachyderma*. A part of the Antarctic Bottom Water flows north into the Arabian Sea and the Bay of Bengal, and having been considerably transformed, it rises to shallower depths and again returns south in the Intermediate current. Further, the Antarctic Bottom Water (which is characterised by negative temperature ranging from $T = -0.24^{\circ}\text{C}$ to -0.07°C and $S = 34.69\text{‰}$ with oxygen content of 4.70 to 5.27 ml/l) as a result of mixing with the North Indian Deep water becomes the Indian Ocean Bottom Water mass (having $T = 0.2^{\circ}\text{C}$ to 1.47°C , $S = 34.69$ to 34.77‰ with dissolved oxygen content of 4.93 to 4.68 ml/l) penetrates into the deepest parts of the Arabian Sea and the Bay of Bengal and rises to higher levels (Gallagher, 1966). Therefore, it may be postulated that Antarctic Bottom Water mass and the Central and Equatorial Water masses flowing northwards north of the equator into the Arabian Sea and the Bay of Bengal are to a greater extent responsible in moving

the sinistral forms at great depth and dextral forms at upper levels northwards and establish their distribution, through upwelling, in the outer shelf and slope sediments of the Arabian Sea (off Cochin, Mangalore, Karwar, Bombay and Gujarat Coast) and the Bay of Bengal off Vishakhapatnam) and possibly in the northern regions also. Thus, the occurrence of thick-walled, left-coiled form of *G. pachyderma* in the deep water sediments of the northern Indian Ocean confirms the role of the Antarctic Bottom Water and the Indian Ocean Bottom water in transporting this species into this region. Similarly, the occurrence of dextrally coiled form also confirms the role of the Indian Central and Equatorial Water masses in the northern movement of this species. The core sediments may well have the answer to the occurrence of this species in the geologically older sediments also.

Therefore, in order to be precise and specific in referring to this species in terms of its occurrence and biogeographic distribution in the Indian Ocean, it is proposed that *Globigerina pachyderma* (Ehrenberg) be referred to as follows:

(1) Those forms which occur in the low latitudes (upto 25°N) in the Northern Indian Ocean (Arabian Sea and the Bay of Bengal) be designated as (a) *Globigerina pachyderma* (Ehrenberg) *forma dextralis typica* Setty n. subsp. (Sensu Stricto) if the species is right-coiled, and (b) *Globigerina pachyderma* (Ehrenberg) *forma sinistralis typica* Setty n. subsp. (Sensu stricto) if the species is left-coiled;

(2) Those forms which occur in the mid-latitudes when they are typically right coiled be designated as *Globigerina pachyderma* (Ehrenberg) *forma dextralis* Setty n. subsp. (Sensu Stricto); and

(3) All those forms which occur in the the high latitudes be designated as *Globigerina pachyderma* (Ehrenberg) (Sensu Stricto) where they are typically left coiled.

Speciation and sub-speciation of *G. pachyderma* in this manner into definite latitudinal zones with vertical and horizontal distribution helps greatly in the standardisation of this species than leaving it ambiguously.

Thus henceforth, all the forms found in the northern Indian Ocean may be considered as *Globigerina*

pachyderma forma dextralis typica Setty and *Globigerina pachyderma forma sinistralis typica* Setty.

ACKNOWLEDGEMENT

The author expresses his thanks and appreciation to Dr. S.Z. Qasim, Director, National Institute of Oceanography, for his interest, and to Don L. Eicher for suggesting the problem.

REFERENCES

- Arthenius, G., 1952. Sediment Cores from the East Pacific. Swedish Deep Sea expd. Repts v. 5.
- Beady, G.P., 1960. The geological significance of coiling ratios in the foraminifera, *Globigerina pachyderma* (Ehrenberg). *J. Paleont.*, vol. 34, No. 4, p. 671-678.
- B. Allan, W., 1960. Some observations on Arctic planktonic foraminifera. *Contrib. Cushman Found. Foram. Res.*, vol. 11, p. 64-68.
- Bhatt, D.K., 1969. Planktonic foraminifera from sediments off the Vishakhapatnam coast, India. *Contrib. Cushman Found. Foram. Res.*, vol. 20, No. 1, p. 30-36.
- Boltovskoy, E., 1969. Living planktonic foraminifera at the 90°W meridian from the equator to the Antarctic. *Micropalaeont.* vol. 15, No. 2, p. 237-255.
- Boltovskoy, E., 1971. Ecology of the planktonic foraminifera living in the surface layer of Drake Passage. *Micropalaeont.* vol. 17, no. 1, p. 53-68.
- Cifelli, R., 1967. Distributional analysis of North Atlantic foraminifera collected in 1961, during Cruises 17 and 21 of the R/V Chain. *Contrib. Cushman Found. Foram. Res.* Vol. 18, Part 3, p. 118-127.
- Ericson, D.B., and G. Wollin, 1956. b. Micropaleontological and isotopic determination off Pleistocene climates. *Micropalaeont.* vol. 2, No. 3, p. 257-270.
- Heezen, B.C., 1959. Coiling direction of *Globigerina pachyderma* as a climatic index., *Science*, vol. 130, No. 3369, p. 219-220.
- Heezen, M., D.B. Ericson, and B.C. Heezen, 1958. Sediments and topography of the Gulf of Mexico in Habitat of Oil. *Amer. Assoc. Petrol. Geol.*, p. 995-1053.
- Hirbridge, E.W., B. Heezen, T. Ichive, and M. Tharp, 1966. Indian Ocean; *The Encyclopaedia of Oceanography* (Encyclopedia of Earth Sciences, Vol. 1). Rainhold Publishing Corporation, New York (Editor R.W. Fairbridge), p. 370-400.
- Freericks, W.E., 1971. Evolution of planktonic foraminifera and paleotemperature. *J. Paleont.* vol. 45, No. 6.
- Gallagher J.F., 1966. The variability of water masses in the Indian Ocean. *Nat. Oceanogr. Data Centre, Gen. Ser. Publ. G-11*, p. 1-74.
- Jenking, D.G., 1967. Recent distribution, origin and coiling ratio changes in *Globigerina pachyderma* (Ehrenberg). *Micropalaeont.* vol. 13, No. p. 195-203.
- Kennett, J.P., 1967. Recognition and Correlation of the Kapitan Stage (upper Miocene, New Zealand). *Newzealand J. Geol. Geophys.*, vol. 10, No. 4, p. 1051-1053.
- Kennett, J.P., 1968. Latitudinal variation in *Globigerina pachyderma* (Ehrenberg) in surface sediments of the southwest Pacific Ocean. *Micropalaeont.* vol. 14, No. 3, p. 305-318.
- Kennett, J.P., 1970. Comparison of *Globigerina pachyderma* (Ehrenberg) in Arctic and Antarctic areas. *Contrib. Cushman Found. Foram. Res.* vol. 21, Part 2, p. 47-49.
- Parker, F.L., 1954. Distribution of the foraminifera in the northeastern Gulf of Mexico. *Bull. Mus. Comp. Zoology.* V. III, No. 10, p. 454-547.
- Parker, F.L., 1955. Distribution of planktonic foraminifera in some Mediterranean sediments. *Papers in Marine Bio. & Oceano Deep Sea Res. Suppl. to vol. 3*, p. 204-211.
- Parker, F.L., 1962. Planktonic foraminiferal species in Pacific sediments. *Micropalaeont.* vol. 8, No. 2, p. 219-254.
- Parker, F.L., 1964. Foraminifera from the experimental Mohole drilling near Guadalupe Island, Mexico. *J. Paleont.* vol. 38, No. 4, p. 617-636.
- Phleger, F.B., 1947. Foraminifera of three submarine cores from the Tyrrahenian Sea. *Göteborgs, Kunge. Vetensk. Och. Vitterhets-Samfundes, Ser. B.* No. 5, 19 p.
- Phleger, F.B., 1960. Ecology and distribution of recent foraminifera. *The Johns Hopkins Press, Baltimore.* 297 p.
- Phleger, F.B., F.L. Parker, and J.F. Pierson, 1953. North Atlantic foraminifera. *Swedish Deep Sea Expd. Repts.* vol. 7, No. 1, p. 1-22.
- Rao, K.K., 1972. Planktonic foraminifera in sediment samples from the eastern Arabian Sea. *Ind. J. Mar. Sci.* vol. 1, p. 1-7.

- Robinson, M.K., 1966. Arabian Sea ; The Encyclopaedia of Oceanography (Editor. Fainbridge, R.W.). Reinhold Publ. Corpn., New York, p. 40-42.
- Setty, M.G. Anantha P., 1972. b. Holocene Planktonic foraminifera from the shelf sediments off Kerala Coast. J. Geol. Soc. India, vol. 13, No. 2, p. 131-138.
- Setty, M.G. Anantha P., and M.V.S. Gupta, 1972. h. Recent planktonic foraminifera from the shelf sediments off Karwar and Mangalore. Ind. Nat. Sci. Acad. vol. 38 A, Nos. 5 & 6, p. 148-160.
- Sewell, R.B.S., 1937. The temperature and salinity of the deeper waters of the Bay of Bengal and Andaman Sea. Mem. Asiatic. Soc. Bengal, vol. 9, No. 1, p. 357-423.
- Smith, A.B., 1963. Distribution of living planktonic foraminifera in the northeastern Pacific. Contrib. Cushman Found. Foram. Res., vol. 14, Part I, p. 1-15.
- Stubbings, H.G., 1937. Stratification of biological remains in marine deposits. The John Murray Exped. Sci. Repts., vol. 3, p. 154-192.
- Sverdrup, H.U., M.W. Johnson and R.H. Fleming, 1962. The Oceans, their physics, Chemistry and General Biology. Chap. 15. p. 605-764. Asia Publ. House Bombay.
- Vaughan, T.W., 1940. Ecology of modern marine organisms with reference to paleogeography. Bull. Geol. Soc. Amer. Vol. 51, p. 433-468.
- Vilks, G., 1969. Recent foraminifera in the Canadian Arctic. Micropalaeont., vol. 15, No. 1, p. 35-60.
- Wilcoxon, J.A., 1964. Distribution of foraminifera of the Southern Atlantic Coast of the United States. Contrib. Cushman Found. Foram. Res., vol. 15, Part I, p. 1-24.