

Occurrence of *Neogloboquadrina pachyderma* New Subspecies in the Shelf-Slope Sediments of Northern Indian Ocean

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Specimens of *N. pachyderma* (Ehrenberg) which are considered to be typical bipolar, cooler-water species, are described in the recent shelf-slope sediments of the northern Indian Ocean as far north as 23°N in the Arabian Sea and 18°N in the Bay of Bengal. Studies of hydrological conditions in the Indian Ocean reveal that the Subtropical Subsurface Water Mass is traceable as far north as the Gulf of Aden, and the Indian Ocean Deep Bottom Water Mass 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 relationships are responsible for 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 finally 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) *Neogloboquadrina pachyderma dextralis typica* Setty, n. subsp. (sensu stricto) if the species is right-coiled, and (b) *Neogloboquadrina pachyderma sinistralis typica* n. subsp. Setty (sensu stricto) if the species is left-coiled; (2) as *Neogloboquadrina pachyderma dextralis* Setty, n. subsp. (sensu stricto) for those which occur in the mid-latitudes; and (3) all those forms which occur in the high latitudes as *Neogloboquadrina pachyderma* (Ehrenberg) (sensu stricto) where they are typically left coiled. Thus speciation and subspeciation into definite latitudinal zones helps greatly in the standardization of this species.

INVESTIGATION of several samples of bottom sediments of the Indian shelf of the Arabian Sea reveals that the planktonic foraminifera increase in their abundance towards 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 is due to the freshwater influx into the sea and consequent fall in salinity, temperature and organic content and a continuous sediment inflow into the region.

The characteristic planktonic foraminifera that are encountered in the surface shelf sediments in the 5 regions of the northern Indian Ocean (4 in the Arabian Sea and 1 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 seems rather intriguing to record the occurrence of undoubted, though rare, specimens of *Neogloboquadrina pachyderma* (= *Globigerina pachyderma*) (Ehrenberg) in the sediments.

As *N. pachyderma* has been considered to be a typical bipolar, cooler water species, its value as a paleoclimatic indicator has been greatest. Therefore, its very presence in a sediment assumes greater importance, more so in areas which are known today as tropical regions of the world.

Results and Discussion

While discussing the antecedents and the distribution of *N. pachyderma*, in the Southern Pacific,

Parker¹ 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 that *N. pachyderma* is recorded in the shelf and slope sediments of the west coast of India, as far north as 9°, 12°, 14°, 19°²⁻⁴ and 23°N in the Arabian Sea⁵ and nearly 18°N in the Bay of Bengal⁶ 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 dominated by 4½ to 5 chambers, are smaller and thinner, whereas Antarctic forms dominated by 4 chambered individuals, are thicker and larger, though both types are sinistrally coiled⁷. However, the typical *N. pachyderma* is characterized by possessing a square outline, the final chamber being smaller than the penultimate one, the last whorl having 4-5 chambers. Srinivasan and Kennett⁸ have distinguished 2 main surface ultrastructures within *N. pachyderma* populations from the South Pacific; reticulate forms with relatively unthickened pitted microcrystalline surface and more thickened crystalline forms with test covered by distinct euhedral calcite rhombs. Intermediate forms link these 2 types.

Distribution (in Space) and Environment (Present)

It is stated that, as a rule, *N. 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°C⁹. 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 in the North Atlantic¹⁰ 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 Ericson¹⁰ and Bandy¹¹ these are characteristic warm water, mid-latitude fauna sometimes extending to low latitudes. Kennett⁸ pointed out that during the Pleistocene time, the Arctic and the 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 spread again further to the north into the Arabian Sea and the Bay of Bengal.

Though the distribution of *N. pachyderma* is considered restricted, its occurrence in other low latitude is observed. In the North Atlantic, *N. pachyderma* is observed between 27° and 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 Stream¹². 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 Mexico¹³. 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 August¹⁴. 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 *N. 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°2'N, 68°29'E). A very few specimens of sinistrally coiled forms are also seen in the Gujarat region. The thin-walled specimens found here are very similar to those figured by Parker¹. Similar dextrally coiled forms are, however, reported from the Recent sediments off New Zealand^{15,16}. This is due to an abrupt change that occurs at 52°S which is the Antarctic Convergence region.

N. pachyderma also has a vertical distribution in addition to lateral or spatial distribution. Vilks¹⁷ has observed that *N. 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. This observation seriously contradicts

the notion that this species is indigenous to the Arctic or Antarctic region and thus only confined to cold water. However, this does not apply to the Antarctic water.

Boltovskoy¹⁸ differentiates *N. pachyderma* based on its appearance into 2 categories—(1) *forma superficialis* which is chiefly confined to the upper layer (0-500 m) water but rare in greater depth and sediment, and (2) *forma typica* which is characteristic of great depths (500-2000 m) but never in surface waters. This confirms that *N. pachyderma* is hemipelagic and occurs at depths ranging from 0-500 to 2000 m also and thereby 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, Boltovskoy¹⁸ has further divided this species into 2 kinds based on their direction of coiling: (i) *forma sinistralis*, a typical low temperature and high latitude (25-65°S and 25-56°N) fauna and (ii) *forma dextralis*, a typical transitional and warm water 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*, *Neogloboquadrina dutertrei* (d'Orbigny) (= *Globigerina eggeri* Rhumbler) in higher frequencies whereas *G. inflata*, *G. quadrilobata*, *G. acquilateralis* and *Globigerinoides ruber* in low frequencies at a mean minimum temperature of 13°C¹⁹. Thus temperature plays a key role in the lateral and vertical distribution of *N. 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 Kennett²⁰ it is more so as a result of environmental variation.

Smith²¹ considered that the juvenile forms of *G. eggeri*, (= *Globoquadrina dutertrei* Parker), *G. quadrilatera*, *G. bulloides* are similar to those of *G. pachyderma* (= *N. pachyderma*) and, therefore, they are considered to be morphologic intergrades. Though the juvenile forms of *Globigerina bulloides* and *Globigerina quinqueloba* resemble very much *Neogloboquadrina pachyderma* they can be distinguished from the latter by their diagnostic surface ultrastructures consisting of spines and spine-bases, where as the genus *Neogloboquadrina* totally lacks spines or spine-bases (Srinivasan, personal communication). Both *N. pachyderma* and *N. dutertrei* have similar surface ultrastructures²² and the juvenile forms of *N. dutertrei* have often been misidentified for *N. pachyderma*, but an important decrease in chambers per whorl with growth in *N. pachyderma* distinguishes it from *N. dutertrei*²³. However, Bé²⁴ has observed that the so-called occurrence of *G. bulloides* in the Central Arctic Sea is only a morphological variant and an earlier development stage of *N. pachyderma*.

Vella²⁵ pointed out that, in surface sediments of the sub-Antarctic and cool subtropical areas of the southeastern Indian Ocean, coiling ratios of *Neogloboquadrina pachyderma* are more dextral in coarser size fractions than in the finer size fractions. The difference decreases toward the north where dextral coiling becomes dominant in all size

fractions. This phenomenon was considered by him to be due to the existence of at least 2 taxa in the range of forms usually classed as *N. pachyderma*. To these, he provisionally applied *N. pachyderma pachyderma* (Ehrenberg) and *N. pachyderma incompta* (Cifelli). However, stereoscan examinations²⁶ indicate that there is no fundamental difference in surface ultrastructures between *G. incompta* Cifelli and *N. pachyderma* and hence *incompta* is considered to be a synonym of the *pachyderma*.

Geological Time and Paleooceanography

Definite and undoubted specimens were recognized 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) compared to only 53% in the overlying (sample No. 13) Pliocene sediments²⁷. These specimens were found to be warm water or transitional zone species and their percentage or coiling ratio changed with the change in temperature/environmental conditions of Pliocene time.

According to Freirichs²⁸ 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 Pacific²⁹⁻³¹ in the Gulf of Mexico³² in the Mediterranean³³, and also in the Arabian Sea³⁴. Thus according to Phlegar³⁵ 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 the mid-latitudes are like those now living in high latitudes. Whether this view corroborates with polar wandering concept during the Tertiary time is not known. Therefore, extending or delimiting the range of distribution of any species but particularly *N. pachyderma* to temperature zones as proposed by Vaughan³⁶ may not be justifiable, because (1) the classifications are for the surface water masses only, (2) the vertical temperature zonation varies considerably, and (3) *N. pachyderma* is also found to live at depths even up to 2000 m, and (4) the thanatacoenosis of this species in the past differs from that of the present. Further, it is also to be noted that the temperature zones of Vaughan³⁶ and others are not free from the influence of currents and water mass movements from the Poles. Therefore, the extension of latitudinal range up to 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 the present time due to the continuous movement of Antarctic [and Arctic (?)] cold currents and water masses at considerable depth.

In the Indian Ocean, the Subtropical Subsurface 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 Subtropical 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^{37,38}. 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^{39,40}. This indicates that the T-S relationship falls within the tolerance range of the right coiling forms of *N. 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 characterized 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/litre) 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 4.03 to 4.68 ml/litre) and penetrates into the deepest parts of the Arabian Sea and the Bay of Bengal and rises to higher levels⁴⁰. Therefore, it may be postulated that Antarctic Bottom Water Mass and the Central and Equatorial Water Mass 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 depth and dextral forms at upper levels northwards and establish their thanatacoenosis, through upwelling, in the outer shelf and slope sediments (finer fractions) of the Arabian Sea (off Kerala coast, Karwar, Mangalore, 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 *N. 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 *Neogloboquadrina pachyderma* (Ehrenberg) be referred to henceforth as follows:

(1) Those forms which occur in the low latitudes (up to 25°N) in the Northern Indian Ocean (Arabian Sea and the Bay of Bengal) be designated as (a) *Neogloboquadrina pachyderma dextralis typica* Setty n. subsp. (sensu stricto) if the species is right coiled, and (b) *Neogloboquadrina pachyderma 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 *Neogloboquadrina pachyderma* (Ehrenberg) *dextralis* Setty n. subsp. (sensu stricto).

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

Speciation and subspeciation of *N. pachyderma* in this manner into definite latitudinal zones with vertical and horizontal distribution helps greatly in the standardization of this species than leaving it ambiguously.

Thus, henceforth, all the forms found in the northern Indian Ocean may be referred to as *Neogloboquadrina pachyderma dextralis typica* Setty and *Neogloboquadrina pachyderma sinistralis typica* Setty.

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