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STEREOSCAN AND OXYGEN ISOTOPE STUDIES OF SOME INDIAN OCEAN PLANKTONIC FORAMINIFERA*

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ABSTRACT

Planktonic foraminifera have been examined from 44 plankton tows and 20 sediment samples from the Indian Ocean. The calcification process which thickens the tests has been investigated by means of the Stereoscan scanning electron microscope. This process, which commences in the surface waters appears to be related to the depth range through which active calcification takes place. A new species of planktonic foraminifera (found in both the plankton hauls and the sediments) is described. The significance of oxygen isotope measurements, on specific species from plankton hauls and sediments, is discussed.

THE objects of this investigation were : (1) to study by means of the 'Stereoscan' scanning electron microscope the calcification of Indian Ocean planktonic foraminifera caught in the tow net at various depths, (2) to determine at species level the range in the oxygen isotopic composition of individual tests (hitherto this has been impossible because roughly 6 mg of $CaCo_3$ was required) and (3) to compare the species distribution in the plankton tows with that found in sea-bed samples. It was hoped that this study would have wider implications especially in the field of palaeosalinity and palaeotemperature changes in the upper layer of the oceans. We have in this paper given special attention to the species *Globorotalia menardii* because of its use by Oba for palaeoclimatic investigations in cores collected south of Ceylon, as well as by Emiliani and Arrhenius for cores collected by the ALBATROSS Expedition in the equatorial Pacific.

One of the great difficulties of carrying out investigations of this nature is the procurement of well-collected samples. We have used sea-bed samples from the Oceanographical collections of the British Museum (Nat. Hist.), as well as samples put at our disposal by the Lamont Geological Observatory. Ideally the net samples should be from horizontal tows, but for samples deeper than 50 m we had to use oblique tows between specific depth limits. These samples were collected by the USS OCEANOGRAPHER in June-August 1967, as well as by the R. V. ANTON BRUNN in March-July 1963. Sub-samples from these tows were kindly put at our disposal by Dr. David Damkaer of the Smithsonian Institution. No sealed sea-water samples were collected from specific depths, so we could not determine the relation between its δO^{18} content and its salinity, nor were any salinity and temperature depth probes made. Temperature, salinity as well as other determinations from standard depths were kindly sent to us by Dr. Damkaer. All the samples used in this investi-

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gation are registered in the Oceanographical collections of the British Museum (Nat. Hist.), and are available for further study. In addition there are a large number of 'Stereoscan' scanning electron microscope photographs.

We have determined the distribution in the Indian Ocean of planktonic foraminifera in 36 horizontal tows at 50 m; in 8 inclined tows collected between 17°N and 30°S, as well as in 20 sediment samples. It is significant that none of these plankton tows contain more than 12 different species, whereas sediment samples from neighbouring localities have more than 20 different species provided that there has been no extensive solution of the calcite tests. The few species found in the plankton tows may well be related to : (1) the seasonal variations in the planktonic foraminiferal population, (2) the limited size of the sub-sample and (3) the effectiveness of the net in taking representative samples. The distribution of *Globigerinoides ruber*, *Globigerinoides sacculifera*, *Globigerinella aequilateralis*, *Globigerina bulloides*, *Globorotalia menardii*, and *Orbulina universa* in the plankton tow are within the same general limits as found by Beliaeva in 1964. In the case of the sediments whilst the distribution of *Globigerina bulloides*, *Orbulina universa* and *Globoquadrina conglomerata* are similar to those given by Beliaeva, *Globigerinoides ruber*, *Globigerinoides sacculifera*, *Globorotalia menardii*, *Pulleniatina obliquiloculata*, *Globoquadrina dutertrei*, *Globigerinoides conglobatus*, *Globigerinoides aequilateralis*, and *Sphaeroidnella dehiscens*, have a wider distribution.

Using the 'Stereoscan' scanning electron microscope we have compared the degree of calcification of the individual species from the various tows with those isolated from sea-bed samples. These studies show, for example, that the tests of *Globorotalia menardii* from 50 m horizontal tows are invariably thin-walled, whilst sea-bed samples contain both thin and thick walled tests. The surface of the later chambers in the last whorl are smooth. Small pustules are, however, developed on the early chambers of the last whorl as well as on the lip and the keel of the early chambers. The last chamber in the final whorl shows very clearly a multitude of pores which are on the average 1½ microns in diameter. They occur not only on the chamber surface but also on the keel which has previously been considered imperforate. Between the pores the chamber surface is relatively smooth.

We have made δO^{18} analyses on single tests of *Globorotalia menardii* isolated from 50 m horizontal tows. The precision of these analyses appears to be almost entirely governed by the mass spectrometer in use, and varies between ± 0.08 parts per thousand for samples of about 0.3 mg weight, and ± 0.13 per thousand for small samples weighing about 0.04 mg (both figures one standard deviation). The results of these analyses shows that in the 50 m horizontal tows the isotopic temperature determined on the tests of *Globorotalia menardii* shows reasonably good agreement with the observed temperature. For example at 28°S-113°E the calculated isotopic temperature for this species at 50 m is 20°C whereas the observed temperature is 19°C, whilst at 7°S-113°E the calculated temperature is 27°C whereas the observed is 26°C. A comparison of our isotopic temperatures with the known temperatures suggests that there is at 50 m a systematic difference of 1°-2°C with the known sea temperatures. It should, however, be pointed out that our analyses are referred to the PDB standard via the NBS 20 standard using the value of $-4.14‰$ δO^{18} obtained for this standard by Craig in 1957. Craig cited only three analyses and drew attention to the fact that this material gave less reproducible results than the other carbonate standards which he analysed. We would suggest that at 50 m the small positive discrepancy between our calculated siotopic temperatures and the observed temperatures is more likely to be due to the difficulty of obtaining a good calibration back to the PDB standard

than to some departure from equilibrium in the calcite tests of planktonic foraminifera.

It is significant that many of the tests of *Globorotalia menardii* in the 125-0 m inclined tows show a notable increase in the number and in the size of the pustules on the ventral surface as well as on the keel. In addition many of the pores on the early chambers of the final whorl have been obliterated by calcification. The thicker tests caught in the 250-0 m inclined tows show under the 'Stereoscan' a great increase in calcification. In the ventral view large pustules surround the umbilicus ; the keel is thickened with calcite rhombs which show an increase in size on early chambers, and it is only on the final and penultimate chambers that the pores can be clearly seen. In the dorsal view the keel is thickened all the way round, and the chambers of the earlier whorl are hidden by calcification in the form of rhombs.

The thickened tests in a 1000-500 m inclined tow do not show any major differences when compared with those from 250-0 m inclined tows. Large pustules occur around the umbilicus, especially on the early chambers. The pustules on the keel have merged to form rhombs which also occur on the lip, and the chamber walls are greatly thickened. The keel as well as the final chamber are heavily calcified ; the keel is at least four times as thick as in the 50 m horizontal tows. The dorsal view of thickened tests from these deep tows shows rhombs covering all the earlier whorls. Rhombs also occur on the early chambers of the final whorl and the later chambers are heavily calcified. It is significant to note that in this deep inclined tow there are a number of thinly calcified tests which are indistinguishable from those caught in the upper layer.

Isotopic temperature measurements have been made on 9 *Globorotalia menardii* tests showing different degrees of calcification in the 1000-500 m inclined tow. It is of considerable interest that the calculated isotopic temperature range is 20.5°-26°C, whereas at this station the temperature at 50 m is 28.05°C. The thermocline starts at a depth of 60 m and finishes at about 500 m where the temperature is 9.97°C. Clearly our isotopic temperature results indicate that in some of the tests there has been a considerable increase in calcification whilst the test was in the thermocline. Although with a greater number of measurements lower and higher temperatures would undoubtedly be found, it seems unlikely that any would fall within the sea temperature range for this inclined tow—namely 6.71°-9.97°C. We may, therefore, tentatively conclude from these isotopic measurements that effective calcification has ceased in depths shallower than 500 m. From our combined studies on the samples available to us we may conclude that calcification has effectively ceased in depths shallower than 250 m ; that calcification commences in the upper isothermal layer where the tests are thinly calcified and show no calcite rhombohedra, and that in the upper layer the tests give calculated isotopic temperatures which are closely comparable with those of the sea. When the tests sink from the isothermal layer into the thermocline a significant proportion of the tests became heavily calcified. It is, however, not clear to us why some of the tests within and below the thermocline are thinly calcified and similar to those in the upper layer. We could, however, suggest as an hypothesis that this may be connected with the process of reproduction.

Tests of *Globorotalia menardii* from sea-bed sediments show a complete range in the degree of calcification. There are thinly calcified tests which are indistinguishable from those caught in the 50 m horizontal tows, as well as intermediate and thickly calcified tests which are similar to the thickly calcified tests from the deeper plankton tows.

Similarly there is in tests of *Globorotalia menardii*, abstracted from a sea-bed sample, a range of calculated isotopic temperatures which apparently corresponds to the degree of calcification. We have determined δO^{18} on 44 tests of this species from three horizons in a deep-sea core. If the δO^{18} measurements from the first and third horizons are adjusted to the average for the second horizon, and the computed temperatures are plotted as a histogram there is a temperature range of 13°-25°C with a peak at about 19.5°C. It is possible that the two tests showing the lowest temperatures at approximately 13.5°C and 15.5°C were derived by vertical mixing from a colder period; an alternative explanation would, however, be that these low temperature are related to a greater than usual calcification within the thermocline. We may conclude from our 'Stereoscan' and isotopic studies that *Globorotalia menardii* is an unsuitable species for palaeosalinity and palaeotemperature investigations (Bé and Ericson, Shackleton, Wiseman warned many years ago against the use of this species). It is possible, however, that this species could be used with some confidence, provided that the isotopic determinations were confined to those thinly calcified tests which we have shown to be the characteristic feature of the upper layer of the sea. Consequently with this limitation this species may eventually prove to be of considerable use for the interpretation of intractable equatorial Pacific cores.

One of the most useful species for palaeosalinity and palaeotemperature investigations is *Globigerinoides sacculifera*. We have studied under the 'Stereoscan' this species from 50 m horizontal tows, 125-0 m, 250-0 m, and 1000-500 m inclined tows. There is in this species no appreciable difference in the degree of calcification in the 50 m horizontal tows than in those from greater depths, although some of the tests from greater depths as well as those from sediments lose their spines. Our studies suggest that in this species calcification is completed between depths of 50-125 m, and that no additional calcification takes place at greater depths. It is, therefore, to be expected that *Globigerinoides sacculifera* would be one of the most suitable species for determining in the upper layer of the sea past changes in salinity and temperature.

Our detailed examination of these tow net samples has led to the discovery of a new planktonic foraminiferal species. The new species is non-spinose. This species has been found in tow net samples both north and south of the equator, and in sediment samples as far north as 18°. It is clearly an equatorial species. It has been provisionally referred to the genus *Globorotalia* Cushman 1927 and to the subgenus *Clavatorella* Blow 1965. This sub-genus is of considerable interest because the only other record known to us is from the West Indies in the Upper Miocene.

We would, in conclusion, like to say that in the course of this investigation we have studied and are still studying other planktonic species by 'Stereoscan' and isotopic techniques, and will shortly be undertaking δO^{18} determinations on sealed samples of water from specific depths. The results of these investigations (there are many interesting features, as well as complications which have not been previously described) will be reported elsewhere. Finally we would like to stress the desirability of the many present-day oceanographical expeditions paying attention to collections, as well as geophysics. The very successful GLOMAR CHALLENGER is a notable example of this. When collecting samples all the relevant physical and chemical information should be determined, and they should be collected under controlled conditions. Every effort should be made to avoid contamination in view of the quantitative techniques which are frequently used today; the samples should of course be stored in Institutes where they can be carefully registered and properly housed.