J. mar. biol. Ass. India, 1976, **18** (3) : 626-631

BOTTOM SEDIMENTS OF THE INDIAN OCEAN AND ANTARCTIC: RADIOLARIAN STRATIGRAPHY*

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ABSTRACT

Recent radiolarian fauna living to the south of the Antarctic Polar Front is known to differ sharply from that living in the tropical regions of the Indo-Pacific. About 78% of the total number of radiolarians in antarctic bottom assemblage were unchanged in the last 1.6 million years. The ancient antarctic assemblage has been different from the then fauna of the low latitudes, but the difference was not so striking as it is now. The ancient fauna of the Antarctic Sea may be regarded as the temperate one.

The recent radiolarian fauna of the low latitudes of the Indian Ocean is older than the antarctic fauna. About 2.5 to 2 million years ago the fauna of the low latitudes was very much the same as the recent, both as to the set of genera and species, and as to the population size.

It is evident that in the last 3 million years the rapidity of the evolution of the radiolarian fauna was different in the high and low latitudes of the Indian Ocean.

RADIOLARIAN biostratigraphic zones were established by J. Hays (Hays, 1965; Hays and Opdyke, 1967) for Antarctic bottom sediments and by W. Riedel (Riedel, 1957; Riedel and Sanfilippo, 1969) for the equatorial sediments. The present paper is devoted to the comparison of the radiolarian zones in sediments from low and high latitudes. Altogether 618 samples from the bottom cores taken in the Antarctic and in the temperate regions of the Indian Ocean and in the Equatorial Indo-Pacific were studied.

The calculation of radiolarian shells and their percentage was carried out. The author succeeded in identifying 40-60% radiolarian shells in the samples of tropical sediments and 75-99% skeletons in the samples of antarctic sediments.

The age of the sediments was determined on the basis of radiolarians (on the basis of the data, given by Hays *et al.* (1969). The task was simplified by an examination of the original samples sent to the author by Prof. W. Riedel and Dr. J. Hays. The author takes this opportunity to acknowledge this help. The age determination of some cores was confirmed by paleomagnetic data as done by Linkova (1969).

The data of different cores, pertaining to the occurrence and to the extinction of some species (obtained by J. Hays and the present author) are given in Fig. 1.

* Presented at the 'Symposium on Indian Ocean and Adjacent Seas—Their Origin, Science and Resources' held by the Marine Biological Association of India at Cochin from January 12 to 18, 1971.

In Fig. 1 the cores, represented with the vertical lines, are placed from left hand to the right, beginning with the most southern localities up to the most northern ones. These diagrams may be counted as the sections through the living area of the species : they demonstrate the time changes of the geographical ranges of the species.

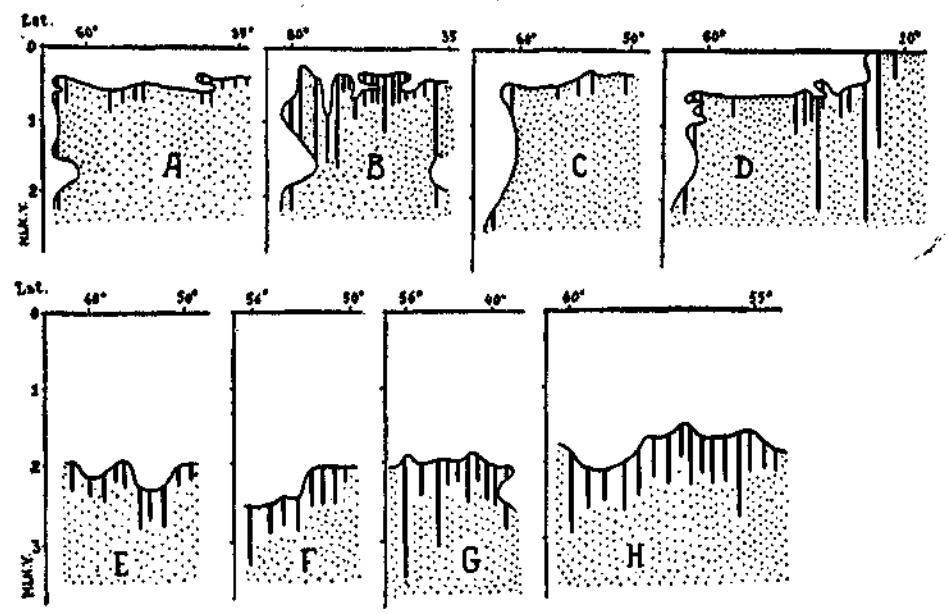

Fig. 1. Geographical and geological distribution of some species : a. *Perichlamidium* sp. ; b. *Stylatractus universa* Hays sens. str. ; c. *Pterocorys ob* Petrushevska ; d. *Saturnalis circularis* Hck. ; e. *Desmospyris spongiosa* Hays ; f. *Pseudocubus vema* (Hays) ; g. *Eucyrtidium calvertense* Martin ; h. *Clathrocyclas anthebicornis* Petrushevska (= *C. bicornis* Hays).

The extinction of some species takes many hundred thousand of years. As example, more than one million years ago *Saturnalis circularis*, occurred everywhere from India up to the Antarctic continent (Fig. 1). Then, with the cooling of the climate, its area diminished, and now *S. circularis* occurs only in the tropical regions, being rather rare even there. The extinction of some other species (e.g., *Eucyrtidium calvertense* Martin) took less time : about 100 - 200 thousand years (Fig. 1 g).

It is more difficult to get evidence about the time of the appearance of new species. The fact is that the material from the cores permits to catch only the moment when the specimens of the new species become numerous and spread all over their living area. It seems likely that species such as *Clathrocyclas bicornis* (Popofsky) (Plate I, I), *Anthocyrtidium ophiurense* (Plate I E), *Pterocorys hertwigii* (Plate III K) [rising : first - from *Clathrocyclas antebicornis* (Plate I G), second - from *Anthocyrtidium ehrenbergii pliocenica*, third - from *Pterocorys campanula* (Plate III J)] got their present area of the distribution in some scores of thousands of years.

For some genera (*Clathrocyclas* in high latitudes and *Anthocyrtidium* in low latitudes) it is possible to follow the history of the replacing the ancestor species by newly evolved ones (Fig. 2). In many cases, the divergence was found to take place: two new species originate from the parent one. One of the daughter-species differs more strikingly from the parent-species (compare Plate I G and I), than another daughter-species (compare Plate I G and H). The other 'new' species as a rule become more numerous and widely distributed.

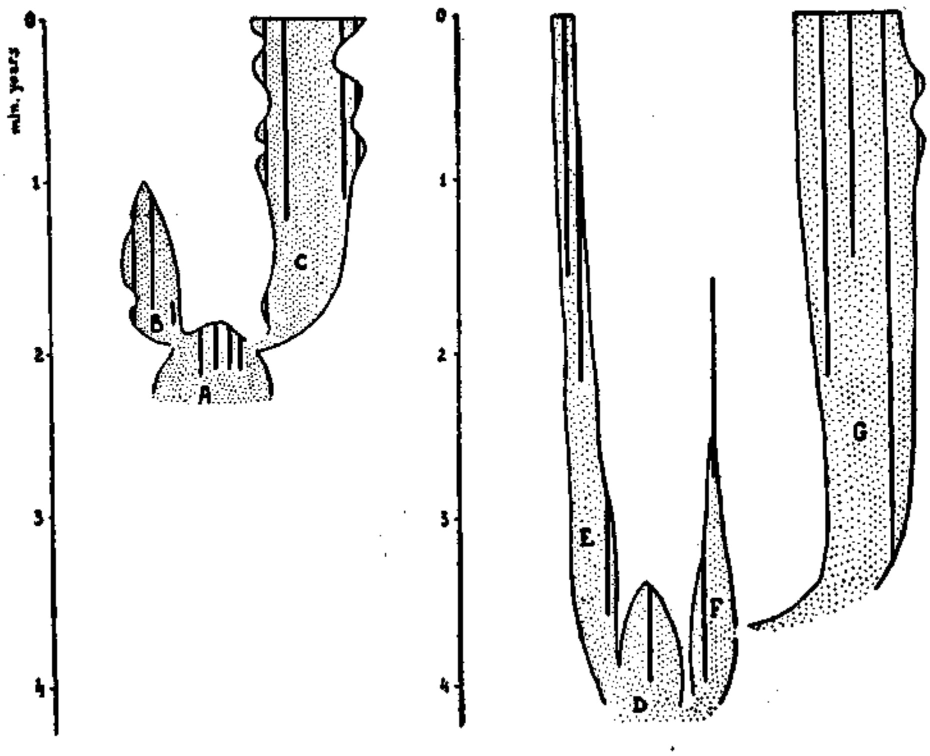

Fig. 2. Late history of *Clathrocyclas* and *Anthocyrtidium*: a. *Clathrocyclas antebicornis*; b. *Clathrocyclas* cf. *anthebicornis*; c. *Clathrocyclas bicornis* (Popofsky); d. *Anthocyrtidium ehrenbergii ehrenbergii*; e. *A. zanguebaricum*; f. *A. ehrenbergii pliocenica*; and g. *A. ophiurense.*

These data contradict with that of Riedel, who believes one species to be gradually transformed into another by one determined tendency. It hardly may be an universal rule. Besides the origin of only one species (Plate II K) after extinction of *Eucyrtidium calvertense* (Plate II J), or the rising of *Saccospyris antarctica* (Plate II C, D) from *Saccospyris preantarctica* (Plate II A, B) prove that the path way, indicated by Riedel, is possible in some cases.

Considering the time-ranges of 126 radiolarian species, 30 species were selected as promising age-indicators. Their specimens are numerous enough, their time-limits and their geographical distribution are established (Plate IV).

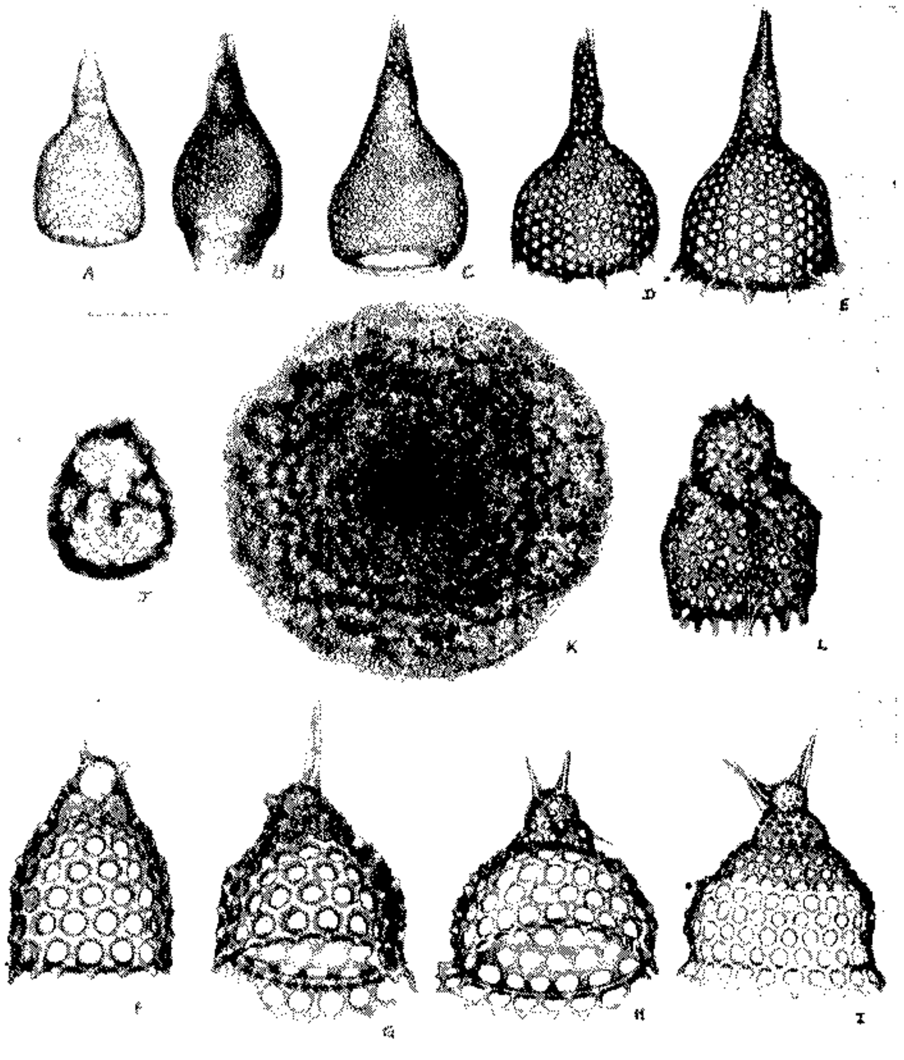

PLATE I. Age-indicator species and radiolarians related to them. A. *Anthocyrtidium zanguebaricum* (Ehr.); B. *Anthocyrtidium* sp.; C. *Anthocyrtidium ehrenbergii ehrenbergii* (Stöhr); D, E. *A. ophirense* Hck.; F. *Clathrocyclas* sp.; G. *C. anthebicornis* Petrush.; H. *C.* cf. *anthebicornis*; I. *C. bicornis* (Popofsky); J. *Antarctissa cylindrica* Petrush.; K. *A. strelkovi* Petrush.; L. *Perichlamydium* sp. All under the same magnification. Marker 50 microns.

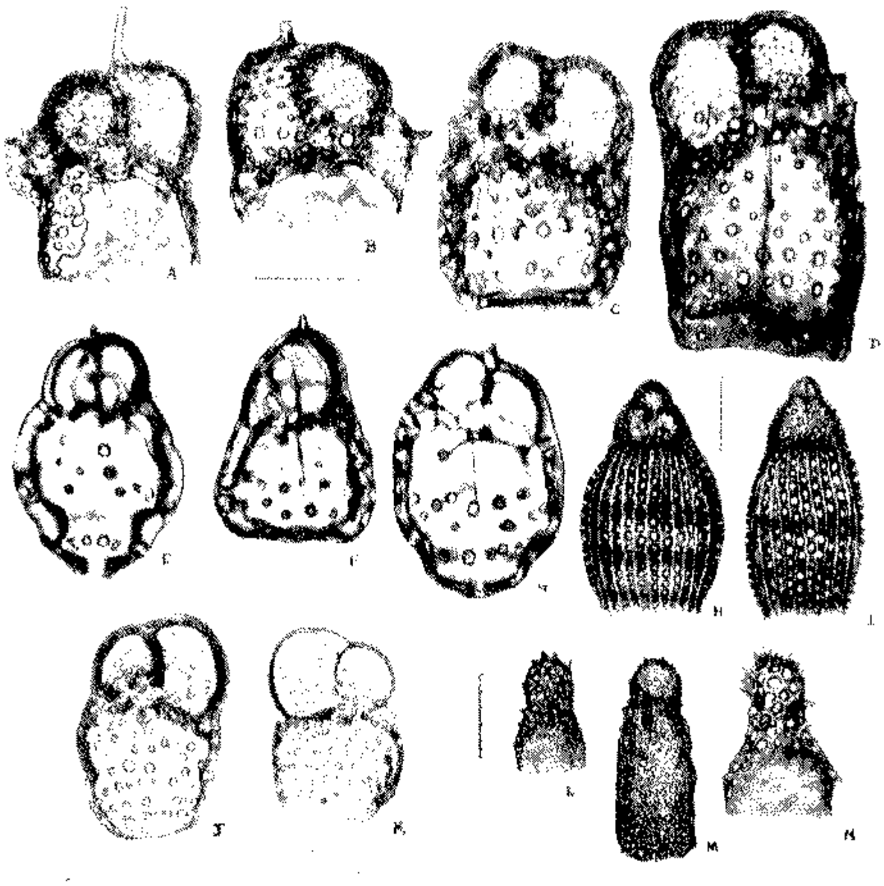

PLATE II. Radiolarians : age-indicators and related to them. A, B *Sacospyris preantarctica* Petrush. ; C, D. *Sacospyris antarctica* Haeckel ; E, F. *Lithobotrys* cf. *conithorax* (Petrush.) ; G. *Lithobotrys conithorax* (Petrush.) ; H, I. *Eucyrtidium calvertense* Martin; *Lithobotrys* sp.; J. *Eucyrtidium calvertense* Martin ; K. *E.* cf. *calvertense* ; L, M. *Lophophaena cylindrica* (Cleve) and N. *Lophophaena hispida* (Ehr.). A - I × 400 ; J, K × 300 ; L-N × 350. Marker 50 microns

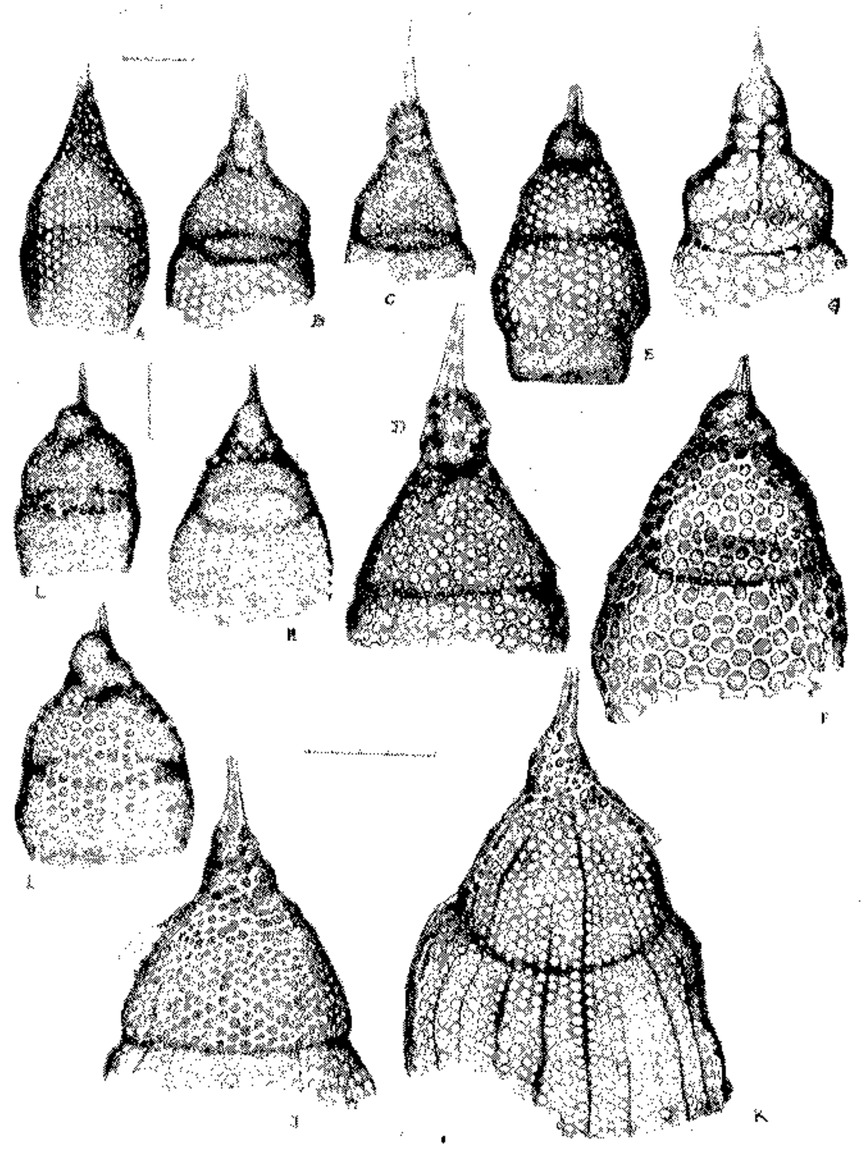

PLATE III. *Pterocorys* species age-indicators and species similar to them. A. *Pterocorys* sp. 1; B. *Pterocorys* sp. 2; C, D. *P. sabae* (Ehr.); E, F. *P. ab* Petrush.; G. *P. zanguebaricus* (Ehr.); H. *P. clausus* (Popofsky); I. *P. clausus compressus*; J. *P. campanula* Hck.; K. *P. hertwigii* (Hck.); L. *Eucyrtidium*(?) *turgidulum* Ehr. A, B, C, E × 300; H and L × 350; D, F, G, I, J, K × 400. Marker 50 microns.

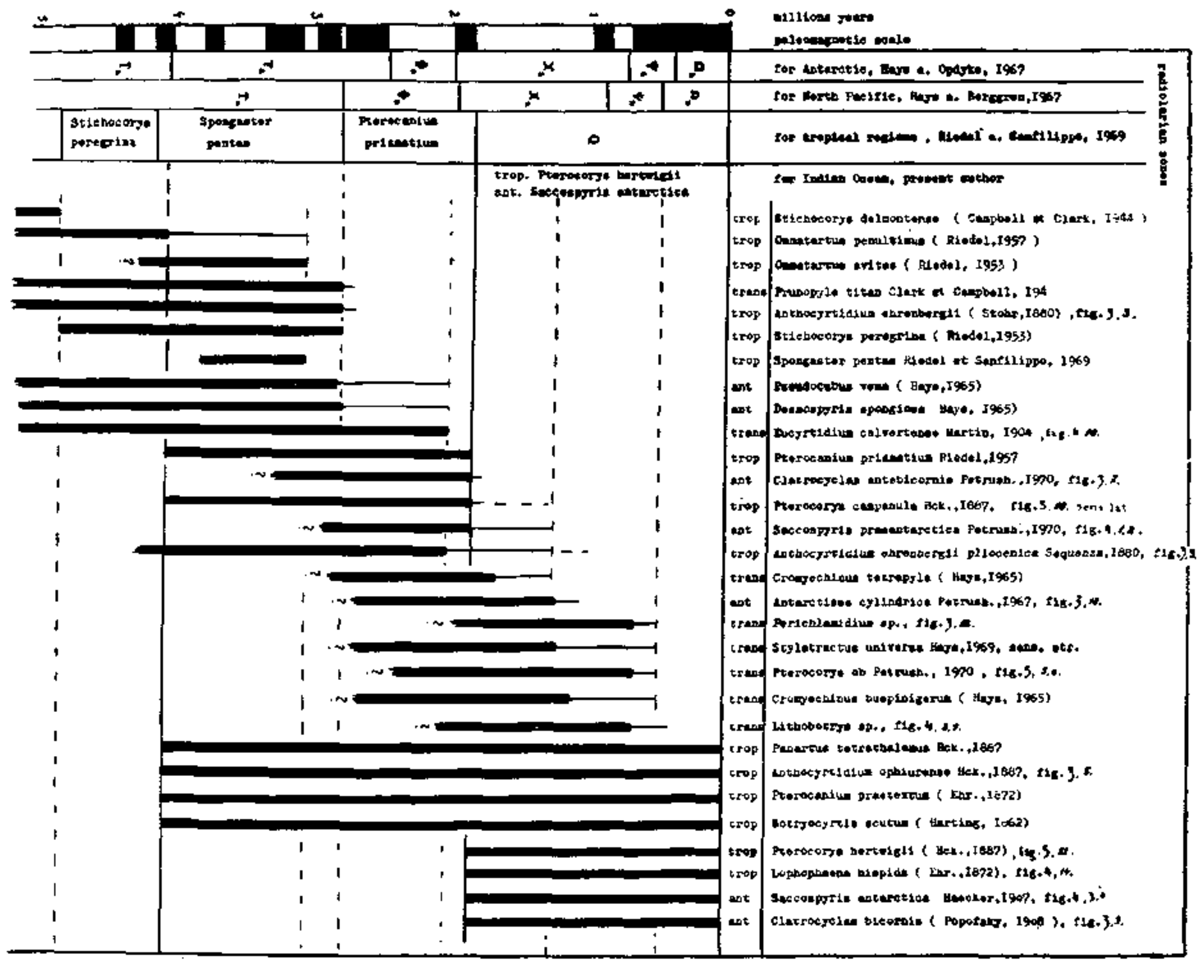

PLATE IV. Radiolarian zonation. Solid lines—zones' boundaries, dotted lines—subzones' boundaries. 'trop'—tropical species, 'trans'—transitional and widely distributed, 'ant'—antarctic species.

It was shown by Riedel and Sanfilippo (1969) that there are certain moments when the extinction of some species and the rising of another took place in the tropical regions. These moments were regarded as the limits of stratigraphical zones.

It is possible to find examples of simultaneous extinction and delivering of species in high, temperate and low latitudes (Petrushevska, 1970). The fact, that these moments are nearly the same in different geographical regions may be considered as the base for the universal stratigraphical zonation adequate to the high and low latitude's deposits. The scheme of such zonation is presented in Plate IV.

The uppermost zone - ' quaternary ' after Riedel - may be named ' *Pterocorys hertwigii*-zone ' in tropics or ' *Saccospyris antarctica*-zone ' in the Antarctic. Its lower boundary is about 1.6-1.8 million years. Below it is the zones: ' *Pterocanium prizmatium*-zone ' and ' *Spongaster pentas*-zone ' in the tropics or ' *Clathrocyclas antebicornis*-zone ' in the Antarctic. ' *Clathrocyclas anthebicornis*-zone ' it is the lowest part of Hays ' ' χ zone ' + ' ϕ zone ' + ' γ zone ' of Hays.

Most of my material concern with the uppermost zone. It may be divided into 3 subzones. The limits of subzones are marked only by the extinction of some species, not by the origin of new ones. The lower limit of the upper subzone (Fig. 6) is marked by latest occurrence of *Perichlamidium* sp., *Lithobotrys* sp., *Pterocorys ob*, *Cromyechinus buspinigerum* and *Stylatractus universa*. The age of that boundary is about 0.45 million years and this subzone is practically equal to the ' Ω zone ' of Hays. As to the next two Hays's zones ψ and χ, I failed to find distinct proof of their limits. Thus, the χ/ψ zones boundary (age 0.6 million years) in the sediments of Antarctic Seas and southern regions of the Indian Ocean is marked only by the diminishing of the area of some warm-water species. The evolutionary changes of the significance, equal to that of the changes which mark the boundary between upper and middle subzones, took place earlier - about 1.2-1.3 million years ago. By then *Pterocorys campanula*, *Saccospyris preantarctica*, *Cromyecinus tetrapyla* (Plate IV) ceased to exist.

Though the boundaries of all described zones and subzones may be found both in high and low latitudes' deposits, these boundaries are more prominent in the Antarctic bottom sediments. By my evidence in the low latitudes in the time between 2 and 1.6 million years ago 5-8% the whole number of the radiolarian shells (specified) were replaced by the specimens of another species. In the Antarctic in that very time about 60-70% radiolarian shells were replaced by those of the other species. In the low latitudes similar striking changes took place earlier—between 4 and 3 million years ago. The rapidity of the radiolarian evolution seems to be different in the low and in the high latitudes.

It seems that in high latitudes as well as in low, evolutionary changes did not go gradually, but by leaps and bounds. The changes of the fauna in the short time of some ' busy ' periods of 0.2-0.5 million years were more significant, then the changes in the time of ' still ' 1.5-2 million years between these ' busy ' periods. Here is the foundation for biostratigraphic zonation: ' still ' periods are zones, ' busy ' periods—boundaries between zones.

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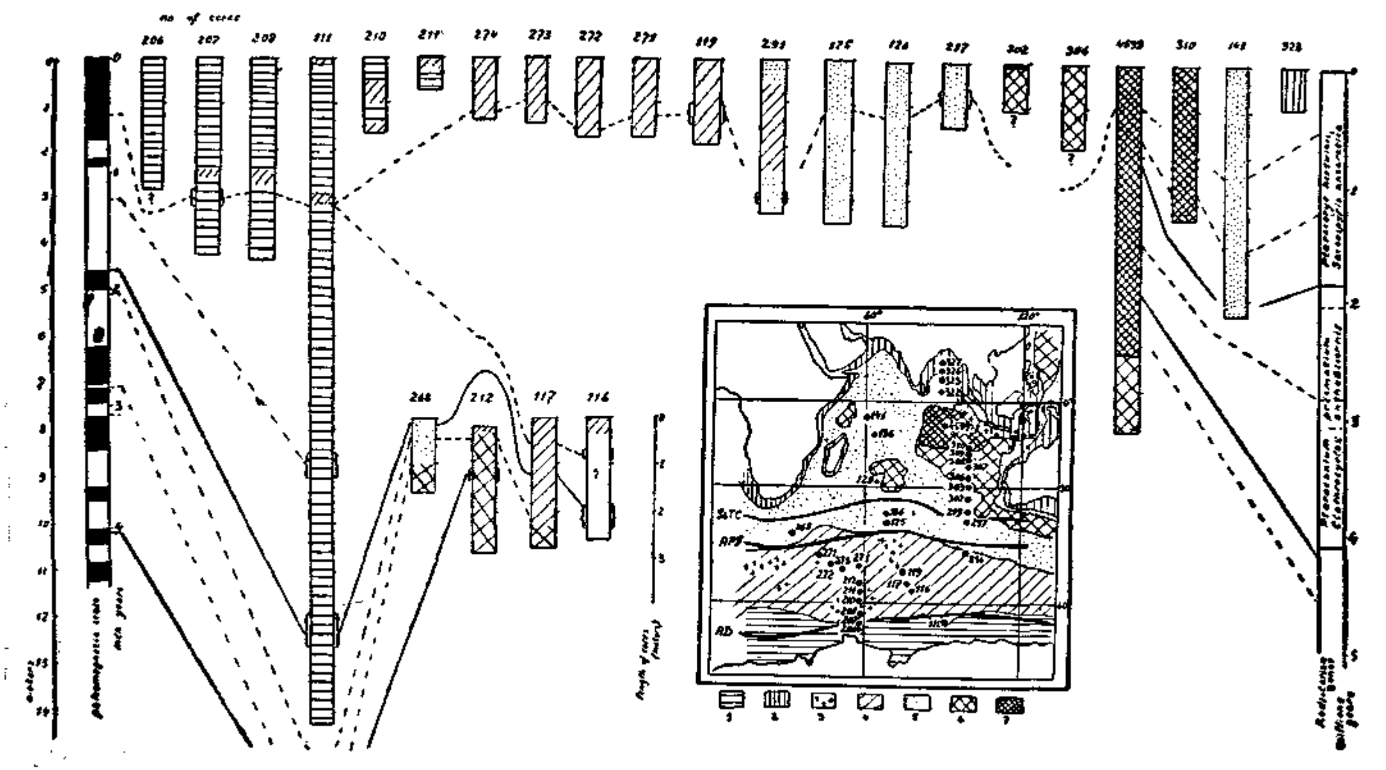

Fig. 3. The thickness of the different zones' sediments (deposits). Position of cores studied is shown on the map. Classification of the bottom sediments and their distribution - after Bezrukov and Lisitzin: 1. terrigeneous Antarctic sediments, 2. other terrigeneous, 3. volcanic, 4. diatom clay, 5. foraminiferous clay, 6. deep-sea red clay and 7. radiolarian clay. APF—Antarctic Polar Front, Sbt C - Subtropical Convergence, AD - Antartic Divergence. Zonation—see Plate IV.

It is not clear, why radiolarian species (as well as species of Foraminifera, Diatoms and Silicoflagellates) appear or become extinct at one and the same time. The hypothesis was advanced by Hays and Opdyke (1967) that paleomagnetic reversals are responsible for the existence of radiolarian species. Really, magnetic reversals, being global phenomena, must influence species of various latitudes at the same time. The less adopted species disappear, to be replaced by some new species. Here may be the ground for the zonation adequate for high and low latitudes deposits. But the real causes of any evolutionary changes are well known to be in the interaction of the individuals in the biocoenosis. Unlike other ocean plankters radiolarians are poorly investigated. So it is difficult to understand the grounds of the radiolarian evolution and therefore the grounds for radiolarian stratigraphy.

As to stratigraphy itself, zonation established (Plate IV) permits the following correlation of the cores studied by the author (Fig. 3). It permits to draw the conclusions on the rates of sedimentation in various regions of the Indian Ocean during certain time.

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