The use of radiolaria in the stratigraphy of deep-sea sediments

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The sediment cores collected by the Swedish Deep-Sea Expedition in 1947-48 offer a unique opportunity for the study of the distribution of the Radiolaria, during the present and geologically recent past, in the tropical parts of all the oceans. With the object of determining to what extent the Radiolaria can be used in deep-sea stratigraphy, the author has undertaken a study of the remains of these animals in the cores collected by the "Albatross" in the Western Pacific Ocean. The present paper, which contains some of the more important results so far obtained from these investigations, indicates the type of problems which can be studied through these microfossils, and the limitations of their stratigraphical use.

From an ecological point of view, the Radiolaria are an imperfectly known group. Their distribution in restricted parts of the oceans is fairly well known from the results of such expeditions as the "Challenger" (Haeckel, 1887), the Deutsche Südpolar-Expedition, the Plankton-Expedition der Humboldt-Stiftung, and others. The Radiolarian records from some of these expeditions are of great value and reliability - this is the case when the living animals are described, and exact data regarding their occurrence are given.

Unfortunately, Haeckel's report of the Radiolaria from the "Challenger", although it remains an extremely important systematic work, is inadequate in this respect. He states (General Introduction, p. cxlvii) :

"The statements made in the systematic portion of this Report regarding the distribution of the Challenger Radiolaria are very incomplete. In most cases only one locality is mentioned, and that is the station in the preparations or bottom deposit from which I first found the species in question. Afterwards I often found the same species again in one or more additional stations (not seldom in numerous preparations both from the Pacific and Atlantic), without the possibility of

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For valuable suggestions regarding the presentation of the systematic section of this paper, the author is indebted to Dr. C.D. Ovey, of the British Museum (Natural History).

adding them to the habitat recorded under the description."
Moreover, there is frequently no indication whether he has found the organisms living, or only as skeletons in the sediment. The Report of the "Challenger" is virtually the only work describing the Radiolaria from the tropical parts of the Indian and Pacific Oceans.

The state of our knowledge of the palaeontology of the Radiolaria is similarly unsatisfactory. Assemblages of their skeletal remains have been described from a number of localities of diverse ages, from the Algonkian to the late Tertiary, in Europe, North America, the East and West Indies, Australia and Asia. Even so, Tan Sin Hok (1932), in a review of the attempts of earlier authors to establish stratigraphical correlations on the basis of Radiolarian faunas, pointed out that these fossils had hitherto proved to be of very little use in this respect. The only fauna which has been shown to be characteristic of a certain period is the Saturnalis-fauna of the Mesozoic: this specialized fauna has been recorded from several localities of the Italian Jurassic and Cretaceous by Squinabol (1914) and from the Cretaceous of California by Campbell and Clark (1944b).

Even the Radiolaria of the Tertiary are poorly known. This is well illustrated by the recent work of Campbell and Clark (1942, 1944a, 1945) on material from the Tertiary of California. From rocks of Eocene and Miocene age, these authors describe some 300 species, subspecies and varieties, all of which are new: and this in spite of the fact that a number of Tertiary Radiolarian faunas have been described from Europe, and the West and East Indies. There are three possible reasons for such a state of affairs. Firstly, the systematic classification of the group may be based on fundamentally false principles. Secondly, the Radiolarian species may have restricted areas of geographical distribution, and/or, thirdly, the species may in general have very short time-ranges. It is hoped that the present paper may go a short way towards deciding which of these is the case.

Materials and Methods.

The object of this paper is not to give a complete picture of the Tertiary Radiolaria encountered in the sediment cores from the Western Pacific. This would involve the description of a large number of new forms, and the identification of hundreds of others. Only one assemblage is discussed at any length, since it shows striking similarities to a fauna described from the Miocene of Southern California by Campbell and Clark (I944a). Also, evidence is brought forward supporting the theory that Tertiary deep-sea deposits are at the present time being eroded by currents and re-deposited simultaneously with material from surface waters. Finally, a second Radiolarian fauna, probably also of Tertiary age, is cursorily described.

The fauna with elements in common with that of the Californian Miocene is best developed in the lower parts of the sediment core No. 87 (Lat. 2 23'N, Long. I73 50'W, depth below sea surface 5560 m.): the material described is from a depth of 999-I000 cms. below the surface of this sediment. Secondly, the material most recently deposited in this region is examined - namely, that from the uppermost centimetre of core No. 87B[x]. Thirdly, with the object of comparing the Radiolaria in the two samples mentioned with those from the surface of the sediments in other parts of the Pacific and Indian Oceans, a table is given showing the prominent Radiolaria in the uppermost parts of the following cores :

Core No.	Latitude.	Longitude.	Depth below sea surface (m.)
74	S 0 29'	W I5I 33'	4525
87B	N 2 23'	W I73 50'	5560
89	S 2 48'	W I78 57'	5480
9IB	S 2 50'	E I7I I8'	4I20
95	N 0 34'	E I59 59'	2880
I3I	S II I0'	E 96 42'	4390
I37	N I 56'	E 88 I2'	4300
I54	S 0 23'	E 54 30'	4860

Fourthly, the second (probably Tertiary) fauna is described from a sample from a depth of I4 metres below the sediment surface of core No. 9I (Lat. S 2 50', Long. E I7I I8', depth below sea surface 4I20 m.). The species lists from each of these samples are in no way exhaustive - only those forms which are most abundant or pertinent to the present problems are included.

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[x] Core No. 87B, taken from the same position as core No. 87, is much shorter than the latter, since it was taken with a core-sampler of a type which ensures that the topmost part of the sediment remains intact. With the longer Kullenberg core-sampler, it is likely that several centimetres of the sediment column are lost through the top of the apparatus. Throughout this paper, the letter "B" after the number of a core indicates that the core was taken with the shorter sampler.

In order to free the Radiolarian skeletons from the sediment, the samples were first treated with cold dilute hydrochloric acid to remove the calcium carbonate, and then boiled with hydrogen peroxide to further the disintegration of the clay aggregates. No attempt was made to separate the organic remains from the finer inorganic debris by sieving or decantation, due to the risk of losing the smaller and more delicate skeletons (Riedel, 1951). The skeletons, together with the remaining non-calcareous sediment, were strewn on slides, dried, and mounted in hyrax. Types and figured specimens are preserved in the Natural History Museum of Göteborg.

A Late Tertiary Radiolarian Fauna.

A Radiolarian fauna containing species in common with the Californian Miocene was met with in a number of cores, including core No. 73 (Lat. 4 04'S, Long. 152 53'W, depth below sea surface 5200 m.), core No. 85 (Lat. 5 34'N, Long. 172 12'W, depth below sea surface 5590 ± 50 m.) and core No. 87 (position given above). It is best developed in the lower parts of core No. 87, where, among others, the following forms are present :

Rhopalodictyum malagaense Campbell and Clark.

Rhopalodictyum (Rhopalodictya) malagaense Campbell and Clark, 1944a, p.29, pl.4, figs. 4 and 5.

This species, which Campbell and Clark describe from the Miocene Malaga mudstone of Southern California, is rather common in the lower parts of our core No. 87 from the Western Pacific.

Lychnocanium grande Campbell and Clark rugosum n. subsp.
(Plate I, figure I)

Lychnocanium (Lychnocanella) grande Campbell and Clark, 1944a, p.42, pl.6, figs. 3, 4 and 6.

This species was described by Campbell and Clark from near the top of the Valmonte diatomite of Southern California.

Specimens from the Western Pacific sediment correspond to the original description in all respects, except that the surface of the thorax is constantly rough - for this reason, the new subspecies is erected.

<u>Lychnocanium grande</u> Campbell and Clark <u>rugosum</u> n. subsp.

(Plate I, figure I)

Shell campanulate, rough, with pronounced cervical stricture. Cephalis subglobular, its length 0.3 that of the thorax, with rough surface and shallow, subcircular pores of moderate size. Apical horn subvertical, broadly conical, its length 0.3 that of the cephalis. Thorax subconical, its maximum breadth 3 times that of the cephalis, its length half that of a foot, with constricted aperture 0.6 as wide as the maximum breadth. Walls of the thorax thick, with rough surface: its pores subcircular, 9-IO in a vertical tier, about 40 around the broadest circumference, decreasing in size from the aperture towards the cervical stricture. Aperturai rim bears slender, short, often oblique spines. Three feet divergent, slightly reflexed or almost straight, three-bladed, distally sharp, proximally thick, arising just above the apertural margin. Cephalis 26 u long, 35 u broad. Thorax 92 u long, II0 u broad. Length of feet I75 u. Diameter of largest thoracic pores 8.4 u.

The species was described by Campbell and Clark (I944a, p.42) from near the top of the Valmonte diatomite of Southern California.

Specimens from the Western Pacific sediment correspond to the Californian form in most respects, but the surface of the thorax of the new subspecies is constantly rough, and the thoracic pores are smaller.

<u>Pterocorys splendens</u> Campbell and Clark <u>albatrossensis</u> n. subsp.

(Plate I, figure 2)

Shell subconical, with cervical stricture less pronounced than that at base of thorax. Cephalis campanulate, hyaline, 0.25 as long and 0.3 as broad as the thorax, bearing I5-20 minute pores. From the apex of the cephalis arises a slightly sinuous, subvertical, rodlike apical horn three times as long as a radial apophysis. Thorax subconical, of the same length as a radial apophysis, laterally bulged especially in the lower half, bearing some 50 unequal, irregularly rounded pores which are I-4 times as broad as the bars: its surface bears scattered, short, slender, oblique spines. Abdomen (missing from figured specimen) subcylindrical, extremely delicate, about half as long as the thorax and almost as broad, with relatively large subcircular pores.

The three radial apophyses, arising near the base of the thorax, are straight, divergent, triangularly bladed, with the dorsal blade continued a short distance along the surface of the thorax. Cephalis 17 u long, 25 u broad. Thorax 70 u long, 78 u broad. Length of apical horn 210 u. Diameter of largest thoracic pores 15.5 u.

Campbell and Clark (1944a, p.46) describe the species from several localities of the Miocene of Southern California.

Specimens from the Western Pacific sediment correspond to the Californian species in general form, and the nature of the thorax and abdomen and their pores - they differ from the latter in that the cephalis bears minute pores, the radial apophyses are less curved inwardly, and the dimensions are generally smaller.

Calocyclas margatensis Campbell and Clark.

(Plate I, figures 3 and 4)

Calocyclas (Calocycletta) margatensis Campbell and Clark, 1944a, p.47, pl.6, figs. 17 and 18.

The specimens from the Western Pacific sediment are quite typical. The original description was from the Valmonte diatomite and the Miocene of the Newport area, Southern California.

Eucyrtidium delmontense Campbell and Clark.

(Plate I, figure 5)

Eucyrtidium (Eucyrtis) delmontense Campbell and Clark, 1944a, p.56, pl.7, figs. 19 and 20.

Specimens assigned to this species show some affinities with Eucyrtidium elongatum Stöhr 1880, from the tripoli of Grotte, Sicily: for example, the number of abdominal joints frequently exceeds three. It is placed in Campbell and Clark's species since the test is apparently thinner than that of Stöhr's species, the pores of the first abdominal segment are larger, and the constrictions between the segments are more pronounced.

This species presents difficulty in classification, because it has some of the characters of the genus Stichocorys, and some of Eucyrtidium. The cephalis, thorax, and first abdominal segment together form a cone, and the subsequent segments are together subcylindrical: in this feature, the species approaches the several species of Stichocorys which Haeckel (1887) described from the Pacific Ocean (Stichocorys wolfii, S. panderi, S. baeri, S. okenii, S. huschkei, S. rathkei and S. mülleri). Occasionally, in the specimens from core No. 87, the second abdominal segment can become rather long, or merged with the third: it then shows some similarity to Stichocorys saccoi Vinassa 1900, originally described from the Miocene of Montegibio, and recorded by Luchesse (1933) from the Miocene of Ca' Lambasini a Bargone. On the other hand, the slight constriction of the mouth, and the fact that there is no especially pronounced constriction between the conical and subcylindrical parts of the shell, support its being placed in the genus Eucyrtidium.

Eucyrtidium delmontense Campbell and Clark may prove to be identical with E. elongatum Stöhr. This question can be settled only by comparison of material from the type localities of the two species, since Stöhr's description and figure are somewhat inadequate. If these two species are identical or closely related, it will constitute a link between the Radiolaria of the tripoli of Grotte and of the Pacific sediment, as Stöhr describes this species as "rather abundant", and E. delmontense Campbell and Clark is one of the dominant species in the lower parts of our core No. 87 (See Pl. II, fig. I).

When it is considered that there are here only five species in common with the fauna described from the Californian Miocene, and that several score of species are present in one or other but not common to the two localities, it may appear that there is little reason for assigning an almost similar age to the two faunas. This would be the case when dealing with most other fossil groups, but the Radiolaria have in general such very short time-ranges that such a degree of similarity may well be significant.

The results of Campbell and Clark (1942, 1944, 1945) in the late Mesozoic and Tertiary of California may be taken as an example illustrating the short time of persistence of Radiolarian species. From the Upper Cretaceous they described some 80 forms, all of which except two were new. From several Eocene localities, 211 species were described, all of which were new, a considerable number occurring in more than one locality. Ninety-one species, all new, were found in the Miocene. Considering this absence of forms common to the different periods, and the fact that these faunas were deposited within such a limited geographical area, and not in isolated basins but in former extensions of the Pacific Ocean, and that all the Tertiary forms apparently lived in warm water, the only possible conclusion is that Tertiary species of Radiolaria have generally short time-ranges.

A large number of species previously described from the Miocene are absent from the fauna of the lower parts of core No. 87. On the other hand, a considerable number of present-day and undescribed forms are present. In view of these, and the previous considerations, a Pliocene age is tentatively assigned to it.

The Radiolaria of Rotti.

The wide distribution of many present-day Radiolaria (see below), and the fact that at least a few species are common to both the Miocene of California and the late Tertiary deposits of the Western Pacific, indicate that it is probable that any late Tertiary Radiolaria found in rocks of the East Indies would show close relationships to the fauna at the bottom of our core No. 87. Assuming, of course, that the East Indies fauna lived in a sea in open contact with the Pacific Ocean, and not in an isolated basin.

Tan Sin Hok (I927) described fossil Radiolaria from the island Rotti, from rocks to which he tentatively assigned a Pliocene age. In all, he described I4I species, three of which were identical with previously-known forms (two Recent and one Triassic). All of the others were new species, though he (I927, p.79) was able to compare twenty of them with species previously described - one was comparable with a Palaeozoic form, I6 with Mesozoic forms, and 3 with forms of unknown age. Nevertheless, he did not regard such a congruence of forms as having any stratigraphical significance.

During the quarter of a century which has elapsed since this work was published, there have been several descriptions of Radiolarian faunas which indicate that the Radiolaria may be more useful for purposes of stratigraphical correlation than Tan Sin Hok believed. The Saturnalis-fauna described from California by Campbell and Clark (I944b) appears to confirm the opinion of Squinabol (I914) that such an assemblage is characteristic of certain Mesozoic deposits. Descriptions of other Mesozoic faunas by Heitzer (1930), Khudyaev (1931) and Chabakov (1937) have increased our knowledge of the Jurassic and Cretaceous forms of these animals. Also, more is known of Tertiary Radiolaria as a result of the work of Campbell and Clark mentioned above.

In the light of the work done subsequent to 1927, the similarities (which Tan Sin Hok himself points out) between the fauna from Rotti and other Mesozoic faunas, and its differences from other Tertiary faunas, it appears probable that this fauna which he doubtfully places in the Pliocene is Mesozoic in age. One striking feature is the great proportion of Cyrtoidea eradiata in the fauna from Rotti, a characteristic which finds its parallel to a certain extent in the Californian Cretaceous (Campbell and Clark, 1944b) and the upper Mesozoic of Russia (Khudyaev, 1931), and more pronouncedly in the Jurassic of the Sonnwendgebirge (Heitzer, 1930) in the Jurassic and Cretaceous in the region of the Ural Mountains (Chabakov, 1937).

Thus, the only Radiolarian fauna from the East Indies which could have been expected to show relationships to the late Tertiary fauna of the Western Pacific, appears to be considerably older than was previously supposed.

Radiolaria at the Top of Core No. 87B.

The following is a list of some of the Radiolaria found in the uppermost centimetre of core No. 87B.

Cyphonium mammarium Haeckel
Panartus quadrijugus Haeckel
Heliodiscus asteriscus Haeckel
Euchitonia elegans (Ehrenberg)
Rhopalodictyum malagaense Campbell and Clark
Spongaster tetras Ehrenberg.
Tetrapyle quadriloba (Ehrenberg)
Lychnocanium grande Campbell and Clark *rugosum* n. subsp.
Anthocyrtidium cineraria Haeckel
Carpocanium peristomium Haeckel
C. petalospyris Haeckel
Pterocorys splendens Campbell and Clark *albatrossensis* n. subsp.
Pterocanium tricolpum Haeckel
Calocyclas amicae Haeckel
Calocyclas margatensis Campbell and Clark

Tricolocampe polyzona Haeckel
Lithomitra lineata Haeckel
Eucyrtidium delmontense Campbell and Clark (in considerable numbers)

Widely Distributed Present-Day Species.

In his monograph on the Radiolaria from the "Challenger" expedition, Haeckel (1887) describes many species as "cosmopolitan", indicating that they are widely distributed in the oceans of the present time. With the object of determining which species are distributed throughout the tropical parts of the Western Pacific and Indian Oceans, the uppermost parts of a number of cores from these regions were examined, and their common forms determined. The results are given in Table I : the positions from which the cores were taken are given in the section "Materials and Methods", above.

A (?) Tertiary Fauna from Core No. 91.

The lower part of this core contains a Radiolarian fauna which appears very different from the present-day fauna of this region, and from that at the bottom of core No. 87. The following forms are abundant; *Dipospyris* aff. *forcipata* Haeckel (recorded from the Central Pacific), *Calocyclas* aff. *virginis* Haeckel (recorded from the Central Pacific), *Stichocorys baeri* Haeckel (recorded from the North Pacific), *Eucyrtidium delmontense* Campbell and Clark (recorded from the Miocene of California), and a number of species of *Dictyospyris* (See Pl. II, fig. 2).

It is likely that solution of the more delicate tests has altered the facies of this fauna subsequent to deposition, but nevertheless the general aspect is not that of a recent assemblage. A more thorough description of this fauna will be given in a later publication.

Evidence of Erosion and Re-Deposition.

From the lists given in the preceding sections, it will be seen that the Radiolarian fauna at the top of core No. 87B includes all the species which occur in the other surface samples ~~mentioned~~ examined, together with species found at a depth of

TABLE I

The Occurrence of some Widely-Distributed Present-Day Radiolaria.

Core No.	74	87B	89	91B	95	131	137	154
Depth below sediment surface (cm.)	1-2	0-1	0-6	0-1	1-2	0-1	1-1.5	2.5-3
Cyphonium mammarium Haeck.	x	x	x	x	x	x	x	x
Panartus quadrijugus Haeck.	x	x	x	x	x	x	x	x
Heliodiscus asteriscus Haeck.	x	x	x	x	x	x	x	x
Euchitonia elegans (Ehr.)	x	x	x	x	x	x	x	x
Spongaster tetras Ehr.	x	x	x	x	x	x	x	x
Tetrapyle quadriloba (Ehr.)	x	x	x	x	x	x	x	x
Anthocyrtidium cineraria Haeck.	x	x	x	x	x	x	x	x
Carpocanium peristomium Haeck.	x	x	x	x	x	x	x	x
C. petalospyris Haeck.	x	x	x	x	x	x	x	x
Pterocanium tricolpum Haeck.	x	x	x	x	x	x	x	x
Calocyclas amicae Haeck.	x	x	?	x	x	x	x	x
Tricolocampe polyzona Haeck.	x	x	x	x	x	x	x	x
Lithomitra lineata (Haeck.)	x	x	x	x	x	x	x	x

IO metres below the surface of the sediment of core No. 87. There There are five possible explanations for such an association of older and newer species.

(I) The Tertiary species may be relics, extinct in most parts of the oceans but still living in certain restricted areas, of which this is one. If this is the case, there is no reason why the tests of the Tertiary species should show more abrasion than the Recent forms - as is pointed out below, the skeletons of Eucyrtidium delmontense Campbell and Clark show unmistakable signs of abrasion. Moreover, it is likely that all of the Tertiary forms concerned are inhabitants of the surface waters, and not of deep basins, so that the chances of isolation are small.

(2) The Tertiary species may be brought to the surface by burrowing invertebrates living at the surface of the sediment, and thus become mixed with the skeletons of present-day species. If this were the only mixing mechanism in action, the proportion of Tertiary forms in relation to Recent forms should decrease as a geometric progression in an upward direction in the sediment. That this is not the case is obvious from an inspection of the fauna at levels one metre apart in the core - the proportion of Tertiary forms to others remains fairly constant in the upper metres.

(3) The older species are mixed with the more recent ones by isolated catastrophes of short duration, such as submarine slumping, density currents, or the disturbing effects of tsunamis or submarine volcanic activity. To test this hypothesis, the levels in the core at which present-day species disappear were determined - the results are given in Table II. It is seen that these forms do not disappear simultaneously, but the vertical ranges of each are different. If one or more isolated catastrophes were responsible for the mixing, there would be abrupt disappearance of many species at certain levels.

(4) Core No. 87 is taken in an area of erosion, so that the sediment at the surface is of an age intermediate between that at the bottom of this core, and the sediment being deposited at the present day in other parts of the ocean. As with suggestion (I), such an explanation is not consistent with the abrasion of the Tertiary forms.

TABLE II

Illustrating the Time-Ranges of some Radiolaria, in Core No. 87.

On the basis of comparison with the results from other cores, it is believed that this table gives a true picture of the relative time-ranges of the species concerned, though there may be some modification due to unobserved slight disconformities.

Depth below sediment surface (cm.)	1	9	20	30	40	50	60	68	80	90	190	290	390	490	587	690	790	890
Cyphonium mammarium Haeck.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-
Panartus quadrijugus H.	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-	-
Heliodiscus asteriscus H.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Euchitonia elegans (Ehr.)	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
Spongaster tetras Ehr.	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-
Tetrapyle quadriloba (Ehr.)	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-	-
Anthocyrtidium cineraria H.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-
Carpocanium peristomium H.	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-	-	-	-
C. petalospyris H.	x	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-
Pterocanium tricolpum H.	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-
Calocyclas amicae H.	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
Tricolocampe polyzona H.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lithomitra lineata (H.)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

(5) The Tertiary species are being carried by a bottom current to the position of core No. 87, from an adjacent area of erosion: they enter the sediment simultaneously with the skeletons of forms living in the surface waters. This appears to be ~~ty~~ the true explanation.

One method of testing the validity of this conclusion is to examine the degree of erosion, or abrasion during transport, of the Tertiary forms found in the surface sediment. Eucyrtidium delmontense Campbell and Clark is a suitable form for such a test. The upper three segments of its skeleton (particularly the thorax and first abdominal segment) are more sturdy than the subsequent ones. If any abrasion takes place, it is the latter segments which will be worn away first. In samples both from the top of core No. 87B and near the bottom of core No. 87, counts were made of the number of specimens of this species which had (I) the first three segments intact, (2) the first four segments intact, and (3) more than the first four segments intact. The results are set out in Table III, below.

Table III

Core No. 87B, the uppermost centimetre.

	No. of intact segments in Eucyrtidium delmontense		
	3	4	More than 4
No. of specimens	I79	97	27
Percentage of total counted	59.I	32.0	8.9

Core No. 87, at a depth of IO metres.

	No. of intact segments in Eucyrtidium delmontense		
	3	4	More than 4
No. of specimens	I67	I28	4I
Percentage of total counted	49.7	38.I	I2.2

Thus it is seen that a greater percentage of specimens with four or more chambers is found in the deeper sample, and the percentage of specimens with only three intact segments is greater in the upper sample. This supports the theory that specimens of this species in the surface sample have been subjected to abrasion, and are probably derived from some other locality where sediments of a late Tertiary age are exposed to the action of currents.

An alternative explanation could be that burrowing invertebrates living at the sediment surface crush the skeletons to a greater extent at present than they did at the time of deposition of the sediment at the bottom of this core. This, however, is unlikely, as even the most delicate of the present-day species are well preserved in the upper sample.

Discussion.

The first question which arises in connection with the foregoing evidence of erosion by currents in the deep-sea is whether this process is wide-spread. It might well be restricted to a few places, where the topography of the sea floor exposes sediments to the action of currents: and the latter may be confined by the topography to a particularly narrow channel, with a consequent increase in their speed, turbulence, and transporting power. Wiseman and Ovey (1950, pp. 45 et seq.) have summarized the results of the few recent investigations on the agents of transportation of material along the deep-sea floor. In the Western Pacific, at least, the effects of such erosion and transportation seem to be rather wide-spread. Preliminary investigations indicate that late Tertiary Radiolaria have been deposited in the uppermost parts of several of the sediment cores taken in this region, e.g. Core No. 85 (Lat. 5 34′N, Long. 149 44′W, depth below sea surface 5590 ± 50 m.) and Core No. 76 (Lat. 3 45′N, Long. 149 44′W, depth below sea surface 5155 m.).

Where the sea floor has not been affected by tectonic movements during the Tertiary, and the older sediments are covered by a thick layer of Pleistocene deposits, disturbance of the sediments by bottom currents would be difficult to detect even if it were universal. Sediment particles under such conditions may undergo no more transport than a little intermittent saltation, even though a considerable number of particles may simultaneously be in suspension some metres above the bottom. In a region of recent diastrophic activity such as the Western Pacific, however, the redistribution of sediments by bottom currents may be expected to have more far-reaching effects. Subsequent to the tectonic movements of the Tertiary, unconsolidated sediments must often have been brought into the sphere of influence of any deep currents which may have existed, and considerable erosion may have taken place.

Our knowledge of the existence and nature of currents at great depths is at present scanty, but some measurements of the turbidity of sea-water made by the hydrographers of the Swedish Deep-Sea Expedition are of interest in this connection. Turbidity measurements were used to estimate the amount of material suspended in the water at different depths, and there was often found to be a concentration of particles in suspension near the sea floor. Jerlov (1950) states :

"Eine solche Schichtung in Bodennähe wurde an vielen Stationen während der Expedition beobachtet. Eine Erklärung für dieses Phänomen kann möglicherweise darin zu suchen sein, dass laminare Strömungen Sediment von in der Nähe gelegenen höheren Stellen mitführen. Dies bedeutet, dass die Sedimentation von der lokalen Topographie beeinflusst wird".

Measurements of turbidity close to the sea floor were unfortunately not made in the Western Pacific, and such an investigation remains one of the more important desiderata of the study of sedimentation in that region.

In the past, workers studying the Radiolaria have taken no account of the possibility of the sea floor being eroded by bottom currents: they have assumed that any skeletal remains at the surface of the sediment are of recent origin. In a group such as the Radiolaria, where our knowledge is largely based on skeletal remains in sediments, the consequences of this are rather serious. For example, Haeckel (1887) described some 1600 species of Radiolaria from the Central and Western Tropical Pacific alone (this figure includes only those species with skeletons capable of preservation in sediments), and it seems not unlikely that a considerable number of these forms are not living at present, but have been derived from late Tertiary deposits.

In the future, it will be necessary for investigators to consider the possibility of mixed faunas, made up of elements which are not isochronous. From one point of view, this has set back our knowledge of the Radiolaria - it is no longer possible to be sure that the species described by such workers as Haeckel are living in the oceans. On the other hand, the fact that Tertiary Radiolaria can occur in Recent sediments enhances the value of this group for geological investigations of deep-sea sediments. These siliceous skeletons resist solution and abrasion to a much greater extent than the remains of most other organisms, and their small size enables them to be carried by currents whenever there is any movement of sediment in suspension. Where mixing of sea-floor sediments has occurred, the Radiolaria, and possibly also the diatoms, are probably the only fossils which will indicate it. The limited time-ranges of the species, and the wide geographical distribution of a large number of forms, are important factors which indicate that the skeletons of these organisms will become increasingly useful for stratigraphical correlations in deep-sea sediments.

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EXPLANATION OF PLATES.

All the figures of Plate I were drawn to 500x, and are reduced one half. The figured specimens all came from a depth of 999-1000 cm. below the surface of the sediment of core No. 87.

For the microphotographs of Plate II, the author is indebted to Dr. T. Levring, director of the Marinbotaniska Institut of Göteborg.

PLATE I

Figure

1. *Lychnocanium grande* Campbell and Clark *rugosum* n. subsp.
2. *Pterocorys splendens* Campbell and Clark *albatrossensis* n.subsp.

3, 4. *Calocyclas margatensis* Campbell and Clark. The damaged specimen (Fig.4) shows the nature of the incomplete septum at the thoracic stricture.

5. *Eucyrtidium delmontense* Campbell and Clark.

PLATE II

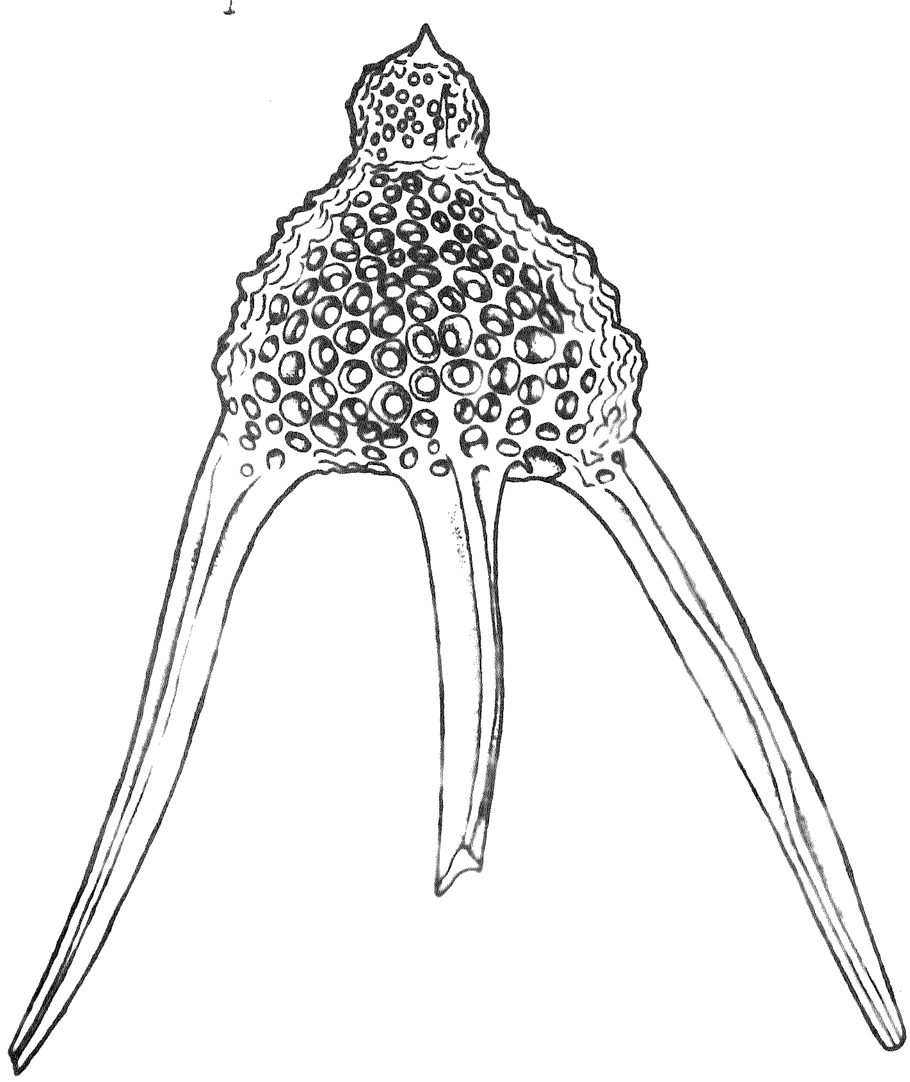
Figure

1. A representative part of a strewn-slide of the Radiolaria from core No. 87 (10 metres below the sediment surface). It illustrates the relative abundance of *Eucyrtidium delmontense* C. and C. 65x.

2. A representative part of a strewn-slide of the Radiolaria from core No. 91 (14 metres below the sediment surface), illustrating the relative abundance of *Eucyrtidium delmontense* C. and C., *Calocyclas* aff. *virginis* Haeck., and *Dictyospyris* spp. 65x.

[Photograph of drawings made for publication]

1



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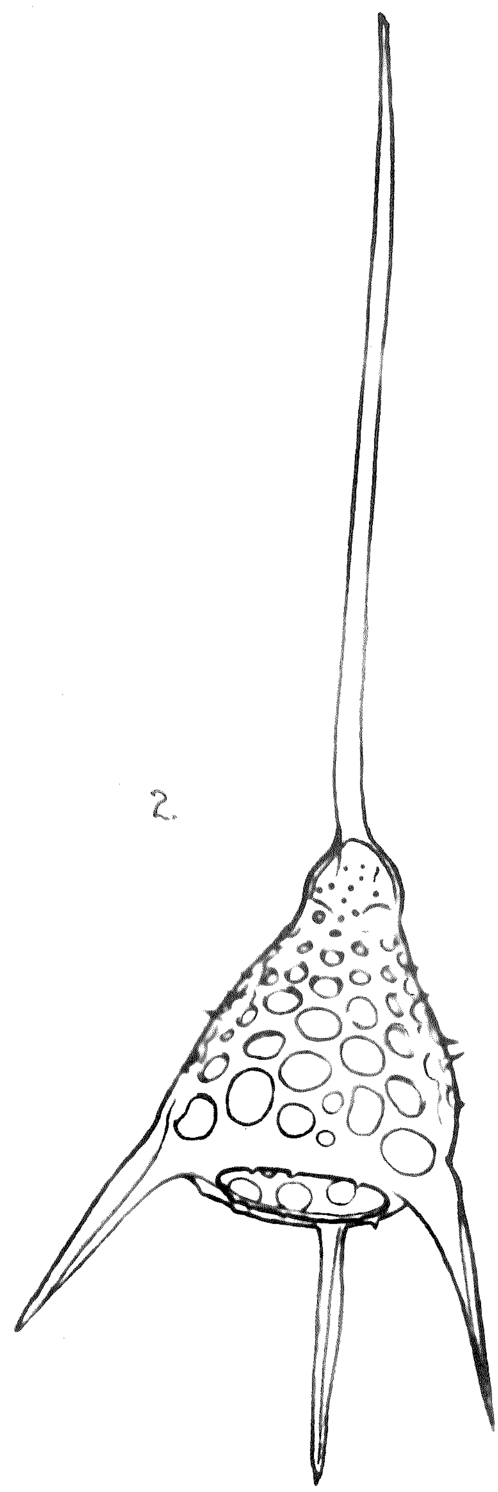

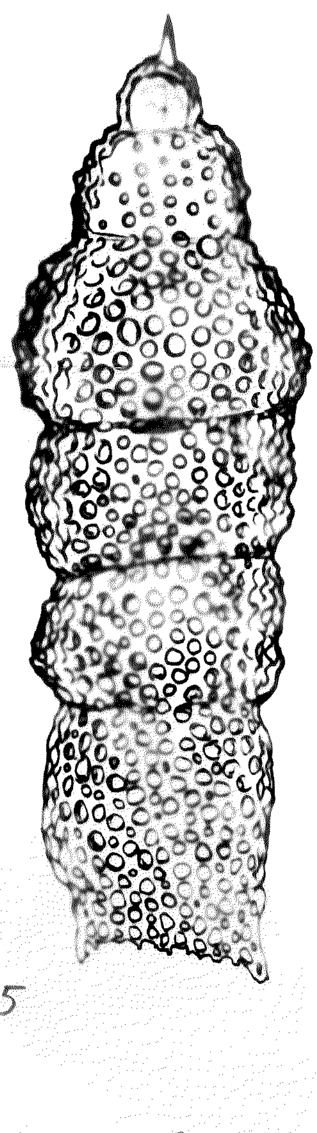

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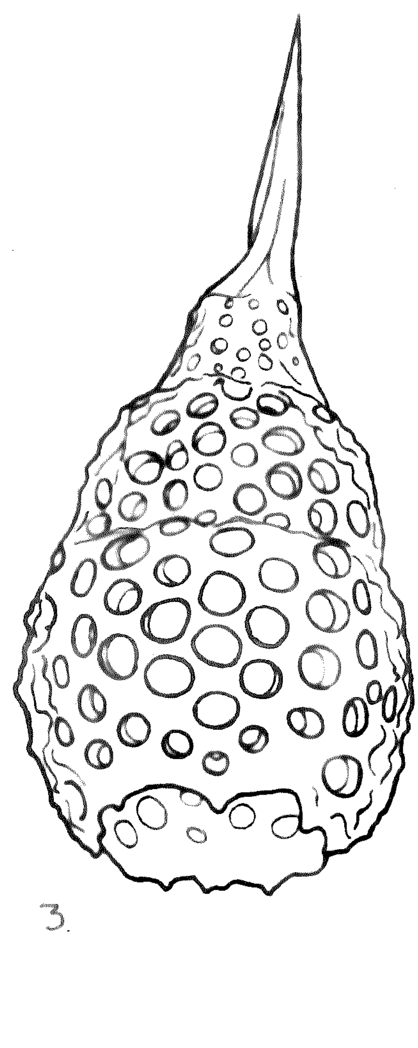

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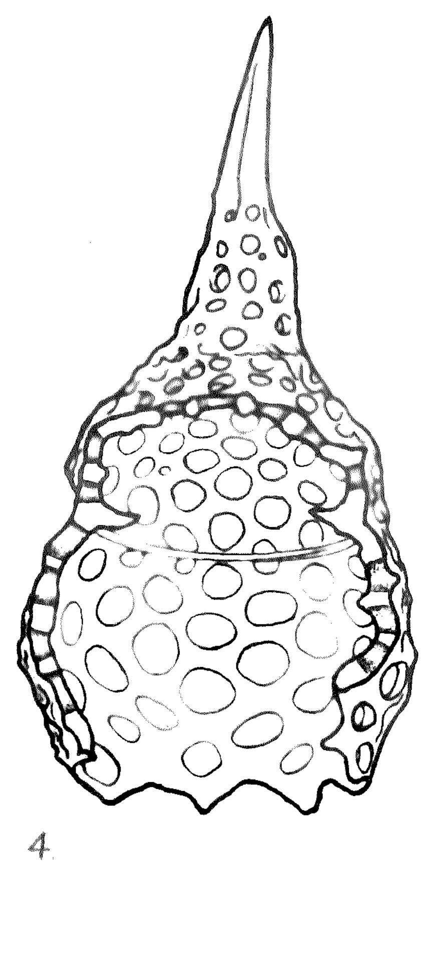

4.

Plate I

[illegible]

x 500 Reduce to exactly $\frac{1}{2}$