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Vertical flux of Radiolaria: A taxon-quantitative sediment trap study from the western tropical Atlantic

ABSTRACT

Radiolarian assemblages comprising 208 taxa were collected from the PARFLUX E sediment trap experiment at a pelagic station in the western tropical Atlantic. Their diversity is among the greatest ever reported for a living community. The settling flux rate of individual skeletons was on the order of 16×10^3 to 24×10^3 shells/m²/day. The species composition of the radiolarians in the sediment traps changed significantly between 389 and 988 m depth. We attributed this change to the input of nassellarian populations dwelling in aphotic deep water. The majority of radiolarian shells settle singly, and apparently reach the sea floor without substantial modification to the species composition and standing stock. The percentage of fragmentation counts of *Pterocorys* suggests that slow dissolution of radiolarian shells begins during the descent through the upper water column prior to reaching the bathypelagic zone.

INTRODUCTION

Detailed studies on living Radiolaria in pelagic environments have been made by many investigators since the classical works by Haeckel in the 19th century (e.g. Casey, 1971a, 1971b; Casey et al., 1971; Petrushevskaya, 1971a, 1971b; Bjørklund, 1974; Kling, 1976, 1979; Renz, 1976; McMillen and Casey, 1978; Leavesley et al., 1978; Casey, Gust et al., 1979; Casey, Spaw et al., 1979; Boltovskoy and Riedel, in press).

Renz (1976) compared the radiolarian biocoenosis (plankton pumps and tows) with the thanatocoenosis (core tops) in the central Tropical Pacific. She reported the elimination of some radiolarian species in the transfer from plankton to sediment. She further indicated that the loss of the species in the transfer increased from 25 to 98% between the tropics and the higher latitudes. Petrushevskaya (1971a) had previously reported that the proportion of radiolarian species in the plankton differs from that in the standing stock of the underlying sediments in the central Tropical Pacific, although she found that all the plankton species were represented in the underlying sediments.

It is generally known that radiolarian remains contribute substantially to the 3 major latitudinal belts of siliceous sediments in the world oceans. According to Lisitzin (1972), radiolarians account for 62 to 99% of the weight of the biogenic opal in the surface water suspension from the tropical Pacific, and hence constitute the major sedimentary component of biogenic opal in the region. Radiolarians in the surface sediments in the Atlantic (Goll and Bjørklund, 1971, 1974) generally occur in smaller numbers per unit weight of sediment than in the Pacific (Lisitzin, 1972). Berger's (1970) basin-basin fractionation model suggests that the Atlantic Ocean, in general, is the least favorable of the 3 major oceans for the preservation of biogenic opal.

On the other hand, the processes of accumulation of radiolarian thanatocoenosis on the sea floor are not yet understood. The description of radiolarian remains subsequent to their production and pre-burial is an important approach to understanding the geological and geochemical processes of oceanic opal. Heath (1974) pointed out that ecological studies of radiolarians bear a key to understanding the silica cycle in the oceans.

Since preservation of biogenic opal in the bottom sediments is principally a reflection of the rate of organic production in the overlying waters rather than a reflection of dissolution history (Riedel, 1959; Heath, 1969), biogenic opal may retain more oceanic environmental records than other sedimentary counterparts. However, the processes of biogenic opal sedimentation are poorly known. An investigation of

descending biogenic opal through the water column would provide important clues for our understanding of the sediment processes.

Geochemical studies based on alkalinity-dissolved silicon indicate that most of the dissolution of biogenic opal occurred on the sea-floor rather than in the water column (Edmond, 1974). Lisitzin (1972) suggested that the major dissolution of radiolarians and silicoflagellates occurs on the sea-floor, whereas most of the diatoms are destroyed in the water column. These statements were usually based on the spatial distribution of suspended opal particles that only provided instantaneous standing crop information. Large shells might have escaped because of their faster settling rate through the water column.

The sediment traps prove an efficient method for collecting vertically settling large particles to determine actual fluxes (e.g. Wiebe et al., 1976; Gardner, 1977; Honjo, 1978). Detailed studies of radiolarian shells collected by sediment traps therefore should clarify important questions regarding the process of sedimentation of opal particles and assist in evaluating the paleoceanographic significance of Radiolaria in the environmental chain. The objective of the present paper is to document the flux of radiolarian shells at several trap depths and at the sea floor, with emphasis on the interpretation of taxonomic variability of samples from different depth intervals.

SOURCE OF SAMPLES; METHOD OF ANALYSIS

The samples used in this study were collected from sediment traps placed at Station E (Honjo, 1980, 13°32.2'N, 54°1'W; corrected water depth: 5288 m) of the PARFLUX Phase 1 program in the western Tropical Atlantic. The sediment traps were deployed for 98 days from November, 1977 through February, 1978. This station is about 750 km from the Guyana Coast in a region where there is little seasonal variation in zooplankton productivity (e.g. Moore and Sander, 1977). The underlying Demerara Abyssal Plain has a gentle topography and is covered with silty clay. The North Equatorial Current flows in a northwesterly direction, but no deep current measurements have been reported in the study area.

The sediment trap array deployed at Station E consisted of 4 traps, PARFLUX Mark II, with 1.5 m² opening (Honjo et al., 1980) and they were moored at 389-, 988-, 3755-, and 5068-m depths. The receiving cup was sealed by a time-controlled spring shutter prior to recovery.

The samples were wet-sieved upon arrival in the laboratory with a 1-mm screen and split into 4 aliquots by an Erez-Honjo precision rotary liquid splitter (Honjo,

TABLE 1
Summary of radiolarian slides used in the present study.

Size Fraction (μm)	Aliquot in Each Slide	No. of Slides Used for Counting	No. of Slides Used for Species Identification and Statistical Assessment
1000–250 (very coarse)	1/256	1	1
250–125 (coarse)	1/1024	1	4
125–63 (medium)	1/1024	1	4
<63 (fine)	1/8000	1	2

1978). An aliquot of material finer than 1 mm was further split into 4 aliquots 4 times. The resulting 1/256 aliquot of the original sample was wet-sieved through 250-, 125-, and 63-μm screens. The samples of 250–125 (defined as coarse size fraction in this paper) and 125–63 μm (defined as medium) were split further to 1/1024 aliquots prior to filtration. A sample of less than 63-μm (fine) size fraction was separately prepared by diluting a 1/64 aliquot to 250 ml in a measuring flask using filtered sea water from the deep Sargasso Sea, and then a 2-ml aliquot was taken by use of a pipet.

The above aliquots were filtered through a Millipore® filter with a nominal 0.45-μm pore size using a rectangular filtration funnel with 19 × 42-mm opening. The residue was rinsed with distilled water, then dried in a 50°C oven. Large foraminifera specimens in 1000–250 μm (very coarse) and coarse size fractions were removed under a binocular microscope. The dried filter sample was mounted on a standard glass slide after trimming off the excess margins. Drops of Cargile® type B compound were applied to clear the sample filter. It took a few days for the bubbles to escape from all radiolarian shells prior to placing a cover glass over the sample area. No vacuum was applied during the preparation. Aliquot size and number of slides which were used in this paper are summarized in table 1.

The slides were studied to identify radiolarian taxa and to count individuals to the species level, under a light microscope. The counts were converted to the flux term, number of individual shells/m²/day.

An abundant, medium-sized radiolarian genus, *Pterocorys* [*P. campanula* Haeckel, pl. 10, figs. 4–5; *P. zancleus* (Müller), pl. 10, figs. 1–3] was chosen in order to assess the range of error induced during sample preparation, and the reproducibility of shell counting. The assessment was made by counting *Pterocorys*

TABLE 2

The radiolarian (species) flux (no. of shells/m²/day) in the western tropical Atlantic Ocean. Data reported here include all size fractions from <63 μ m (fine) to 1 mm–250 μ m (very coarse).

Taxon	Sediment trap depth (m)			
	389	988	3755	5068
Suborder SPUMELLARIA				
Family SPHAEROZOIDAE Haeckel				
*Raphidozoum pandora Haeckel	86	71	63	12
*Total SPHAEROZOIDAE	86	71	63	12
Family COLLOSPHAERIDAE Müller				
Collosphaera tuberosa Haeckel	19	9	31	29
Acrosphaera spinosa Haeckel	10	58	65	116
Siphonospaera polysiphonia Haeckel	19	15	19	26
Otosphaera polymorpha Haeckel	40	29	40	29
Total COLLOSPHAERIDAE	88	111	155	200
Family LIOSPHERIDAE Haeckel				
Cenosphaera huxleyi Müller	5	46	107	38
Styptosphaera sp.	74	74	162	143
Plegmosphaera lepticali Renz	21	0	15	18
Total LIOSPHERIDAE	100	120	284	199
Family ACTINOMMIDAE Haeckel				
Acanthosphaera actinota (Haeckel)	38	0	61	51
Acanthosphaera sp. A	11	33	20	11
Heliosphaera radiata Popofsky	10	15	12	9
Thecosphaera inermis (?) (Haeckel)	251	58	409	194
Actinomma arcadophorum Haeckel	56	40	56	65
Trilobatum (?) aciferum Popofsky	238	58	673	437
Cromyechinus borealis (Cleve)	0	3	0	0
Cladococcus abietinus Haeckel	0	3	18	2
Cladococcus scoparius Haeckel	5	2	7	14
Astrosphaera hexagonalis Haeckel	5	5	16	0
Arachnosphaera hexasphaera Popofsky	21	12	37	23
Stylosphaera melpomene Haeckel	132	64	52	110
Stylosphaera lithatractus Haeckel	0	7	89	166
Xiphatractus pluto (?) (Haeckel)	0	2	57	26
Rhodosphaera (?) group	54	7	18	0
Staurotonche group	25	23	15	33
Staurotonche (?) sp.	2	16	19	14
Staurocontium sp.	9	0	0	0
Xiphosphaera tesseraetis Dreyer	2	0	5	2
Hexancistra sp.	41	36	139	70
Hexalonche sp.	6	6	0	10
Hexacontium axotrias Haeckel	22	33	71	21
Hexacromyrium elegans Haeckel	0	16	5	7
Centracontarium hexacontarium Popofsky	21	23	16	12
Centronche hexalonche Popofsky	0	3	5	5
Leptosphaera sp.	38	45	72	138
Centrocubus cladostylus Haeckel	3	0	3	14
Ommatartus tetrathalamus (Haeckel) subsp. A	104	161	156	149
Ommatartus tetrathalamus (Haeckel) subsp. B	21	16	41	27
Spongoliva cf. ellipsoides Popofsky	15	8	5	0
Total ACTINOMMIDAE	1130	695	2077	1610
Family PHACODISCIDAE Haeckel				
Heliodiscus asteriscus Haeckel	3	2	2	13
Spongaster tetras tetras Ehrenberg	42	46	63	99
Spongodiscus resurgens Ehrenberg	808	929	1337	1498
Spongodiscus sp. B				
Spongotrochus glacialis Popofsky				

TABLE 2

(Continued)

Taxon	Sediment trap depth (m)			
	389	988	3755	5068
Spongotrochus sp. A	44	45	73	14
Spongocore puella Haeckel	23	5	22	7
Total PHACODISCIDAE	920	1027	1497	1631
Family PORODISCIDAE Haeckel				
Amphirhopalum ypsilon Haeckel	0	0	7	3
Euchitonia elegans (Ehrenberg)	26	39	68	57
Euchitonia furcata Ehrenberg	106	32	128	46
Hymeniasstrum euclidis Haeckel	81	72	126	102
Porodiscus micromma (Harting)	76	160	257	114
Stylochlamydidium asteriscus Haeckel	121	72	55	91
Ommatodiscus murrayi Dreyer	0	0	36	16
Total PORODISCIDAE	410	375	677	429
Family LITHELLIDAE Haeckel				
Tholospira cervicornis Haeckel group	191	365	176	371
Larcospira quadrangula Haeckel	2	0	9	3
Hexapyle dodecantha Haeckel	32	6	12	33
Pylonena armata Haeckel group	163	85	186	111
Tetrapyle octacantha Müller	513	444	947	458
Octopyle stenozonea Haeckel	53	56	72	37
Total LITHELLIDAE	954	956	1402	1013
Suborder NASSELLARIA				
Family PLAGONIIDAE Haeckel				
Plectanium sp.	5	18	0	5
Archiscenium quadrispinum (?) Haeckel	17	86	158	152
Campylacantha sp.	75	239	129	83
Cladoscenium anacorum Haeckel	123	320	267	419
Obeliscus pseudocuboides Popofsky	83	131	167	113
Phormacantha hystrix (Jørgensen)	150	141	330	260
Peridium spinipes Haeckel	1251	2184	3114	2173
Peridium sp.	6	96	41	47
Lophophaena cf. capito Ehrenberg	21	17	36	28
Lophophaena cylindrica (Cleve) }	2445	1283	1925	1570
Peromelissa phalacra Haeckel				
Lampromitra circumtexta Popofsky	5	0	37	11
Acanthocorys cf. variabilis Popofsky	594	538	982	146
Helotholus histricosa Jørgensen	313	251	238	120
Callimitra elisabethae Haeckel	2	3	19	0
Callimitra emmae Haeckel	22	27	21	7
Total PLAGONIIDAE	5112	5334	7464	5134
Family ACANTHODESMIIDAE Haeckel				
Zygocircus capulosus Popofsky	248	596	795	285
Zygocircus productus (Hertwig)	453	436	634	431
Neosemantis distephanus Popofsky	39	43	19	98
Acanthodesmia vinculata (Müller)	108	91	69	54
Lophospyris pentagona pentagona (Ehrenberg)	20	35	60	72
Lophospyris pentagona hyperborea (Jørgensen)	64	44	83	38
Dictyospyris sp. A and B	109	54	36	9
Tholospyris fornicata Popofsky	0	13	0	11
Cantharospyris platybursa Haeckel	28	83	16	14
Amphospyris costata Haeckel	128	175	56	56
Total ACANTHODESMIIDAE	1197	1570	1768	1068
Family SETHOPHORMIDAE Haeckel				
Sethophormis pentactis Haeckel	0	0	0	18
Sethophormis rotula Haeckel	0	6	98	57
Total SETHOPHORMIDAE	0	6	98	75

TABLE 2
(Continued)

Taxon	Sediment trap depth (m)			
	389	988	3755	5068
Family THEOPERIDAE Haeckel				
<i>Cornutella profunda</i> Ehrenberg	64	141	367	160
<i>Peripyras circumtexta</i> Haeckel	0	16	40	39
<i>Theopilum tricostratum</i> Haeckel	28	34	49	20
<i>Clathrocyclas danaes</i> Haeckel	46	30	50	43
<i>Litharacnium tentorium</i> Haeckel	0	2	5	14
<i>Dictyophimus crisiae</i> Ehrenberg	0	2	48	49
<i>Pseudodictyophimus gracilipes</i> (Bailey)	14	163	361	260
<i>Pterocanium praetextum</i> (Ehrenberg)	207	158	102	88
<i>Dictyoceras virchowii</i> Haeckel	40	69	36	19
<i>Dictyoceras pyramidale</i> (Popofsky)				
<i>Eucyrtidium hexastichum</i> (Haeckel)	120	45	133	40
<i>Lithopera bacca</i> Ehrenberg	14	15	27	37
<i>Cyrtopera languncula</i> Haeckel	0	15	46	31
<i>Stichophormis</i> cf. <i>cornutella</i> Haeckel	0	54	7	2
<i>Theocorys veneris</i> Haeckel	9	24	215	53
<i>Theocalyptra davisiana</i>	82	354	784	207
<i>cornutoides</i> (Petrushevskaya)				
<i>Theocalyptra davisiana davisiana</i> (Ehrenberg)	83	122	197	75
Total THEOPERIDAE	707	1244	2467	1137
Family PTEROCORYTHIDAE Haeckel				
<i>Anthocyrtidium ophirensis</i> (Ehrenberg)	9	37	122	79
<i>Pterocorys zancleus</i> (Müller)	2966	2381	2698	1654
<i>Pterocorys campanula</i> Haeckel				
Total PTEROCORYTHIDAE	2975	2418	2820	1733
Family ARTOSTROBIIDAE Riedel				
<i>Siphocampe nodosaria</i> (Haeckel)	0	3	135	26
<i>Phormostichoartus corbula</i> (Harting)	0	30	17	17
<i>Spirocyrtilis scalaris</i> Haeckel	91	79	67	101
<i>Spirocyrtilis</i> sp. aff.	1496	629	653	660
<i>S. seriata</i> /S. <i>subscalaris</i>				
<i>Carpocanarium papillosum</i> (Ehrenberg)	0	7	2	56
Total ARTOSTROBIIDAE	1587	748	874	860
Family CANNOBOTRYIDAE Haeckel				
<i>Acrobotrys</i> sp. A, B, and C	123	76	126	68
<i>Botryocyrtilis scutum</i> (Harting)	226	167	212	111
Total CANNOBOTRYIDAE	349	243	338	178
Family CARPOCANIIDAE Haeckel				
<i>Carpocanistrum</i> sp.	9	69	72	7
Total CARPOCANIIDAE	9	69	72	7
Suborder PHAEODARIA Haeckel				
Family CHALLENGERIIDAE Murray				
<i>Challengeron willemoesii</i> Haeckel	128	110	62	36
<i>Challengeron radians</i> Borgert	6	0	6	5
<i>Challengeron balfouri</i> (Murray)	6	2	0	0
<i>Challengeron diodon</i> Haeckel	14	3	19	20
<i>Protocystis thomsoni</i> (Murray)	0	7	2	2
<i>Protocystis</i> sp.	0	0	12	0
<i>Protocystis harstoni</i> (Murray)	2	11	0	3
<i>Protocystis tritonis</i> (Haeckel)	0	2	0	3
<i>Protocystis xiphodon</i> (Haeckel)	135	64	36	40
Total CHALLENGERIIDAE	291	199	137	109
Family POROSPATHIIDAE Borgert				
<i>Porospathis holostoma</i> (Cleve)	0	0	8	0
Total POROSPATHIIDAE	0	0	8	0

TABLE 2
(Continued)

Taxon	Sediment trap depth (m)			
	389	988	3755	5068
Family MEDUSETTIDAE Haeckel				
<i>Euphysetta lucani</i> Borgert	0	0	2	0
<i>Euphysetta elegans</i> Borgert	8	86	96	93
<i>Euphysetta pusilla</i> Cleve	407	229	188	21
<i>Medusetta ansata</i> Borgert	73	15	59	33
Total MEDUSETTIDAE	488	330	345	147
Family LIRELLIDAE Ehrenberg				
<i>Borgertella caudata</i> (Wallich)	252	62	149	180
<i>Lirella melo</i> (Cleve)	0	7	380	199
<i>Lirella bullata</i> (Stadum and Ling)	2	384	603	705
Total LIRELLIDAE	254	453	1132	1084
Family CASTANELLIDAE Haeckel				
Castanellids group	7	3	0	2
Total CASTANELLIDAE	7	3	0	2
Family CIRCOPORIDAE Haeckel				
<i>Haeckeliana darwiniana</i> Haeckel	0	2	0	2
<i>Circoporus oxyacanthus</i> Borgert	5	0	2	3
Total CIRCOPORIDAE	5	2	2	5
Family CONCHARIIDAE Haeckel				
+ <i>Conchellium capsula</i> Borgert	27	0	10	2
+ <i>Conchellium</i> sp.	0	1	0	0
+ <i>Conchidium caudatum</i> (Haeckel)	103	2	25	30
+ <i>Conchopsis compressa</i> Haeckel	0	3	0	0
+Total CONCHARIIDAE	130	6	35	32
Family AULOSPHAERIDAE Haeckel				
** <i>Aulosphaera labradoriensis</i> Borgert	2	0	3	2
Total AULOSPHAERIDAE	2	0	3	2

* These designate number of spicule swarms rather than shells.

** Incomplete fragments are counted.

+ Each valve is counted as a half (0.5) shell.

shells in a given slide. This taxon occurs mostly in the coarse and medium size fractions. The counting reproducibility by duplicate countings of an identical slide proved to be more than 90%. Statistical variability among 4 slides prepared from the coarse and medium size fractions is due to errors involving slide preparation, including wet-sieving and splitting. The variability ranged from 0.14 to 0.26 standard deviation for 95% confidence interval (1 sigma). A sample aliquot of the very coarse size fraction (1/256) is 4 times greater than those of the coarse-medium size fractions (1/1024). Therefore, counts of the former are more reliable than are the latter, although no standard deviation was obtained. Counts of duplicate slides of the fine size fraction (mostly fragments) resulted in less error than

TABLE 3

Summary of radiolarian (suborders) flux (no. of shells/m²/day) in the western tropical Atlantic.

Suborder	Sediment Trap Depth (m)			
	389	988	3755	5068
Spumellaria	3688 ± 26%	3355 ± 14%	6155 ± 17%	5094 ± 26%
%*	21	21	26	31
Nassellaria	11,936 ± 26%	11,637 ± 14%	15,901 ± 17%	10,192 ± 26%
%*	72	73	67	61
Phaeodaria	1177 ± 26%	993 ± 14%	1662 ± 17%	1381 ± 26%
%*	7	6	7	8
Total Radiolaria	16,801 ± 26%	15,985 ± 14%	23,718 ± 17%	16,667 ± 26%
N/S ratio**	3.24	3.47	2.58	2.00

*% = (suborder flux/total radiolarian flux) × 100

N/S ratio** = nassellarian flux/spumellarian flux

those obtained for the above coarse and medium size fractions. In summary, for the size fractions considered, our radiolarian species counts are considered to be reproducible to better than 74%.

RESULTS AND DISCUSSION

Counts of radiolarian taxa

Most of the radiolarian specimens found in the slide samples were identified to the species level. One to five specimens in a given slide were not identified. They represented less than 0.2% of all radiolarian counts and were insignificant in our statistics.

Two hundred and eight species were identified from the 4-sediment trap samples (pls. 1–15). They belong to 4 subgroups, and are comprised of 89 Spumellaria, 84 Nassellaria, 34 Phaeodaria, and 1 Sticholonchidea species. The number of species contained in the counting slides (table 1) appeared to be less than that in slides used for species identification, because we used only 1 slide for counting and 1 to 4 slides, depending on the size fraction for species identification. Several species were combined into 1 group in counting (table 2). The resulting number of species consisted of 56 Spumellaria, 54 Nassellaria and 25 Phaeodaria—135 Radiolaria in all. They represent an average 67% of the identified species. *Sticholonche zanclea* Hertwig, a sticholonchid, was not quantified because only spines of this species were found (pl. 5, fig. 5 arrow; pl. 12, fig. 6 arrow; pl. 15, fig. 5). Solitary radiolarian spicules also were not counted.

Table 2 shows the radiolarian flux normalized to the number of individual shells/m²/day for each taxon. The flux in each suborder is presented in table 3 and text-figure 1. The size fractioned fluxes of radiolarian families are presented in table 4. Percentages of actual specimens counted with respect to the radiolarian flux (shells/m²/day) are also given in table 4.

SYSTEMATICS

The high-level classification followed herein is based mainly on that proposed by Riedel (1967a, 1967b, 1971) for polycystines and by Borgert (1901a, 1906, 1907, 1910, 1911) for phaeodarians. Synonymies of taxa include the original descriptions and only those which reflect the current usage for polycystines. In the case of phaeodarians relatively little documentation has been accomplished thus far and available literature is much less than that for polycystines. Therefore, we have attempted to list all references for phaeodarians where possible.

Kingdom PROTISTA Haeckel, 1866

Phylum SARCODINA Hertwig and Lesser, 1874

Class ACTINOPODA Calkins, 1909

Subclass RADIOLARIA Müller, 1858a

Order POLYCYSTINA Ehrenberg, 1838, emend. Riedel, 1967a

Suborder SPUMELLARIA Ehrenberg, 1875

Family SPHAEROZOIDAE Haeckel, 1862, emend. Campbell, 1954

Genus RHAPHIDOZOOM Haeckel, 1862

Rhaphidozoum pandora Haeckel

Plate 1, figure 1

Rhaphidozoum pandora HAECKEL, 1887, p. 49, pl. 4, fig. 6.

Family COLLOSPHAERIDAE Müller, 1858a

Genus COLLOSPHAERA Müller, 1855

Collosphaera tuberosa Haeckel

Plate 1, figure 2

Collosphaera tuberosa HAECKEL, 1887, p. 97. See Nigrini, 1971, p. 445, pl. 34.1, fig. 1.

Collosphaera polygona Haeckel

Plate 1, figure 3

Collosphaera polygona HAECKEL, 1887, p. 96, pl. 5, fig. 13.

Genus ACROSPHAERA Haeckel, 1881

Acrosphaera spinosa (Haeckel)

Plate 1, figure 6

Collosphaera spinosa HAECKEL, 1860b, p. 845; 1862, p. 536, pl. 34, figs. 12, 13.

TABLE 4

The size fractionated radiolarian flux (no. of shells/m²/day) in each family from the western tropical Atlantic sediment traps. The proportion of counted specimens (%) with respect to the radiolarian flux (shells/m²/day) is given in the bottom row.

Taxon	Sediment trap depth (m) 389				Sediment trap depth (m) 988				Sediment trap depth (m) 3,755				Sediment trap depth (m) 5,068			
	Size fraction (μm)				Size fraction (μm)				Size fraction (μm)				Size fraction (μm)			
	1000-250 very coarse	250-125 coarse	125-63 medium	< 63 fine	1000-250 very coarse	250-125 coarse	125-63 medium	< 63 fine	1000-250 very coarse	250-125 coarse	125-63 medium	< 63 fine	1000-250 very coarse	250-125 coarse	125-63 medium	< 63 fine
Suborder SPUMELLARIA																
Family SPHAEROZOIDAE	9	12	65	0	5	36	29	0	7	50	6	0	2	0	10	0
COLLOSPHAERIDAE	5	30	51	0	10	12	88	0	42	21	93	0	24	44	77	54
LIOSSPHAERIDAE	40	36	23	0	59	24	37	0	82	72	75	54	61	77	62	0
ACTINOMMIDAE	176	388	294	272	169	193	279	54	437	401	804	435	293	356	739	218
PHACODISCIDAE	84	285	280	272	94	199	353	381	134	79	631	653	122	192	501	816
PORODISCIDAE	40	255	61	54	84	90	147	54	155	129	231	163	106	186	83	54
LITHELIIDAE	93	486	322	54	56	241	441	218	108	179	625	490	94	159	434	327
Total SPUMELLARIA	447	1492	1096	652	477	795	1374	707	965	931	2465	1795	702	1014	1905	1469
Suborder NASSELLARIA																
Family PLAGONIIDAE	71	583	1138	3320	134	410	1639	3156	367	666	2188	4245	179	520	2427	2014
ACANTHODESMIDAE	124	322	532	218	61	157	640	707	136	156	822	653	138	164	439	327
SETHOPHORMIDAE	0	0	0	0	0	6	0	0	19	50	29	0	21	27	26	0
THEOPERIDAE	24	225	350	109	59	133	345	707	228	286	972	980	141	268	511	218
PTEROCORYTHIDAE	174	613	1535	653	120	157	1433	707	233	150	1620	816	152	175	1079	327
ARTOSTROBIDAE	37	158	686	707	24	30	368	327	40	29	370	435	59	49	589	163
CANNOBOTRYIDAE	17	61	107	163	21	18	96	109	10	0	110	218	31	11	83	54
CARPOCANIIDAE	0	0	9	0	7	0	7	54	0	0	17	54	2	0	5	0
Total NASSELLARIA	477	1962	4357	5170	426	911	4528	5767	1033	1337	6128	7401	723	1214	5154	3103
Suborder PHAEODARIA																
Family CHALLENGERIIDAE	14	170	107	0	31	36	22	109	19	36	81	0	30	49	31	0
POROSPATHIIDAE	0	0	0	0	0	0	0	0	2	0	6	0	0	0	0	0
MEDUSETTIDAE	23	42	42	281	9	12	37	272	31	7	197	109	31	27	88	0
LIRELLIDAE	3	0	33	218	3	0	15	436	10	0	197	925	106	16	36	925
CASTANELLIDAE	7	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0
CIRCOPORIDAE	5	0	0	0	2	0	0	0	2	0	0	0	5	0	0	0
CONCHARIIDAE	11	118	0	0	5	0	0	0	17	18	0	0	10	22	0	0
AULOSPHERIDAE	2	0	0	0	0	0	0	0	3	0	0	0	2	0	0	0
Total PHAEODARIA	65	330	182	599	53	48	74	817	84	61	481	1034	186	114	155	925
Total RADIOLARIA	959	3784	5635	6421	956	1754	5976	7291	2082	2329	9074	10230	1611	2342	7214	5497
% Counted Specimens	58	16	21	2	58	17	14	2	57	14	17	2	57	18	19	2

Polysolenia spinosa (Haeckel).—NIGRINI, 1967, p. 14, pl. 1, fig. 1.
Acrosphaera spinosa (Haeckel).—BOLTOVSKOY and RIEDEL, in press, pl. 1, figs. 1–3.

Acrosphaera murrayana (Haeckel)
 Plate 1, figure 7

Choenicosphaera murrayana HAECKEL, 1887, p. 102, pl. 8, fig. 6.—
 BENSON, 1966, p. 120, pl. 2, fig. 3.
Trypanosphaera brachysiphon CLEVE, 1900b, p. 13, pl. 6, fig. 3.
Polysolenia murrayana (Haeckel).—NIGRINI, 1968, pl. 1, fig. 1a–b.
Acrosphaera murrayana (Haeckel).—POPOFSKY, 1917, p. 259, text-
 figs. 22, 23.

Genus SIPHONOSPHERA Müller, 1858a

Siphonosphaera polysiphonia Haeckel
 Plate 1, figure 8

Siphonosphaera polysiphonia HAECKEL, 1887, p. 106.—NIGRINI,
 1967, p. 18, pl. 1, figs. 4a, 4b.

Siphonosphaera martensi Brandt
 Plate 1, figure 9

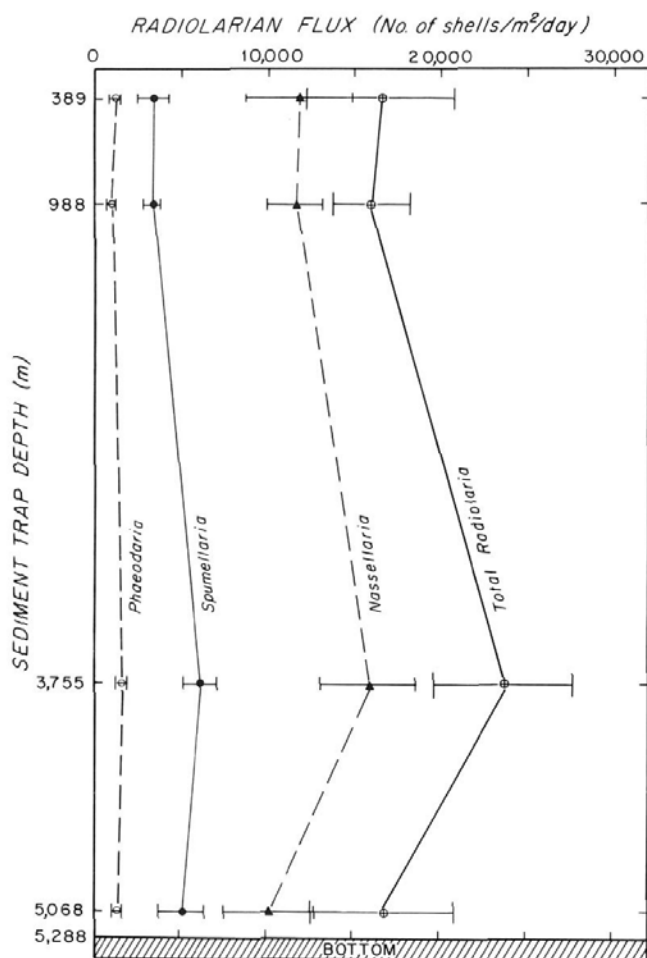
Siphonosphaera martensi BRANDT, 1905, p. 339, pl. 9, figs. 9–12.—
 STRELKOV and RESHETNYAK, 1971, p. 356, fig. 28.—BOLTOV-
 SKOY and RIEDEL, in press, pl. 1, fig. 8.

Genus DISOLENIA Ehrenberg, 1860a

Disolenia sp.
 Plate 1, figure 10

Disolenia zanguebarica (Ehrenberg)
 Plate 1, figure 11

Trisolenia zanguebarica EHRENBURG, 1872a, p. 321; 1872b, p. 149,
 pl. 10, fig. 11.
Solenosphaera zanguebarica (Ehrenberg).—BRANDT, 1905, p. 330,
 pl. 10, figs. 28–31.—POPOFSKY, 1917, p. 249, text-fig. 9.—BOL-
 TOVSKOY and RIEDEL, in press, pl. 1, fig. 11.
Disolenia zanguebarica (Ehrenberg).—NIGRINI, 1967, p. 20, pl. 1,
 fig. 6.—RENN, 1976, p. 87, pl. 1, fig. 2.



TEXT-FIGURE 1

Vertical fluxes (no. of shells/m²/day) of Radiolaria and their suborders from the western tropical Atlantic. Horizontal bars represent standard deviation at 0.95 confidence level.

Genus OTOSPHAERA Haeckel, 1887

Otosphaera polymorpha Haeckel
Plate 1, figure 12

Otosphaera polymorpha HAECKEL, 1887, p. 116, pl. 7, fig. 6.—NIGRINI, 1967, p. 23, pl. 1, fig. 8.

Family LIOSPHAERIDAE Haeckel, 1881
Genus CENOSPHAERA Ehrenberg, 1854

Cenosphaera compacta Haeckel
Plate 1, figure 4

Cenosphaera compacta HAECKEL, 1887, p. 65, pl. 12, fig. 7.—BOLTOVSKOY and RIEDEL, in press, pl. 1, fig. 13.

Cenosphaera huxleyi Müller
Plate 1, figure 5

Cenosphaera huxleyi MÜLLER, 1855, p. 238; 1858a, p. 55, pl. 8, figs. 6–9.—STRELKOV and RESHENYAK, 1971, p. 332, pl. 4, 21–23; figs. 19–21.

Genus STYPTOSPHAERA Haeckel, 1881

Styptosphaera sp.
Plate 1, figure 13

Remarks: Spongy framework of the sphere is clearly formed. The meshes are finer than those of *S. (?) spumacea* Haeckel described by Nigrini (1970) and *S. spongiacea* Haeckel shown by Renz (1976).

Genus PLEGMOSPHAERA Haeckel, 1881

Plegmosphaera pachyplegma Haeckel
Plate 1, figure 14

Plegmosphaera pachyplegma HAECKEL, 1887, p. 89.—BOLTOVSKOY and RIEDEL, in press, pl. 1, fig. 17.

Plegmosphaera lepticali Renz
Plate 1, figures 15–16

Plegmosphaera lepticali RENZ, 1976, p. 115, pl. 1, fig. 14.

Family ACTINOMMIDAE Haeckel, 1862, emend. Riedel, 1971
Genus ACANTHOSPHAERA Ehrenberg, 1858

Acanthosphaera actinota (Haeckel)
Plate 1, figures 18–19

Heliosphaera actinota HAECKEL, 1860a, p. 803; 1862, p. 352, pl. 9, fig. 3.

Acanthosphaera tenuissima (Haeckel).—RENTZ, 1976, p. 99, pl. 2, fig. 11.

Acanthosphaera actinota (Haeckel).—BOLTOVSKOY and RIEDEL, in press, pl. 1, fig. 19.

Acanthosphaera sp. A
Plate 1, figure 20

Acanthosphaera sp. B
Plate 1, figure 21

Genus HELIOSPHAERA Haeckel, 1862

Heliosphaera radiata Popofsky
Plate 1, figure 22

Heliosphaera radiata POPOFSKY, 1912, p. 98, text-fig. 10.—BENSON, 1966, p. 160, pl. 5, figs. 1, 2.

Genus LIOSPHAERA Haeckel, 1882

Liosphaera hexagonia Haeckel
Plate 1, figure 23

Liosphaera hexagonia HAECKEL, 1887, p. 76, pl. 20, fig. 3.

Genus HELIOSOMA Haeckel, 1881

Heliosoma watkinsi Keany
Plate 1, figure 24

Heliosoma watkinsi KEANY, 1979, p. 52, pl. 1, figs. 6–9; pl. 5, fig. 2.

Genus THEOCOSPHAERA Haeckel, 1881

Theocosphaera inermis (?) (Haeckel)
Plate 2, figures 1–2

Haliomma inerme HAECKEL, 1860a, p. 815.

Actinomma inerme HAECKEL, 1862, p. 440, pl. 24, fig. 5.

Theocosphaera inermis HAECKEL, 1887, p. 80.

Theocosphaera inermis (Haeckel).—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 6.

Thecosphaera sp.

Plate 2, figure 3

Genus ACTINOMMA Haeckel, 1860a

Actinomma sp. A cf. **A. arcadophorum** Haeckel and **A. medianum** Nigrini

Plate 2, figure 4

Actinomma arcadophorum HAECKEL, 1887, p. 255, pl. 29, figs. 7, 8.

Actinomma medianum NIGRINI, 1967, p. 27, pl. 2, figs. 2a, 2b.

Remarks: This species bears a smaller number of radial spines than does *A. arcadophorum*, and the radial spines are longer than those of *A. arcadophorum* and *A. medianum*. The cortical shell is of thin polygonal meshwork, and the surface is irregular as contrasted to that of *A. medianum* of Nigrini.

Actinomma arcadophorum Haeckel

Plate 2, figure 5

Actinomma arcadophorum HAECKEL, 1887, p. 255, pl. 29, figs. 7, 8.—NIGRINI, 1967, p. 29, pl. 2, fig. 3.

Actinomma sp. B

Plate 2, figure 6

Genus TRILOBATUM Popofsky, 1912

Trilobatum (?) **acuferum** Popofsky

Plate 2, figure 7

Trilobatum acuferum POPOFSKY, 1912, p. 132, text-fig. 48.

Remarks: This species has 2 medullary shells and 1 cortical shell that are spherical rather than discoidal and thus classified herein. Spines extend eccentrically and are 2–3 times longer than the radius of the cortical shell. This species is moderately abundant at the equatorial Atlantic site.

Genus CROMYECHINUS Haeckel, 1862

Cromyechinus borealis (Cleve)

Plate 2, figure 8

Actinomma borealis CLEVE, 1899, p. 26, pl. 1, fig. 5c.

Cromyechinus borealis (Cleve).—JØRGENSEN, 1900, p. 59; 1905, p. 117, pl. 8, fig. 35, pl. 9, figs. 36, 37.—BJØRKLUND, 1974, p. 20, figs. 5–7; 1976a, pl. 2, figs. 7–15.

Genus HETEROSPHAERA Mast, 1910

Heterosphaera tenuis Campbell

Plate 2, figure 9

Heterosphaera tenuis CAMPBELL, 1954, p. 66, fig. 28, no. 8.

Genus CLADOCOCCUS Müller, 1857

Cladococcus abietinus Haeckel

Plate 2, figure 10

Cladococcus abietinus HAECKEL, 1887, p. 226, pl. 27, fig. 3.

Cladococcus scoparius Haeckel

Plate 2, figure 11

Cladococcus scoparius HAECKEL, 1887, p. 225, pl. 27, fig. 2.

Genus ASTROSPHAERA Haeckel, 1887

Astrosphaera hexagonalis Haeckel

Plate 2, figure 12

Astrosphaera hexagonalis HAECKEL, 1887, p. 250, pl. 19, fig. 4.

Genus ARACHNOSPHERA Haeckel, 1862

Arachnosphaera hexasphaera Popofsky

Plate 2, figure 13

Arachnosphaera hexasphaera POPOFSKY, 1912, p. 108, text-figs. 19–21.

Genus STYLOSPHAERA Ehrenberg, 1847a

Stylosphaera melpomene Haeckel

Plate 2, figure 14

Stylosphaera melpomene HAECKEL, 1887, p. 135, pl. 16, fig. 1.

Stylosphaera lithatractus Haeckel

Plate 3, figure 1

Stylosphaera lithatractus HAECKEL, 1887, pl. 16, figs. 4, 5.

Stylosphaera group

Plate 3, figure 2

Genus AMPHISPHERA Haeckel, 1881

Amphisphaera group

Plate 3, figure 3

Genus XIPHATRACTUS Haeckel, 1887

Xiphatractus pluto (?) (Haeckel)

Plate 3, figure 4

Amphisphaera pluto HAECKEL, 1887, p. 144, pl. 17, figs. 7, 8.

?*Xiphatractus stahli* DREYER, 1889, p. 129, pl. 6, fig. 17.

Xiphatractus pluto (Haeckel).—BENSON, 1966, p. 184, pl. 7, figs. 14–17.

Remarks: The thick cortical shell has a thorny surface. The 2 opposite dissimilar polar spines are short.

Genus DRUPPATRACTUS Haeckel, 1887

Drupptractus acqilonius Hays

Plate 3, figure 5

Drupptractus acqilonius HAYS, 1970, pl. 1, figs. 4, 5.—LING, 1975, p. 717, pl. 1, figs. 17, 18.

Stylacanthium acqilonium (Hays).—KLING, 1973, p. 632.—LING, 1973, p. 777, pl. 1, figs. 6, 7.

Remarks: Our specimens have 2 dissimilar polar spines that are not three-bladed at the base. Although Hays regarded this species as restricted to the North Pacific, this seems not to be the case.

Genus RHODOSPHERA Haeckel, 1881

Rhodospaera (?) group

Plate 3, figure 6

Genus STAUROLONCHE Haeckel, 1881

Staurolonche group

Plate 3, figure 7

Staurolonche (?) sp.

Plate 3, figure 8

Genus STAURACONTIUM Haeckel, 1881

Staurocontium sp.

Genus XIPHOSPHAERA Haeckel, 1881

Xiphosphaera tesseractis Dreyer

Plate 3, figure 9

Xiphosphaera tesseractis DREYER, 1913, p. 10, pl. 2, figs. 3, 3a.—RENZ, 1976, p. 106, pl. 2, fig. 2.—MCMILLEN and CASEY, 1978, pl. 1, fig. 18.

Genus HEXANCISTRA Haeckel, 1881

Hexancistra sp.

Plate 3, figure 10

Genus STYLACONTARIUM Popofsky, 1912

Stylacontarium bispiculum Popofsky

Plate 3, figure 11

Stylacontarium bispiculum POPOFSKY, 1912, pl. 2, fig. 2.

Genus HEXACLADUS Vinassa, 1900

Hexacladus sp.

Plate 3, figure 12

Genus HEXACONTIUM Haeckel, 1881

Hexacontium arachnoidale Hollande and Enjume

Plate 3, figure 13

Hexacontium arachnoidale HOLLANDE and ENJUMET, 1960, p. 96, pl. 53, fig. 1.—BJØRKLUND, 1976b, p. 118, pl. 1, figs. D–F.

Hexacontium axotrias Haeckel

Plate 3, figure 14

Hexacontium axotrias HAECKEL, 1887, p. 192, pl. 124, fig. 3.

Remarks: Some specimens of this species have very fine secondary spines on the cortical shell.

Genus HEXACROMYUM Haeckel, 1881

Hexacromyum elegans Haeckel

Plate 3, figure 15

Hexacromyum elegans HAECKEL, 1887, p. 201, pl. 24, fig. 9.

Genus HEXALONCHE Haeckel, 1881

Hexalonche sp.

Hexalonche hystricina Haeckel

Plate 3, figure 16

Hexalonche hystricina HAECKEL, 1887, p. 187, pl. 25, fig. 6.

Remarks: Two concentric latticed shells. Medullary shell small, about one-fifth of the diameter of the cortical shell. Cortical shell thick and thorny. Six concentric spines are short and thick.

Genus CENTRACONTARIUM Popofsky, 1912

Centracontarium hexacontarium Popofsky

Plate 3, figure 17

Centracontarium hexacontarium POPOFSKY, 1912, p. 90, text-fig. 4.

Remarks: Six thin bars meeting at the center and con-

necting with external, 3-bladed thick concentric spines at the cortical shell.

Genus CENTROLONCHE Popofsky, 1912

Centrolonche hexalonche Popofsky

Plate 3, figure 18

Centrolonche hexalonche POPOFSKY, 1912, pl. 1, fig. 1.

Genus LEPTOSPHAERA Haeckel, 1887

Leptosphaera sp.

Plate 3, figures 19–20

Genus CENTROCUBUS Haeckel, 1887

Centrocubus cladostylus Haeckel

Plate 4, figure 1

Centrocubus cladostylus HAECKEL, 1887, p. 278, pl. 18, fig. 1.

Genus OMMATARTUS Haeckel, 1881, emend. Riedel, 1971

Ommatartus tetrathalamus (Haeckel) subsp. A

Plate 4, figures 2–3

Ommatartus tetrathalamus (Haeckel) subsp. B

Plate 4, figures 4–6

Panartus tetrathalamus HAECKEL, 1887, p. 378, pl. 40, fig. 3.—NIGRINI, 1967, p. 30, pl. 2, figs. 4a–4d.

Ommatartus tetrathalamus (Haeckel).—RENZ, 1976, p. 107, pl. 1, fig. 6.—MCMILLEN and CASEY, 1978, pl. 2, figs. 13a, 13b.

Remarks: Subspecies A and B are clearly distinct. Cortical shell size is one of the most distinguishing features, about 120 μ m for subspecies A and about 95 μ m for subspecies B. The cortical shell is more constricted at the equator in subspecies A than in B. Subspecies A bears no polar caps nor relatively simple ones, whereas subspecies B has complicated and thorny polar caps and a subsequent growth of extra cortical shell.

Genus SPONGOLIVA Haeckel, 1887

Spongoliva cf. **ellipsoides** Popofsky

Plate 1, figure 17

Spongoliva ellipsoides POPOFSKY, 1912, p. 117, text-fig. 28.

(?) *Spongoliva* cf. *ellipsoides* Popofsky.—BENSON, 1966, p. 190, pl. 8, fig. 6.

(?) *Cypassis irregularis* NIGRINI, 1968, p. 53, pl. 1, figs. 2a–2c.

Family PHACODISCIDAE Haeckel, 1881

Genus HELIODISCUS Haeckel, 1862

Heliodiscus asteriscus Haeckel

Plate 4, figures 7–8

Heliodiscus asteriscus HAECKEL, 1887, p. 445, pl. 38, fig. 8.—NIGRINI, 1967, p. 32, pl. 3, figs. 1a, 1b; 1970, pl. 2, fig. 1.—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 8.

Genus SPONGASTER Ehrenberg, 1860b

Spongaster tetras tetras Ehrenberg

Plate 4, figure 9

Spongaster tetras EHRENBURG, 1872b, p. 299, pl. 6, fig. 8.

Spongaster tetras tetras Ehrenberg.—NIGRINI, 1967, p. 41, pl. 5, figs. 1a, 1b.

Spongaster* cf. *pentas Riedel and Sanfilippo
Plate 4, figure 10

Spongaster pentas RIEDEL and SANFILIPPO, 1970, p. 523, pl. 15, fig. 3.—MCMILLEN and CASEY, 1978, pl. 3, fig. 14.

Genus SPONGODISCUS Ehrenberg, 1854

Spongodiscus resurgens Ehrenberg
Plate 4, figure 11

Spongodiscus resurgens EHRENBURG, 1854, p. 240.—HAECKEL, 1887, p. 577.—PETRUSHEVSKAYA and KOZLOVA, 1972, p. 523, pl. 21, fig. 5.

Spongodiscus resurgens resurgens Ehrenberg.—PETRUSHEVSKAYA and BJØRKLUND, 1974, p. 40, text-fig. 6.

Remarks: *Spongodiscus resurgens* Ehrenberg, *Spongodiscus* sp. B, and *Spongotrochus glacialis* Popofsky were combined in the counts because of uncertainties regarding identification

***Spongodiscus* (?) sp.**
Plate 4, figure 12

***Spongodiscus* sp. A**
Plate 4, figure 13

Spongodiscus sp. aff. *S. resurgens* Ehrenberg.—RENZ, 1976, p. 96, pl. 3, fig. 10.

***Spongodiscus* sp. B**
Plate 4, figures 14–15

Genus SPONGOPYLE Dreyer, 1889

***Spongopyle setosa* (?) Dreyer**
Plate 4, figure 16

Spongopyle setosa DREYER, 1889, p. 119, pl. 11, figs. 97, 98.—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 14.

Spongopyle osculosa DREYER, 1889, p. 118, pl. 11, figs. 99, 100.—RIEDEL, 1958, p. 226, pl. 1, fig. 12.—MCMILLEN and CASEY, 1978, pl. 3, fig. 11.—NIGRINI and MOORE, 1979, p. S115, pl. 15, fig. 1.

Genus SPONGOTROCHUS Haeckel, 1860b

Spongotrochus glacialis Popofsky
Plate 4, figure 17

Spongotrochus glacialis POPOFSKY, 1908, p. 228, pl. 26, figs. 7, 8.—KEANY, 1979, p. 54, pl. 2, fig. 7; pl. 5, fig. 7.—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 15.

Spongotrochus (?) *glacialis* Popofsky.—RIEDEL, 1958, p. 227, pl. 2, figs. 1, 2.

***Spongotrochus* sp. A**
Plate 4, figure 18

***Spongotrochus* sp. B**
Plate 4, figure 19

Remarks: The spongy discoidal shell is large (~180 μ m) and has numerous spines about twice as long as the shell radius.

Genus SPONGOCORE Haeckel, 1887

Spongocore puella Haeckel
Plate 4, figure 20

Spongocore puella HAECKEL, 1887, p. 347, pl. 48, fig. 6.

Family PORODISCIDAE Haeckel, 1881, emend. Petrushevskaya and Kozlova, 1972

Genus AMPHIRHOPALUM Haeckel, 1881

Amphirhopalum ypsilon Haeckel
Plate 5, figure 1

Amphirhopalum wyvilleanum HAECKEL, 1887, p. 523, pl. 45, fig. 12.

Amphirhopalum ypsilon HAECKEL, 1887, p. 522.—NIGRINI, 1967, p. 35, pl. 3, figs. 3a–3d.—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 16.

Genus EUCHITONIA Ehrenberg, 1860b, emend. Haeckel, 1887

Euchitonia elegans (Ehrenberg)
Plate 5, figure 2

Pteractis elegans EHRENBURG, 1872a, p. 319; 1872b, p. 299, pl. 8, fig. 3.

Euchitonia elegans (Ehrenberg).—HAECKEL, 1887, p. 535.—NIGRINI, 1967, p. 39, pl. 4, figs. 2a, 2b.

Euchitonia furcata Ehrenberg
Plate 5, figure 6

Euchitonia furcata EHRENBURG, 1872b, p. 308, pl. 6, fig. 6.

Genus HYMENIASTRUM Ehrenberg, 1947a

Hymeniasstrum euclidis Haeckel
Plate 5, figures 3–5

Hymeniasstrum euclidis HAECKEL, 1887, p. 531, pl. 43, fig. 13.—BENSON, 1966, p. 222, pl. 12, figs. 1–3.—LING and ANIKOU-CHINE, 1967, p. 1488, pl. 191, fig. 3, pl. 192, fig. 3.—NIGRINI, 1970, p. 168, pl. 2, fig. 4, text-fig. 16.

Remarks: Several forms are recognized but they are considered as different growth stages.

Genus PORODISCUS Haeckel, 1881

Porodiscus micromma (Harting)
Plate 5, figures 7–8

Flustrella micromma HARTING, 1863, p. 16, pl. 3, fig. 47.

Porodiscus micromma (Harting).—BOLTOVSKOY and RIEDEL, in press, pl. 3, fig. 17.

Genus STYLOCHLAMYDIUM Haeckel, 1881

Stylochlamydium asteriscus Haeckel
Plate 5, figure 9

Stylochlamydium asteriscus HAECKEL, 1887, p. 514, pl. 41, fig. 10.—RENZ, 1976, p. 109, pl. 3, fig. 12.—MCMILLEN and CASEY, 1978, pl. 2, fig. 20.—BOLTOVSKOY and RIEDEL, in press, pl. 4, fig. 2.

Genus STYLODICTYA Ehrenberg, 1847a

Stylodictya multispina Haeckel
Plate 5, figure 10

Stylodictya multispina HAECKEL, 1860b, p. 842.—HAECKEL, 1862, p. 496, pl. 29, fig. 5.—RENZ, 1976, p. 111, pl. 3, fig. 13.—BOLTOVSKOY and RIEDEL, in press, pl. 4, figs. 4a–4b.

***Stylodictya* sp.**

Plate 5, figure 13

Genus OMMATODISCUS Stohr, 1880

***Ommatodiscus murrayi* Dreyer**

Plate 5, figure 11

Ommatodiscus murrayi DREYER, 1889, pl. 9, fig. 56.

***Ommatodiscus fragilis* Stohr**

Plate 5, figure 12

Ommatodiscus fragilis STOHR, 1880, p. 116, pl. 6, figs. 5, 10, 12a.—CAMPBELL, 1954, p. 92, pl. 44, fig. 3.

Family LITHELIIDAE Haeckel, 1862

Genus DISCOPYLE Haeckel, 1887

***Discopyle elliptica* Haeckel**

Plate 5, figure 14

Discopyle elliptica HAECKEL, 1887, p. 573, pl. 48, fig. 20.

Genus LARCOPYLE Dreyer, 1889

***Larcopyle butschlii* Dreyer**

Plate 5, figure 15

Larcopyle butschlii DREYER, 1889, pl. 10, fig. 10.

Genus THOLOSPIRA Haeckel, 1887

***Tholospira cervicornis* Haeckel group**

Plate 5, figures 16–18

Tholospira cervicornis HAECKEL, 1887, p. 700, pl. 49, fig. 5.

Remarks: Cortical shell oval but very irregular. Thorny spines usually short. Medullary shell is less irregular.

Genus LARNACALPIS Haeckel, 1887

***Larnacalpis* sp.**

Plate 6, figure 1

Genus LARCOSPIRA Haeckel, 1887

***Larcospira quadrangula* Haeckel**

Plate 6, figure 2

Larcospira quadrangula HAECKEL, 1887, p. 696, pl. 49, fig. 3.—BENSON, 1966, p. 266, pl. 18, figs. 7, 8.—NIGRINI, 1970, p. 169, pl. 2, fig. 9, text-fig. 21.

Genus HEXAPYLE Haeckel, 1881

***Hexapyle dodecantha* Haeckel**

Plate 6, figure 3

Hexapyle dodecantha HAECKEL, 1887, p. 569, pl. 48, fig. 16.

Remarks: Our specimens show only fine spines on the cortical shell, although Haeckel described 2 kinds of spines.

Genus PYLOLENA Haeckel, 1887

***Pylolela armata* Haeckel group**

Plate 6, figure 4

Pylolela armata HAECKEL, 1887, p. 568, pl. 48, fig. 15.

Genus TETRAPYLE Müller, 1858b

***Tetrapyle octacantha* Müller**

Plate 6, figures 5–6

Tetrapyle octacantha MÜLLER, 1858b, p. 154; 1858a, p. 33, figs. 1–6.—BENSON, 1966, p. 245, pl. 15, figs. 3–10.—MCMILLEN and CASEY, 1978, pl. 3, figs. 2a, 2b.

Genus OCTOPYLE Haeckel, 1881

***Octopyle stenozona* Haeckel**

Plate 6, figure 7

Octopyle stenozona HAECKEL, 1887, p. 652, pl. 9, fig. 11.—BENSON, 1966, p. 251, pl. 16, figs. 3, 4.

Suborder NASSELLARIA Ehrenberg, 1875

Family PLAGONIIDAE Haeckel, 1881, emend. Riedel, 1967b

Genus PLECTANIUM Haeckel, 1881

***Plectanium* sp.**

Plate 6, figure 8

Genus PROTOSCENIUM Jørgensen, 1905

***Protoscenium* (?) sp.**

Plate 6, figure 9

Genus ARCHISCENIUM Haeckel, 1881

***Archiscenium quadrispinum* (?) Haeckel**

Plate 6, figures 10–11

Archiscenium quadrispinum HAECKEL, 1887, p. 1150, pl. 53, fig. 11.

Genus CAMPYLACANTHA Jørgensen, 1905

***Campylacantha* sp.**

Plate 6, figure 12

Genus CLADOSCENIUM Haeckel, 1881

***Cladoscenium* sp.**

Plate 6, figure 13

***Cladoscenium anacoratum* Haeckel**

Plate 6, figure 14

Cladoscenium anacoratum HAECKEL, 1887, p. 1149, pl. 53, fig. 13.

Genus OBELISCUS Popofsky, 1913

***Obeliscus pseudocuboides* Popofsky**

Plate 6, figure 15

Obeliscus pseudocuboides POPOFSKY, 1913, pl. 29, figs. 4, 5.

Genus CLATHROMITRA Haeckel, 1881

***Clathromitra pterophormis* Haeckel**

Plate 6, figure 16

Clathromitra pterophormis HAECKEL, 1887, p. 1219, pl. 57, fig. 8.

Remarks: Our specimens are twice as large as Haeckel's.

Genus PHORMACANTHA Jørgensen, 1905

***Phormacantha hystrix* (Jørgensen)**

Plate 6, figures 17–19

Peridium hystrix Jørgensen, 1900, p. 76.

Phormacantha hystrix Jørgensen, 1905, p. 132, pl. 14, figs. 59–63.

Genus PERIDIUM Haeckel, 1887

Peridium spinipes Haeckel

Plate 6, figure 20

Peridium spinipes HAECKEL, 1887, p. 1154, pl. 53, fig. 9.

Peridium sp.

Plate 6, figure 21

Genus LOPHOPHAENA Ehrenberg, 1847b

Lophophaena cf. **capito** Ehrenberg

Plate 6, figure 22

(?) *Lophophaena capito* EHRENBURG, 1873, p. 242; 1875, pl. 8, fig. 6.

Lophophaena cf. *capito* Ehrenberg.—BENSON, 1966, p. 378, pl. 24, figs. 22, 23; pl. 25, fig. 1.

Lophophaena cylindrica (Cleve)

Plate 7, figure 2

Lophophaena cylindrica (Cleve).—PETRUSHEVSKAYA, 1971c, p. 115, fig. 61.—RENTZ, 1976, p. 159, pl. 6, fig. 21.

Acanthocorys variabilis POPOFSKY, 1913, p. 360, text-figs. 74–77.—BENSON, 1966, p. 373, pl. 24, fig. 19.

Genus LAMPROMITRA Haeckel, 1881

Lampromitra circumtexta Popofsky

Plate 6, figure 23

Lampromitra circumtexta POPOFSKY, 1913, p. 336, pl. 32, fig. 1, text-fig. 53.

Genus ACANTHOCORYS Haeckel, 1881

Acanthocorys cf. **variabilis** Popofsky

Plate 7, figure 1

Acanthocorys variabilis POPOFSKY, 1913, p. 360, text-figs. 71, 72. *Acanthocorys* sp. aff. *A. variabilis* Popofsky.—RENTZ, 1976, p. 155, pl. 6, fig. 20.

Genus PEROMELISSA Haeckel, 1881

Peromelissa phalacra Haeckel

Plate 7, figures 3–5

Peromelissa phalacra HAECKEL, 1887, p. 1236, pl. 57, fig. 11.—MCMILLEN and CASEY, 1978, pl. 4, fig. 20.—BOLTOVSKOY and RIEDEL, in press, pl. 5, fig. 3.

Psilomelissa phalacra (Haeckel).—POPOFSKY, 1908, pl. 32, fig. 4.

Psilomelissa tricuspidata POPOFSKY, 1908, pl. 32, fig. 9.

Psilomelissa tricuspidata abdominalis POPOFSKY, 1908, pl. 33, fig. 4.

Lithomelissa monoceras POPOFSKY, 1913, p. 335, text-fig. 43, pl. 32, fig. 7.—RENTZ, 1976, p. 158, pl. 6, fig. 12.

Genus HELOTHOLUS Jørgensen, 1905

Helotholus histicosa Jørgensen

Plate 7, figures 6–7

Helotholus histicosa Jørgensen, 1905, p. 137, pl. 16, figs. 86–88.—BENSON, 1966, p. 459, pl. 31, figs. 4–8.

(?) *Artostrobos joergenseni* Petrushevskaya.—BJØRKLUND, 1976, pl. 11, figs. 12, 13.

Genus CLATHROCANIUM Ehrenberg, 1860a

Clathrocanium diadema Haeckel

Plate 7, figure 8

Clathrocanium diadema HAECKEL, 1887, p. 1212, pl. 64, fig. 2.—

POPOFSKY, 1913, pl. 32, fig. 4.—MCMILLEN and CASEY, 1978, pl. 5, fig. 5.

Genus CALLIMITRA Haeckel, 1881

Callimitra elisabethae Haeckel

Plate 7, figures 9–10

Callimitra elisabethae HAECKEL, 1887, p. 1218, pl. 63, fig. 6.

Callimitra emmae Haeckel

Plate 7, figure 11

Callimitra emmae HAECKEL, 1887, p. 1218, pl. 63, figs. 3, 4.

Family ACANTHODESMIIDAE Haeckel, 1862

Genus ZYGOCIRCUS Bütschli, 1882

Zygocircus capulosus Popofsky

Plate 7, figure 12

Zygocircus capulosus POPOFSKY, 1913, p. 287, pl. 28, fig. 4.—RENTZ, 1976, p. 169, pl. 8, fig. 6.

Zygocircus productus (Hertwig)

Plate 7, figures 13–14

Lithocircus productus HERTWIG, 1879, p. 197, pl. 12(7), fig. 4.

Zygocircus productus (Hertwig).—PETRUSHEVSKAYA, 1971c, p. 281, fig. 16; II, 145: 10, 11.—BOLTOVSKOY and RIEDEL, in press, pl. 4, fig. 17.

Zygocircus cf. **piscicaudatus** Popofsky

Plate 7, figure 15

Zygocircus piscicaudatus POPOFSKY, 1913, p. 287, pl. 28, fig. 3.

Zygocircus sp. cf. *Z. piscicaudatus* Popofsky.—RENTZ, 1976, p. 171, pl. 8, fig. 3.

Genus NEOSEMANTIS Popofsky, 1913

Neosemantis distephanus Popofsky

Plate 7, figure 17

Neosemantis distephanus POPOFSKY, 1913, p. 299, pl. 29, fig. 2.—PETRUSHEVSKAYA, 1971c, p. 152, figs. 77: I–III.—BOLTOVSKOY and RIEDEL, in press, pl. 4, fig. 14.

Genus ACANTHODESMIA Müller, 1857

Acanthodesmia vinculata (Müller)

Plate 7, figures 18–19

Lithocircus vinculata MÜLLER, 1857, p. 484.

Acanthodesmia vinculata MÜLLER, 1858a, p. 30, pl. 1, figs. 4–7.—PETRUSHEVSKAYA, 1971c, p. 278, figs. 143, I–VII; 144, I–VI.—LING, 1972, p. 169, pl. 1, fig. 6.—BOLTOVSKOY and RIEDEL, in press, pl. 4, fig. 12.

Eucoronis nephropsyrnis HAECKEL, 1887, p. 977, pl. 82, fig. 5.—BENSON, 1966, p. 304, pl. 21, figs. 6–8.

Eucoronis angulata HAECKEL, 1887, p. 978, pl. 82, fig. 3.

Eucoronis challengerii HAECKEL, 1887, p. 978, pl. 82, fig. 4.

Giraffospyris angulata (Haeckel).—RENTZ, 1976, p. 167, pl. 8, fig. 5.—GOLL, 1969, p. 331, pl. 59, figs. 4, 6, 7, 9, text-fig. 2.

Genus LOPHOSPYRIS Haeckel, 1881, emend. Goll, 1976

Lophospyris pentagona pentagona (Ehrenberg)

Plate 7, figures 20–21

Ceratospys pentagona EHRENBURG, 1872a, p. 303; 1872b, p. 302, pl. 15, fig. 15.

Ceratospys allmersii HAECKEL, 1887, p. 1067, pl. 86, fig. 3.

Ceratospys strasburgeri HAECKEL, 1887, p. 1067, pl. 86, fig. 2.

Dorcadospyrus pentagona (Ehrenberg).—GOLL, 1969, p. 338, pl. 59, figs. 8, 10–12.—LING, 1972, p. 168, pl. 2, fig. 5.
Lophospyrus pentagona pentagona (Ehrenberg).—GOLL, 1976, pp. 384, 398, pl. 10, figs. 1–7; pl. 11, figs. 1–3, 5.—NIGRINI and MOORE, 1979, p. N15, pl. 19, fig. 5.

Lophospyrus pentagona hyperborea (Jørgensen), emend. Goll
 Plate 7, figures 22–26

Ceratospyris hyperborea JØRGENSEN, 1905, p. 130, pl. 13, fig. 49.
Lophospyrus pentagona hyperborea (Jørgensen), emend. GOLL, 1976, p. 400, pl. 14, figs. 4–6, 8–9, 11–12; pl. 15, figs. 1–12.

Genus TRIPODOSPYRIS Haeckel, 1881

Tripodospyrus sp.
 Plate 7, figure 27

Genus DICTYOSPYRIS Ehrenberg, 1847b

Dictyospyris sp. A
 Plate 7, figure 28

Dictyospyris sp. B
 Plate 7, figure 29

Genus THOLOSPYRIS Haeckel, 1881, emend. Goll, 1969

Tholospyris fornicata Popofsky
 Plate 7, figure 30

Tholospyris fornicata POPOFSKY, 1913, p. 309, pl. 30, fig. 2.—
 RENZ, 1976, p. 177, pl. 8, fig. 15.

Tholospyris baconiana baconiana (Haeckel)
 Plate 8, figure 3

Tricolospyris baconiana HAECKEL, 1887, p. 1098, pl. 88, fig. 8.
Tholospyris baconiana baconiana (Haeckel).—GOLL, 1972, p. 451,
 pl. 1, figs. 7–9; pl. 2, figs. 1–8; pl. 4, figs. 1–4; pl. 5, figs. 1–3.

Tholospyris baconiana cf. *variabilis* (Haeckel)
 Plate 8, figure 4

Tholospyris baconiana variabilis GOLL, 1972, p. 452, pl. 8, figs. 1–8;
 pl. 9, figs. 1–12.

Tholospyris sp.
 Plate 7, figure 16

Remarks: This species is related to unnamed transition specimens between *T. baconiana spinula* and *T. rhombus* shown by Goll, 1972, pl. 15, figs. 1–11.

Genus CANTHAROSPYRIS Haeckel, 1887

Cantharospyris platybursa Haeckel
 Plate 7, figure 32

Cantharospyris platybursa HAECKEL, 1887, p. 1051, pl. 53, fig. 7.—
 RENZ, 1976, p. 171, pl. 8, fig. 10.

Cantharospyris cf. *clathrobursa* (Haeckel)
 Plate 7, figure 31

Tessarospyris clathrobursa HAECKEL, 1887, p. 1045, pl. 53, fig. 8.

Genus AMPHISPYRIS Haeckel, 1881

Amphispyris costata Haeckel
 Plate 8, figures 1–2

Amphispyris costata HAECKEL, 1887, p. 1097, pl. 88, fig. 3.—
 NIGRINI, 1967, p. 45, pl. 5, fig. 4.—MCMILLEN and CASEY, 1978,
 pl. 5, fig. 9.

Family SETHOPHORMIDIDAE Haeckel, 1881, emend. Petrushevskaya, 1971a

Genus SETHOPHORMIS Haeckel, 1881

Sethophormis pentalactis Haeckel
 Plate 8, figure 5

Sethophormis pentalactis HAECKEL, 1887, p. 1244, pl. 56, fig. 5.—
 RENZ, 1976, p. 165, pl. 7, fig. 7.

Sethophormis rotula Haeckel
 Plate 8, figures 6–7

Sethophormis rotula HAECKEL, 1887, p. 1246, pl. 57, fig. 9.—RENZ,
 1976, p. 166, pl. 7, fig. 14.

Remarks: Examined specimens show 3, 9, or 12 radial ribs comparable to 12 ribs described by Renz. Cephalis and subtriangular collar-ring vary in shape and size.

Sethophormis cf. *dodecaster* (Haeckel)
 Plate 8, figure 8

Tetraphormis dodecaster HAECKEL, 1887, p. 1248, pl. 56, fig. 12.

Family THEOPERIDAE Haeckel, 1881, emend. Riedel, 1967a
 Genus CORNUTELLA Ehrenberg, 1838

Cornutella profunda Ehrenberg
 Plate 8, figure 9

Cornutella profunda EHRENBURG, 1858, p. 31.—NIGRINI, 1967, p.
 60, pl. 6, figs. 5a–5c.

Genus PERIPYRAMIS Haeckel, emend. Riedel, 1958

Peripyramis circumtexta Haeckel
 Plate 8, figures 10–11

Peripyramis circumtexta HAECKEL, 1887, p. 1162, pl. 54, fig. 5.—
 RIEDEL, 1958, p. 231, pl. 2, figs. 8, 9.—BENSON, 1966, p. 426,
 pl. 29, fig. 4.

Genus THEOPILIUM Haeckel, 1881

Theopilium tricostratum Haeckel
 Plate 8, figure 12

Theopilium tricostratum HAECKEL, 1887, p. 1322, pl. 70, fig. 6.

Genus CLATHROCYCLAS Haeckel, 1881

Clathrocyclas danaes Haeckel
 Plate 8, figure 13

Clathrocyclas danaes HAECKEL, 1887, p. 1388, pl. 59, figs. 13, 14.

Genus LITHARACHNIUM Haeckel, 1860b

Litharachnium tentorium Haeckel
 Plate 8, figures 15–16

Litharachnium tentorium HAECKEL, 1860b, p. 836; 1862, p. 281, pl.
 4, figs. 7–10.—RENZ, 1976, p. 150, pl. 7, fig. 6.—BOLTOVSKOY
 and RIEDEL, in press, pl. 5, fig. 14.

Genus DICTYOPHIMUS Ehrenberg, 1847a

Dictyophimus butschlii Haeckel
 Plate 8, figure 14

Dictyophimus butschlii HAECKEL, 1887, p. 1201, pl. 60, fig. 2.

Dictyophimus sp.
 Plate 8, figures 17–18

Dictyophimus plectaniscus (?) Haeckel

Plate 8, figure 19

Dictyophimus crisiae Ehrenberg

Plate 9, figures 1–2

Dictyophimus crisiae EHRENBERG, 1954, p. 241. See Nigrini, 1967, p. 66, pl. 6, figs. 7a, 7b.*Dictyophimus plectaniscus* HAECKEL, 1887, p. 1196, pl. 61, figs. 8, 9.

Genus PSEUDODICTYOPHIMUS Petrushevskaya, 1971c

Pseudodictyophimus gracilipes (Bailey)

Plate 9, figures 3–4

Dictyophimus gracilipes BAILEY, 1856, p. 4, pl. 1, fig. 8.*Pseudodictyophimus gracilipes* (Bailey).—PETRUSHEVSKAYA, 1971c, p. 93, fig. 48: I, IV, V.

Genus PTEROCANIUM Ehrenberg, 1847a

Pterocanium praetextum (Ehrenberg)

Plate 9, figures 5–6

Lychnocanium praetextum EHRENBERG, 1872a, p. 316; 1872b, p. 297, pl. X, fig. 2.*Pterocanium praetextum* (Ehrenberg).—HAECKEL, 1887, p. 1330.—NIGRINI, 1967, p. 68, pl. 7, fig. 1.

Genus DICTYOCERAS Haeckel, 1862

Dictyoceras virchowii Haeckel

Plate 9, figures 7–8

Dictyoceras virchowii HAECKEL, 1862, p. 333, pl. 8, figs. 1–5.*Dictyoceras neglectum* CLEVE, 1900a, p. 7, pl. 4, fig. 5.—POPOFSKY, 1913, pl. 34, fig. 4.—RENZ, 1976, p. 121, pl. 4, fig. 10.**Dictyoceras pyramidale** (Popofsky)

Plate 9, figure 9

Theopilium pyramidale POPOFSKY, 1913, p. 376, pl. 37, fig. 1.—RENZ, 1976, p. 126, pl. 4, fig. 13.

Genus LITHOSTROBUS Bütschli, 1882

Lithostrobus hexagonalis Haeckel

Plate 9, figure 10

Lithostrobus hexagonalis HAECKEL, 1887, p. 1475, pl. 79, fig. 20.—RENZ, 1976, p. 123, pl. 5, fig. 15.

Genus STICHOPILIUM Haeckel, 1881

Stichopilium bicornne Haeckel

Plate 9, figure 11

Stichopilium bicornne HAECKEL, 1887, p. 1437, pl. 77, fig. 9.—RENZ, 1976, p. 125, pl. 4, fig. 9.

Genus EUCYRTIDIUM Ehrenberg, 1847a

Eucyrtidium hexastichum (Haeckel)

Plate 9, figure 12

Lithostrobus hexastichum HAECKEL, 1887, p. 1470, pl. 80, fig. 15.—BENSON, 1966, p. 506, pl. 34, figs. 13–16.*Stichopilium annulatum* POPOFSKY, 1913, p. 403, pl. 37, figs. 2, 3.*Eucyrtidium hexastichum* (Haeckel).—PETRUSHEVSKAYA, 1971c, p. 221, fig. 99.—RENZ, 1976, p. 132, pl. 5, fig. 9.

Genus LITHOPERA Ehrenberg, 1847a

Lithopera bacca Ehrenberg

Plate 9, figure 13

Lithopera bacca EHRENBERG, 1872a, p. 314.—NIGRINI, 1967, p. 54, pl. 6, fig. 2.—RENZ, 1976, p. 133, pl. 5, fig. 12.

Genus CYRTOPERA Haeckel, 1881

Cyrtopera languncula Haeckel

Plate 9, figure 14

Cyrtopera languncula HAECKEL, 1887, p. 1451, pl. 75, fig. 10.—CASEY, 1971b, pl. 23.1, fig. 10.—RENZ, 1976, p. 120, pl. 4, fig. 7.

Genus STICHOPHORMIS Haeckel, 1881

Stichophormis cf. **cornutella** Haeckel

Plate 9, figure 15

Stichophormis cornutella HAECKEL, 1887, p. 1455, pl. 75, fig. 9.

Genus COROCALYPTRA Haeckel, 1887

Corocalyptra columba (Haeckel)

Plate 9, figure 16

Pterocorys columba HAECKEL, 1887, pl. 71, fig. 2.**Remarks:** This species resembles *C. killmari* Renz, 1976 (p. 118, pl. 4, fig. 11), but differs in details such as length and angle of feet.

Genus THEOCORYS Haeckel, 1881

Theocorys veneris Haeckel

Plate 9, figure 17

Theocorys veneris HAECKEL, 1887, p. 1415, pl. 69, fig. 5.—BENSON, 1966, p. 492, pl. 33, figs. 12, 13.—RENZ, 1976, p. 137, pl. 5, fig. 11.

Genus THEOCALYPTRA Haeckel, 1881

Theocalyptra davisiana cornutoides (Petrushevskaya)

Plate 9, figure 18

Cycladophora (?) *davisiana* EHRENBERG, 1861, p. 297; 1872b, pl. 2, fig. 11.*Stichopilium davisianus* (Ehrenberg).—HAECKEL, 1887, p. 1437.*Theocalyptra davisiana* (Ehrenberg).—RIEDEL, 1958, p. 239, pl. 4, figs. 2, 3, text-fig. 10.—BENSON, 1966, p. 441, pl. 29, figs. 14–16.*Cycladophora davisiana* Ehrenberg *cornutoides* PETRUSHEVSKAYA, 1967, pl. 70, figs. 1–3.**Theocalyptra davisiana davisiana** (Ehrenberg)

Plate 9, figures 19–20

Pterocorys bicornis POPOFSKY, 1908, pl. 34, figs. 7, 8.*Calthrocyclas alcmanae* Haeckel.—POPOFSKY, 1913, pl. 37, fig. 4.*Theocalyptra davisiana* (Ehrenberg).—NIGRINI and MOORE, 1979, p. N57, pl. 24, figs. 2a, b.

Family PTEROCORYTHIDAE Haeckel, 1881, emend. Riedel, 1967a

Genus ANTHOCYRTIDIUM Haeckel, 1881

Anthocyrtidium zanguebaricum (Ehrenberg)

Plate 9, figure 21

Anthocyrtis zanguebarica EHRENBERG, 1872a, p. 301; 1872b, p. 285, pl. ix, fig. 12.*Anthocyrtium zanguebaricum* (Ehrenberg).—HAECKEL, 1887, p. 1277.*Anthocyrtis ovata* HAECKEL, 1887, p. 1272, pl. 62, fig. 13.*Sethocyrtis oxycephalis* HAECKEL, 1887, p. 1299, pl. 62, fig. 9.*Anthocyrtium oxycephalis* (Haeckel).—BENSON, 1966, p. 468, pl. 32, figs. 3–5.

Anthocyrtidium zanguebaricum (Ehrenberg).—NIGRINI, 1967, p. 58, pl. 6, fig. 4.—GOLL and BJØRKLUND, 1971, p. 450, text-fig. 8.

Anthocyrtidium ophirens (Ehrenberg)

Plate 9, figure 22

Anthocyrtis ophirens EHRENBURG, 1872a, p. 301; 1872b, p. 285, pl. ix, fig. 13.

Anthocyrtidium cineraria HAECKEL, 1887, p. 1278, pl. 62, fig. 16.

Anthocyrtidium ophirens (Ehrenberg).—NIGRINI, 1967, p. 56, pl. 6, fig. 3.

Remarks: Subterminal spines are thinner and longer, and apical horn is shorter, than those described by Nigrini.

Genus LAMPROCYCLAS Haeckel, 1881

Lamprocyclus maritilis polypora Haeckel

Plate 9, figures 23–24

Lamprocyclus maritilis HAECKEL, 1887, p. 1390, pl. 74, figs. 13, 14.

Lamprocyclus maritilis polypora Haeckel.—NIGRINI, 1967, p. 76, pl. 7, fig. 6.

Lamprocyclus maritilis maritilis Haeckel

Plate 9, figure 26

Lamprocyclus maritilis HAECKEL, 1887, p. 1390, figs. 13, 14.

Lamprocyclus maritilis maritilis Haeckel.—NIGRINI, 1967, p. 74, pl. 7, fig. 5.

Lamprocyclus* (?) *hannai (Campbell and Clark)

Plate 9, figure 25

Theoconus junonis HAECKEL, 1887, p. 1401, pl. 69, fig. 7.

(?) *Lamprocyclus junonis* (Haeckel) group.—PETRUSHEVSKAYA and KOZLOVA, 1972, p. 545, pl. 36, fig. 8.

Calocyclus hannai CAMPBELL and CLARK, 1944, p. 48, pl. 6, figs. 21, 22.

Lamprocyrtis (?) *hannai* (Campbell and Clark).—KLING, 1973, p. 638, pl. 5, figs. 12–14, pl. 12, figs. 10–14.—NIGRINI and MOORE, 1979, p. N83, pl. 25, fig. 8.

Genus PTEROCORYS Haeckel, 1881

Pterocorys zancleus (Müller)

Plate 10, figures 1–3

Eucyrtidium zancleum MÜLLER, 1858a, p. 41, pl. 6, figs. 1–3.

Theoconus zancleus (Müller).—BENSON, 1966, p. 482, pl. 33, fig. 4 (not fig. 5).

Pterocorys zancleus (Müller).—NIGRINI and MOORE, 1979, p. N89, pl. 25, figs. 11a, 11b.

Remarks: Several specimens showing binary fission have been observed.

Pterocorys campanula Haeckel

Plate 10, figures 4–5

Pterocorys campanula HAECKEL, 1887, p. 1316, pl. 71, fig. 3.

Remarks: Several specimens showing binary fission have been observed. The feature of the abdomens of 2 shells being fused is similar to that in *P. zancleus*.

Pterocorys hirundo Haeckel

Plate 10, figure 6

Pterocorys hirundo HAECKEL, 1887, p. 1318, pl. 71, fig. 4.—RIEDEL, 1958, p. 238, pl. 3, fig. 11; pl. 4, fig. 1.—BOLTOVSKOY and RIEDEL, in press, pl. 5, fig. 20.

Genus EUSYRINGIUM Haeckel, 1881

Eusyringium siphonostoma Haeckel

Plate 10, figure 7

Eusyringium siphonostoma HAECKEL, 1887, p. 1499, pl. 80, fig. 14.—BENSON, 1966, p. 498, pl. 34, figs. 6–9.

Eusyringium cannostoma HAECKEL, 1887, p. 1499, pl. 80, fig. 13.

Family ARTOSTROBIDAE Riedel, 1967b, emend. Foreman, 1973

Genus ARTOSTROBUS Haeckel, 1887

Artostrobos annulatus (Bailey)

Plate 10, figure 8

Cornutella (?) *annulata* BAILEY, 1856, p. 3, pl. 1, figs. 5a, 5b.

Artostrobos annulatus (Bailey).—HAECKEL, 1887, p. 1481.—RENZ, 1976, p. 117, pl. 4, fig. 5.—LING, 1975, p. 731, pl. 13, fig. 10.

Genus BOTRYOSTROBUS Haeckel, 1887

Botryostrobus aquilonaris (Bailey)

Plate 10, figures 9–10

Eucyrtidium aquilonaris BAILEY, 1856, p. 4, pl. 1, fig. 9.

Eucyrtidium tumidum BAILEY, 1856, p. 5, pl. 1, fig. 11.

Botryostrobus aquilonaris (Bailey).—see NIGRINI, 1977, p. 246, pl. 1, fig. 1.

Genus SIPHOCAMPE Haeckel, 1887

Siphocampe nodosaria (Haeckel)

Plate 10, figures 11–12

Lithomitra nodosaria HAECKEL, 1887, p. 1484, pl. 79, fig. 1.—PETRUSHEVSKAYA and KOZLOVA, 1972, pl. 24, figs. 29, 30.

Lithomitra eruca HAECKEL, 1887, p. 1485, pl. 79, fig. 3.—PETRUSHEVSKAYA and KOZLOVA, 1972, p. 539, pl. 24, figs. 32, 33. *Siphocampe nodosaria* (Haeckel).—NIGRINI, 1977, p. 256, pl. 3, fig. 11.

Genus PHORMOSTICHOARTUS Campbell, 1951, emend. Nigrini, 1977

Phormostichoartus corbula (Harting)

Plate 10, figures 13–14

Lithocampe corbula HARTING, 1863, p. 12, pl. 1, fig. 21.

Siphocampe corbula (Harting).—NIGRINI, 1967, p. 85, pl. 8, fig. 5.—RIEDEL and SANFILIPPO, 1971, p. 1601, pl. 1H, figs. 18–25.—RIEDEL and SANFILIPPO, 1978, p. 73, pl. 9, fig. 7.

Phormostichoartus corbula (Harting).—NIGRINI, 1977, p. 252, pl. 1, fig. 10.

Genus SPIROCARTIS Haeckel, 1881

Spirocarytis scalaris Haeckel

Plate 10, figure 15

Spirocarytis scalaris HAECKEL, 1887, p. 1509, pl. 76, fig. 14.—RENZ, 1976, p. 142, pl. 6, fig. 1.—NIGRINI, 1977, pl. 2, fig. 12.

Spirocarytis* sp. aff. *S. seriata Jørgensen and ***S. subscalaris*** Nigrini
Plate 10, figure 16

Spirocarytis seriata JØRGENSEN, 1905, p. 140, pl. 18, figs. 102–104.—BJØRKLUND, 1976a, pl. 10, figs. 7–12.

Spirocarytis subscalaris NIGRINI, 1977, pl. 3, figs. 1, 2.

Description: Cephalis hemispherical, apical horn straight upward, tube extending laterally, abdomen consisting of 3 segments separated by conspicuous constrictions and increasing their width distally. Ter-

minial segment narrowing and thinning from maximum width toward terminal opening. Cephalis and thorax with regularly arranged circular pores. Abdominal segments with numerous regularly arranged circular pores, and terminal one with about 20 pores in a row. Number of rows ranging from 4–5 for the first, 5–7 for the second, to more than 15 for the terminal abdominal segment.

Remarks: The present specimens differ from *S. seriatata* and *S. subscalaris* in having many more pores than the latter. The present specimens have a horizontally extending tube which is compared with the obliquely upwardly extending tube of *S. subscalaris*. There is no description of the tube by Jørgensen.

Genus CARPOCANARIUM Haeckel, 1887, emend. Nigrini and Moore, 1979

Carpocanarium papillosum (Ehrenberg)

Plate 10, figure 17

Eucyrtidium papillosum EHRENBURG, 1872a, p. 310; 1872b, p. 293, pl. 7, fig. 10.

Dictyocyrtidius papillosus (Ehrenberg).—NIGRINI, 1967, p. 63, pl. 16, fig. 6.—LING, 1975, p. 731, pl. 13, fig. 10.

Carpocanarium papillosum (Ehrenberg).—NIGRINI and MOORE, 1979, p. N27, pl. 21, fig. 3.

Family CANNOBOTRYIDAE Haeckel, 1881, emend. Riedel, 1967a

Genus ACROBOTRYS Haeckel, 1881

Acrobotrys sp. A

Plate 10, figure 18

Acrobotrys sp. B

Plate 10, figure 19

Acrobotrys sp. C

Plate 10, figure 20

Genus BOTRYOCYRTIS Ehrenberg, 1860b

Botryocyrtis scutum (Harting)

Plate 10, figures 23–24

Haliomma scutum HARTING, 1863, p. 11, pl. 1, fig. 18.

Botryocyrtis caput serpentis EHRENBURG, 1872a, p. 301; 1872b, p. 287, pl. X, fig. 21.

Botryocyrtis scutum (Harting).—NIGRINI, 1967, p. 52, pl. 6, figs. 1a–1c.

Family CARPOCANIIDAE Haeckel, 1881, emend. Riedel, 1967b

Genus CARPOCANISTRUM Haeckel, 1887

Carpocanistrum sp. aff. **Carpocanistrum** sp. D Ling

Plate 10, figures 21–22

Carpocanistrum sp. D LING, 1975, p. 730, pl. 12, fig. 6. See Benson, 1966, p. 434, pl. 29, figs. 9, 10, fig. 25.

Order TRIPYLEA Hertwig, 1879

Suborder PHAEODARIA Haeckel, 1879

Family CHALLENGERIIDAE Murray, 1876

Genus CHALLENGERON Haeckel, 1887

Challengeron willemoesii Haeckel

Plate 10, figures 25–29

Challengeron willemoesii HAECKEL, 1887, p. 1659, pl. 99, fig. 13.—BORGERT, 1911, p. 456, pl. 34, figs. 4–6.

Challengeron rottenburgi BORGERT, 1892, p. 182, pl. 6, fig. 1; 1911, p. 458, pl. 35, figs. 1, 2.

Challengeron armatum BORGERT, 1901a, p. XV33, fig. 39; 1911, p. 454, pl. 34, figs. 7–11.

Challengeron gracile BORGERT, 1911, p. 458, pl. 35, figs. 6, 7.

Challengeron gracillimum BORGERT, 1911, p. 459, pl. 35, figs. 3–5.

Challengeron walwini WOLFENDEN, 1902, p. 359, pl. 2, figs. 1, 1a.

Remarks: The concept of this species herein is somewhat broader than Borgert's. Based on examinations of several tens of specimens the authors believe that intra-species morphological variations of the present species occur to such an extent that previous authors separated this group into several species. The variations observed include size and shape of the shell, length, number and arrangement (i.e., alternation of longer and shorter ones) of spines. However, the angle between 2 pairs of divergent teeth is consistent.

Challengeron wyvillei Haeckel (1887, p. 1660, pl. 99, fig. 15) and *Challengeron* sp. (Ling and Takahashi, 1977, p. 208, pl. 1, figs. 1–5) differ slightly from the present species especially in the angle between the pair of teeth, but they could be classified as a subspecies of the present species. A form with sabre-shaped terminal teeth such as those of *C. wyvillei* has not been recognized from the present study area (Haeckel's specimens were from the eastern tropical Atlantic).

Challengeron radians Borgert

Plate 11, figures 1–2

Challengeron radians BORGERT, 1903, p. 743, text-fig. J.—BORGERT, 1911, p. 453, pl. 34, fig. 3.

Challengeron balfouri (Murray)

Plate 11, figures 5–6

Challengeria balfouri MURRAY, 1885, p. 226, pl. A, fig. 10.

Challengeron balfouri (Murray).—HAECKEL, 1887, p. 1655.—BORGERT, 1901a, p. XV31, fig. 37; 1911, p. 449, pl. 33, figs. 5–9.—WOLFENDEN, 1902, p. 360, pl. 2, figs. 2, 2a, 3, 3a. See Borgert (1911) for additional references.

Challengeron diodon Haeckel

Plate 12, figures 1–3

Challengeron diodon HAECKEL, 1887, p. 1654, pl. 99, fig. 6.—BORGERT, 1901a, p. 30, fig. 34; 1911, p. 448, pl. 33, figs. 10, 11.—BJØRKLUND, 1974, p. 28, fig. 10; 1976a, pl. 12, figs. 8–11. See Borgert (1911) for additional references.

Genus PROTOCYSTIS Wallich, 1869

Protocystis thomsoni (Murray)

Plate 11, figures 3–4

Challengeria thomsoni MURRAY, 1885, pl. A, figs. 2, 2a.—HAECKEL, 1887, p. 1650.

Protocystis thomsoni (Murray).—HAECKER, 1906a, p. 291, text-fig. Fb; 1908, p. 261, pl. 49, figs. 388–389, text-fig. 29b.—BORGERT, 1911, p. 440, text-figs. 7a, b.—RESHETNYAK, 1955, p. 98; 1 pl., figs. 1, 2.—LING, 1966, p. 206, pl. 1, figs. 1–11; pl. 2, figs. 1–7.—LING and TAKAHASHI, 1977, p. 209, pl. 2, figs. 1–6.

Protocystis bicornis BORGERT, 1901a, p. XV29, text-fig. 32, pl. 33, figs. 3, 4.

Protocystis sp.

Plate 11, figures 8–10

Description: Shell circular to ovate, strongly compressed and lenticular, and shell wall of hexagonal meshwork. Characteristic terminal wings of peristome open laterally toward terminal end, forming a mouth opening. Shell diameter 120–145 μm . Apparently the present form is a new taxon whose shell size and peristome shape differ from *Challengeria macleari* Murray (1885, p. 226, pl. A, fig. 3) (Haeckel, 1887, p. 1651) and *Protocystis grava* Borgert (1903, p. 741, figs. Ga, Gb).

Protocystis harstoni (Murray)

Plate 11, figure 11

Challengeria harstoni MURRAY, 1885, p. 226, pl. A, fig. 14a (not fig. 14).—HAECKEL, 1887, p. 1650.

Protocystis harstoni (Murray).—BORGERT, 1901a, p. XV28, fig. 30.—BJØRKLUND, 1976a, pl. 12, fig. 5.—DUMITRICA, 1973, p. 755, pl. 8, fig. 5.

(?) *Protocystis harstoni* (Murray).—HAECKEL, 1908, p. 49, text-fig. 150.—BORGERT, 1911, p. 436, text-fig. 4a.—STADUM and LING, 1969, p. 483, pl. 1, figs. 1–3.—BJØRKLUND, 1976a, pl. 12, figs. 6, 7.

Protocystis nautiloides BORGERT, 1903, p. 738, text-figs. Da, Db.

Protocystis antarctica SCHRÖDER, 1913, pl. 21, fig. 1.

(?) *Challengeria zetlandica* WOLFENDEN, 1902, p. 361, pl. 2, fig. 5.

See Borgert (1911) for additional references.

Remarks: Specimens shown by Haeckel (1908), Borgert (1911), Stadum and Ling (1969), and Bjørklund (1976a, p. 12, figs. 6, 7 of the Cleve collection) are different in angle, length, and shape of peristome from the rest in the references listed above and our specimens. The former can be classified as a subspecies of the present species.

Protocystis naresi (Murray)

Plate 11, figure 12

Challengeria naresii MURRAY, 1885, p. 226, pl. A, figs. 1, 1a–1e.—HAECKEL, 1887, p. 1648.

Challengeria naresi Murray.—HAECKEL, 1906a, p. 290, text-figs. A, Fa; 1908, p. 258, pl. 48, fig. 370; pl. 49, fig. 377; pl. 52, figs. 429, 430, text-figs. 27, 28.—RESHETNYAK, 1955, p. 95, pl. fig. 62.

Protocystis naresi (Murray).—BORGERT, 1911, p. 432, text-fig. 2.

Remarks: This species is similar to *P. tritonis*. However, the size is significantly different. Our specimens ranged from 480 to 680 μm in the longer axis of the ovate shell. This is the largest species of the present genus, and some specimens exceed 1 mm in length including its tooth. This size is comparable to that of another large size phaeodarian species, *Conchopsis compressa* Haeckel (pl. 14, figs. 8–10; pl. 15, fig. 1).

Protocystis tritonis (Haeckel)

Plate 11, figure 13

Challengeria tritonis HAECKEL, 1887, p. 1649, pl. 99, fig. 5.—WOLFENDEN, 1902, p. 360, pl. 2, fig. 4.

Protocystis tritonis (Haeckel).—BORGERT, 1901a, p. XV28, fig. 29; 1911, p. 434, pl. 31, figs. 8, 9.

Protocystis xiphodon (Haeckel)

Plate 11, figure 14

Challengeria xiphodon HAECKEL, 1887, p. 1648.—HAECKER, 1908, p. 260, pl. 49, figs. 378–381.

Protocystis xiphodon (Haeckel).—BORGERT, 1901a, p. XV27, fig. 28; 1903, p. 738; 1911, p. 433, pl. 31, figs. 5–7.—JØRGENSEN, 1905, p. 141.—STADUM and LING, 1969, p. 483, pl. 1, figs. 4, 5.—BJØRKLUND, 1976, pl. 12, fig. 4. See Borgert (1911) for additional references.

Family POROSPATHIDIDAE Borgert, 1901a

Genus POROSPATHIS Haeckel, 1879

Porospathis holostoma (Cleve)

Plate 11, figure 15

Polypetta holostoma CLEVE, 1899, p. 32, pl. 3, figs. 4a, 4b; 1900b, p. 180.

Porospathis holostoma (Cleve).—BORGERT, 1901a, p. 48, figs. 56, 56a; 1903, p. 752; 1910, p. 387, pl. 29, figs. 1–8; pl. 30, figs. 1, 2.—HAECKER, 1908, p. 240, pl. 48, figs. 371–376; pl. 49, figs. 392, 393.—SCHRÖDER, 1913, p. 166, text-fig. 9.—RESHETNYAK, 1955, p. 95, fig. 66 (in plate); 1966, p. 166, fig. 52.—STADUM and LING, 1969, p. 485, pl. 1, figs. 16–18.—DUMITRICA, 1973, p. 754, pl. 5, figs. 1, 2, 6.

Family MEDUSETTIDAE Haeckel, 1887

Genus EUPHYSETTA Haeckel, 1887

Euphysetta lucani Borgert

Plate 11, figure 7

Euphysetta lucani BORGERT, 1892, p. 181, pl. 6, fig. 8; 1901a, p. 37, fig. 45; 1901b, p. 242, pl. 11, fig. 4; 1906, p. 151, pl. 6, figs. 4–6.—HAECKER, 1908, p. 306, pl. 53, figs. 436, 439, 442.—DUMITRICA, 1973, p. 756, pl. 9, fig. 1; pl. 12, fig. 6.

Euphysetta elegans Borgert

Plate 12, figures 4–5

Euphysetta elegans BORGERT, 1902, p. 569, text-fig. F; 1906, p. 154, pl. 11, figs. 7–9.—HAECKER, 1904a, p. 138; 1906a, p. 273; 1908, p. 307, pl. 53, figs. 435, 438.—DUMITRICA, 1973, p. 756, pl. 5, fig. 8; pl. 6, figs. 1–3; pl. 12, fig. 8.

Remarks: Our specimens fit well with Borgert's descriptions but are different from *E. staurocodon* described by Haeckel (1887).

Euphysetta pusilla Cleve

Plate 12, figure 8

Euphysetta pusilla CLEVE, 1900a, p. 7, pl. 3, fig. 16; 1900b, p. 160.—BORGERT, 1902, p. 567, fig. D; 1906, p. 152, pl. 11, figs. 1–3.—DUMITRICA, 1973, p. 756, pl. 9, fig. 6; pl. 12, fig. 5.

Remarks: We have observed also a few specimens with an apical spine, as noted by Borgert (1906).

Genus MEDUSETTA Haeckel, 1887

Medusetta ansata Borgert

Plate 12, figures 6–7

Medusetta ansata BORGERT, 1902, p. 564, fig. B; 1906, p. 146, pl. 12, figs. 1, 2.

Medusetta sp.

Plate 12, figures 9–10

Remarks: Ovate shell with 4 similar bifurcated legs. Absence of apical spine may be due either to loss or to an original feature.

Medusetta inflata Borgert

Plate 12, figure 11

Medusetta inflata BORGERT, 1902, p. 563, fig. A; 1906, p. 146, pl. 11, figs. 10, 11.—CLEVE, 1903, p. 354.—DUMITRICA, 1973, p. 756, pl. 13, fig. 1.

Family LIRELLIDAE Ehrenberg, 1872c
Genus BORGERTELLA Dumitrica, 1973

Borgertella caudata (Wallich)

Plate 12, figure 12

Cadium caudatum WALLICH, 1869, pl. 3, figs. 7–10.—BÜTSCHLI, 1882, pl. 32, fig. 15a.

Cadium inauris BORGERT, 1903, p. 747, fig. O; 1910, p. 402, pl. 30, figs. 4–10.

Borgertella caudata (Wallich).—DUMITRICA, 1973, p. 755, pl. 8, figs. 6–8; pl. 12, figs. 13–17.—LING, 1975, p. 732, pl. 13, fig. 24.

Genus LIRELLA Ehrenberg, 1872

Lirella melo (Cleve)

Plate 12, figures 13, 14, 16

Beroetta melo CLEVE, 1899, p. 27, pl. 1, fig. 8.

Cadium melo (Cleve).—BORGERT, 1901a, p. XV50, fig. 58; 1910, p. 401, pl. 30, figs. 3–5.—STADUM and LING, 1969, p. 484, pl. 1, figs. 6–8.—DUMITRICA, 1973, p. 755, pl. 7, figs. 3, 4; pl. 12, fig. 9. See Borgert (1910) and Dumitrica (1973) for additional references.

Lirella sp.

Plate 12, figure 15

Remarks: Shell is ovoid and larger than that of *L. melo* and *L. bullata* and possesses about 15 longitudinal striae whose surfaces have a transverse wavy structure.

Lirella bullata (Stadum and Ling)

Plate 13, figures 1–2

Cadium bullatum STADUM and LING, 1969, p. 484, pl. 1, figs. 9–14.

Remarks: Specimens observed by SEM show a smooth open bubble which forms a mouth, although the opening of the bubble is not visible under a light microscope. Position of the bubble is nearly at a pole and slightly different from that shown by Stadum and Ling.

Family CASTANELLIDAE Haeckel, 1879
Genus CASTANISSA Haeckel, 1879

Castanissa nationalis Schmidt

Plate 13, figure 3

Castanissa nationalis SCHMIDT, 1907, p. 300, fig. 5.

Castanissa circumvallata Schmidt

Plate 13, figure 4

Castanissa circumvallata SCHMIDT, 1907, p. 301, fig. 6.—BORGERT, 1908, p. 257, pl. 20, fig. 6.—KLING, 1971, p. 665, pl. 4, figs. 1–4.

Castanissa similis BORGERT, 1908, p. 257, pl. 20, fig. 5.

Genus CASTANIDIUM Haeckel, 1879

Castanidium sp.

Plate 13, figure 5

Genus CASTANARIUM Haeckel, 1879

Castanarium sp.

Plate 13, figure 6

Description: Shell wall thin, pores circular and variable in size; by-spines numerous and 2 to 3 times as long as pore diameter; main-spines absent; and mouth without teeth and 3 to 4 times as wide as pores. Shell diameter ranges from 155 to 210 μm .

Remarks: The present species resembles *Castanidium? fenestratum* Haecker described by Dumitrica (1973). However, the former differs from *Castanidium? fenestratum* described by Kling (1966) in spines and shell size.

Castanarium favosum Haecker

Plate 13, figure 9

Castanarium favosum HAECKER, 1908, p. 156, pl. 34, fig. 258.—SCHRÖDER, 1913, p. 147.—RESHETNYAK, 1966, p. 139, fig. 77.

Description: Large shell, yellowish thick wall, pores of uneven size, and very short, conical by-spines.

Family CIRCOPORIDAE Haeckel, 1879

Genus HAECKELIANA Murray, 1877

Haeckeliana darwiniana Haeckel

Plate 13, figures 7–8

Haeckeliana darwiniana HAECKEL, 1887, p. 1702, pl. 114, figs. 1, 2. *Haeckeliana labradoriana* BORGERT, 1909, p. 330, pl. 24, figs. 1–3.

Remarks: Length of main spines and absence or presence of subspines varies significantly, based on observation of tens of specimens. However, distance between coronets, number of pores (usually 5, occasionally 4, and rarely 6), and morphology of shell surface dimples do not vary significantly. Some specimens have closed pores in coronets. Unfortunately, the specimens shown in plate 13 do not represent mouth openings due to orientation and spines due to breakage, but generally our specimens conform with Haeckel's description. As he noted, it may be possible to combine his several species into a single species when specimens from various parts of the world are studied.

Genus CIRCOPORUS Haeckel, 1879

Circoporus oxyacanthus Borgert

Plate 15, figures 6–7

Circoporus oxyacanthus BORGERT, 1902, p. 571, fig. H; 1903, p. 753; 1909, p. 335, pl. 25, figs. 1–4.—HAECKER, 1908, p. 185, pl. 20, fig. 173.

Family CONCHARIIDAE Haeckel, 1879

Genus CONCHELLIUM Haeckel, 1887

Conchellium capsula Borgert

Plate 14, figures 1–4

Conchellium capsula BORGERT, 1907, p. 208, pl. 17, figs. 1–4.

Description: This species has not been described

since Borgert (1907). Shell nearly spherical, pores circular and similar in size except smaller ones along frontal margin of each valve. Both valves equal in size and possessing 12 to 14 smooth conical teeth 3 to 4 times as long as diameter of pores and acting as interlocking device for the 2 valves. Smooth polar end of valves forming small mouth opening. Shell diameter from 150 to 250 μm based on examination of more than 30 valves and a few intact bivalved shells.

Conchellium sp.

Plate 15, figure 3

Remarks: This species is similar to *C. capsula*. However, the shell is larger, about 260 μm , and thicker in meshwork than the latter. This species is rare in our samples.

Genus CONCHIDIUM Haeckel, 1887

Conchidium caudatum (Haeckel)

Plate 14, figures 5–7

Conchoceras caudatum HAECKEL, 1887, p. 1727, pl. 24, fig. 15.—HAECKER, 1905, p. 351; 1906b, p. 34, fig. 1.

Conchidium caudatum (Haeckel).—BORGERT, 1903, p. 756, fig. 5; 1907, p. 210, pl. 16, figs. 5–7.

Genus CONCHOPHACUS Haecker, 1906b

Conchophacus diatomeus (Haeckel)

Plate 15, figure 2

Concharium diatomeum HAECKEL, 1887, p. 1717, pl. 123, fig. 1.—BORGERT, 1901b, p. 244.

Conchidium diatomeum (Haeckel).—HAECKER, 1906b, p. 34.

Conchophacus diatomeus (Haeckel).—BORGERT, 1907, p. 212, pl. 15, figs. 5–8.

Genus CONCHOPSIS Haeckel, 1887

Conchopsis compressa Haeckel

Plate 14, figures 8–10; plate 15, figure 1

Conchopsis compressa HAECKEL, 1887, p. 1725, pl. 125, figs. 7, 8.

Remarks: Observed specimens possess about 40 conical teeth of similar size and conform with Haeckel's original description. Although the rest of the features are quite similar to those of the present species, *C. orbicularis* and *C. pilidium* described by Haeckel (1887) differ in number and shape/size of their teeth. *Conchopsis barca* Borgert, 1907 is also similar to the present species except for circular pores along the keel and slightly less teeth (31 to 36). It is quite possible that further studies will lead to a combination of the above closely related species into a single species. Our specimens range from 495 to 810 μm in shell length.

Family AULOSPHAERIDAE Haeckel, 1862

Genus AULOSPHAERA Haeckel, 1860a

Aulosphaera labradoriensis Borgert

Aulosphaera labradoriensis BORGERT, 1901a, p. XV16, figs. 15, 15a, 15b.—HAECKER, 1904b, p. 640; 1908, p. 117, pl. 11, fig. 104; pl.

12, figs. 120, 125–127; pl. 47, fig. 351.—SCHRÖDER, 1913, p. 134.—RESHETNYAK, 1966, p. 124, figs. 51, 54.

Order STICHOLONCHIDEA Poche, 1913

Family STICHOLONCHIDAE

Genus STICHOLONCHE Hertwig, 1877

Sticholonche zanclea Hertwig

Plate 15, figure 5; plate 5, figure 5, arrow mark; plate 12, figure 6.

Sticholonche zanclea HERTWIG, 1877, p. 324, pl. 19, figs. 1–6. See Takahashi and Ling, 1980, for complete references.

Remarks: Only spines of this species were found, and no complete form was present in all samples of the sediment trap material. Fecal aggregates consisting of radiolaria and silicoflagellates such as that in plate 15, figure 11 contain numerous spines of this species, suggesting predation by higher trophic organisms and rapid transport to the sea floor. The systematic position of this group is uncertain, and it is presently classified as above.

DIVERSITY INDEX ANALYSIS

The diversity index used in this analysis is that of Pielou (1969), and is computed by the following equation:

$$H' \text{ (natural bels)} = - \sum_{i=1}^n P_i \ln P_i$$

where P_i is the proportion of the i th species of the total population dealt with, n is the number of species, and H' is the diversity in natural bels, i.e., natural logarithms to the base 10. This index is highest with many species, each of which constitutes an equal part of the total population, and lowest when there are few species, or where one species predominates.

Diversity indices were computed for each suborder as well as for total Radiolaria at each trap depth. The results are presented in table 5 and text-figure 2. The computed diversity indices of total Radiolaria ranged from 3.3 to 3.6 (natural bels unit). These values are the highest values ever reported in the water column. This is mainly due to the difference in sampling and analytical methods: our sediment traps collected all size particles as well as rapidly settling particles in the water column, whereas most of the previous works (Casey et al., 1971; Casey, Gust et al., 1979; Casey, Spaw et al., 1979; Petrushevskaya, 1971a, 1971b; Kling, 1976; McMillen and Casey, 1978; Boltovskoy and Riedel, in press) involved plankton tows and/or water bottles. Renz (1976) was able to collect 137 species of Radiolaria in the central tropical Pacific by the use of a pumping system with a 35- μm mesh as well as plankton nets. McMillen and Casey (1978) reported living polycystine diversity indices of up to 1.2 from the surface to 2000-m depth in the Gulf of Mexico and Caribbean Sea. Their sampling method involved use of a Nansen closing net with a 76- μm mesh size. Differences in the degree of taxonomic "split-

TABLE 5

Diversity indices of Radiolaria and their subgroups from the sediment traps deployed in the western tropical Atlantic.

	Sediment Trap Depth (m)			
	389	988	3755	5068
Spumellaria	3.0788	2.8410	2.9553	2.8827
Nassellaria	2.4883	2.8223	2.8641	2.8071
Phaeodaria	1.8851	1.8027	1.9189	1.6715
Total Radiolaria	3.3187	3.5609	3.6245	3.6040

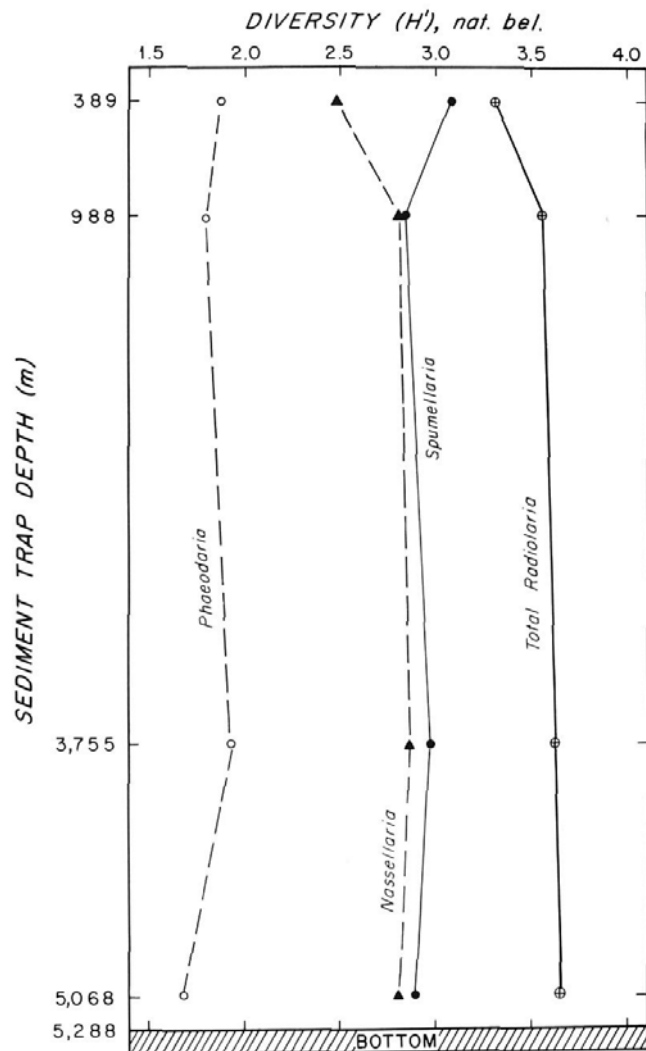
ting" by the various authors are probably responsible for part of the differences in reported diversities.

Our diversity indices of Spumellaria and Nassellaria at 988 m and below show (text-fig. 2) approximately uniform values with depth, indicating that species diversity of the suborders did not change significantly during their descent from 988 to 5068 m. A relatively low value of nassellarian diversity index at 389 m reflects the total radiolarian diversity index at that depth. This is because the Nassellaria had a greater flux than the rest of the suborders, as shown earlier. One possible explanation of the increase in nassellarian diversity index from 389 to 988 m is the introduction of tropical submergent species proposed by Casey and his associates (Casey, 1971a, 1971b; Casey and McMillen, 1977; Casey, Gust et al., 1979) and introduction of deep water species (Reshetnyak, 1955; Casey, Gust et al., 1979). Many species in the families Plagoniidae and Theoperidae increased their fluxes between 389- and 988-m trap depth as shown in table 2. The representative species that agreed with the scheme of deep-water species (Casey, Gust et al., 1979) are: *Cyrtopera languncula* Haeckel; *Peripyramis circumtexta* Haeckel; *Litharacnium tentorium* Haeckel; and *Cornutella profunda* Ehrenberg. An alternative explanation of the increase in nassellarian diversity index is dissolution of some nassellarian shells in the sediment trap receiving cup at 389 m. The diversity index of Spumellaria decreased slightly from 389 to 988 m.

Phaeodaria presented the lowest indices among the 3 suborders. They were more variable in the bathypelagic zone. Possible dissolution of shallow water forms and introduction of deep-water species (Reshetnyak, 1955) result in appearances and disappearances at each trap depth (table 2). Typical deep-water species are *Euphysetta elegans* Borgert, *Lirella melo* (Cleve), and *L. bullata* (Stadum and Ling). Previously Borgert (1906, p. 174-175) reported occurrence of *E. elegans* between 1000 and 5000 m. Haecker (1908, p. 557) reported *L. melo* from 1500 to 5000 m.

Percent similarity analysis

The percent similarity index *S* (Whittaker and Fairbanks, 1958) has been applied to measure differences



TEXT-FIGURE 2

Diversity index (H'), natural bels, of Radiolaria and their suborders from the western tropical Atlantic.

in the relative proportion of species in pairs of sediment trap samples at different depths. Application of this index was analogous to the community comparison reported previously (e.g. Honjo and Okada, 1974). The index is computed by the use of the following equation:

$$S = 100 \times (1.0 - 0.5 \sum_{i=1}^n |P_{ij} - P_{ik}|)$$

where P_{ij} and P_{ik} are the proportion of the i th species in the j th and k th sample depths, and n is the number of species.

As shown in table 6, the similarity indices relative to Spumellaria were less variable and ranged from 73 to 79. They were within similar values between all the probable pairs of depths. This suggested that com-

position and population between all possible pairs of depths involving Spumellaria were similar.

The similarity indices computed for Nassellaria between 389 m and the rest of the depths (70–75%) differ significantly from those between the rest (81–86%) (table 6). This is probably due to an introduction of some deep-water species between 389 and 988 m, as discussed earlier. Below 988 m the similarity indices between pairs of depths stayed similarly high, suggesting little change in nassellarian flux.

Phaeodaria presented a markedly decreasing trend in the similarity indices between 389 m and the progressively greater depths (50 to 28%, table 6). This was attributed to the additions of deep-water species as mentioned in the previous section and to dissolution of specimens probably during their descent. The index between 3755 and 5068 m showed about 78%; this was comparable to those of polycystines, indicating that phaeodarian shells are constantly replaced by the same species if significant dissolution takes

place in the bathypelagic zone. Microstructure of phaeodarian shells, which include more organic matter and are thinner and more porous than those of other suborders, may contribute to the high rate of dissolution/destruction. As stated earlier, some phaeodarians were already lost in the mesopelagic and upper bathypelagic zones during their descent (table 2). Fluxes of the remaining phaeodarians as well as additionally introduced deep-water species were not much modified between 3755- and 5068-m depth.

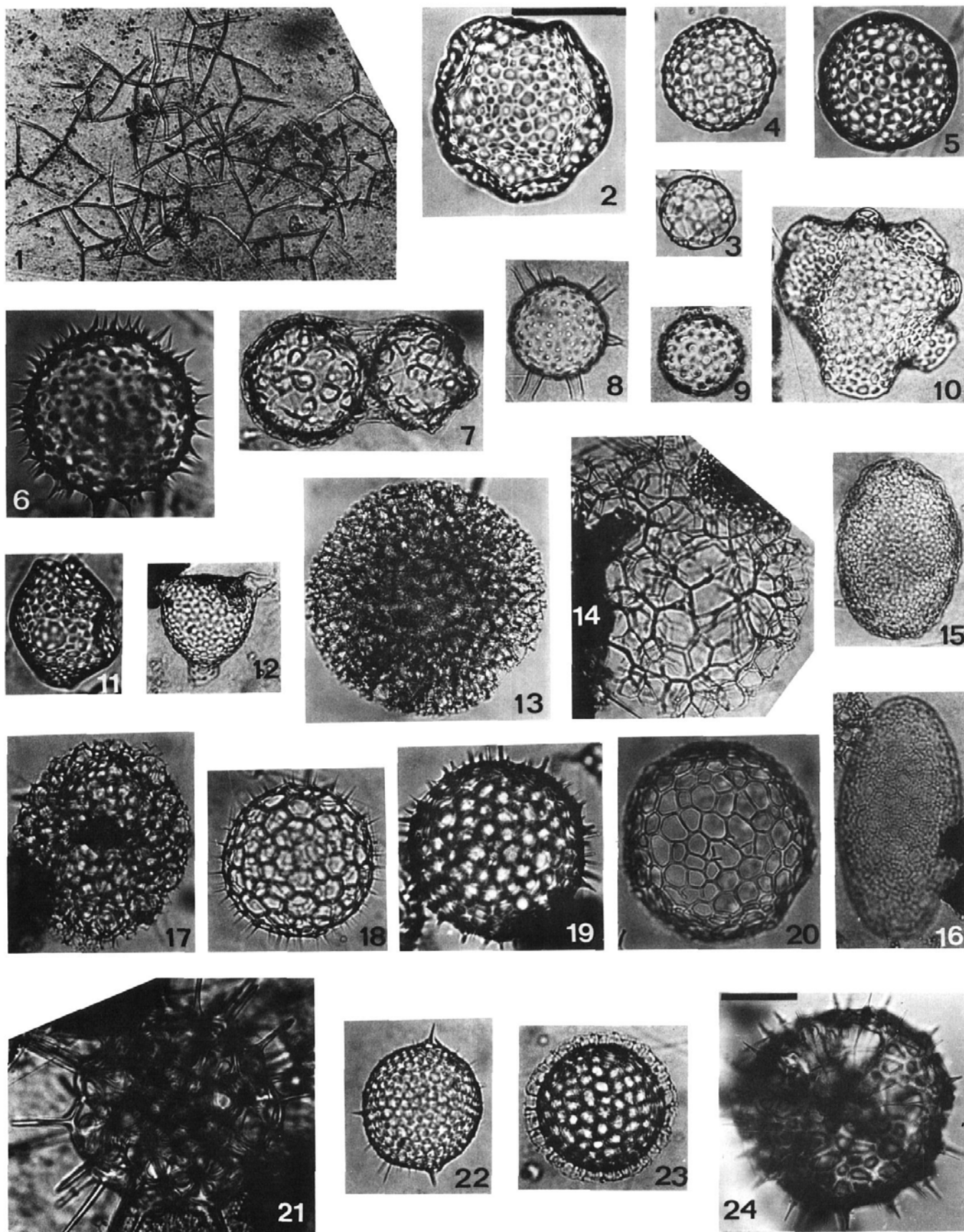
Vertical flux of Radiolaria

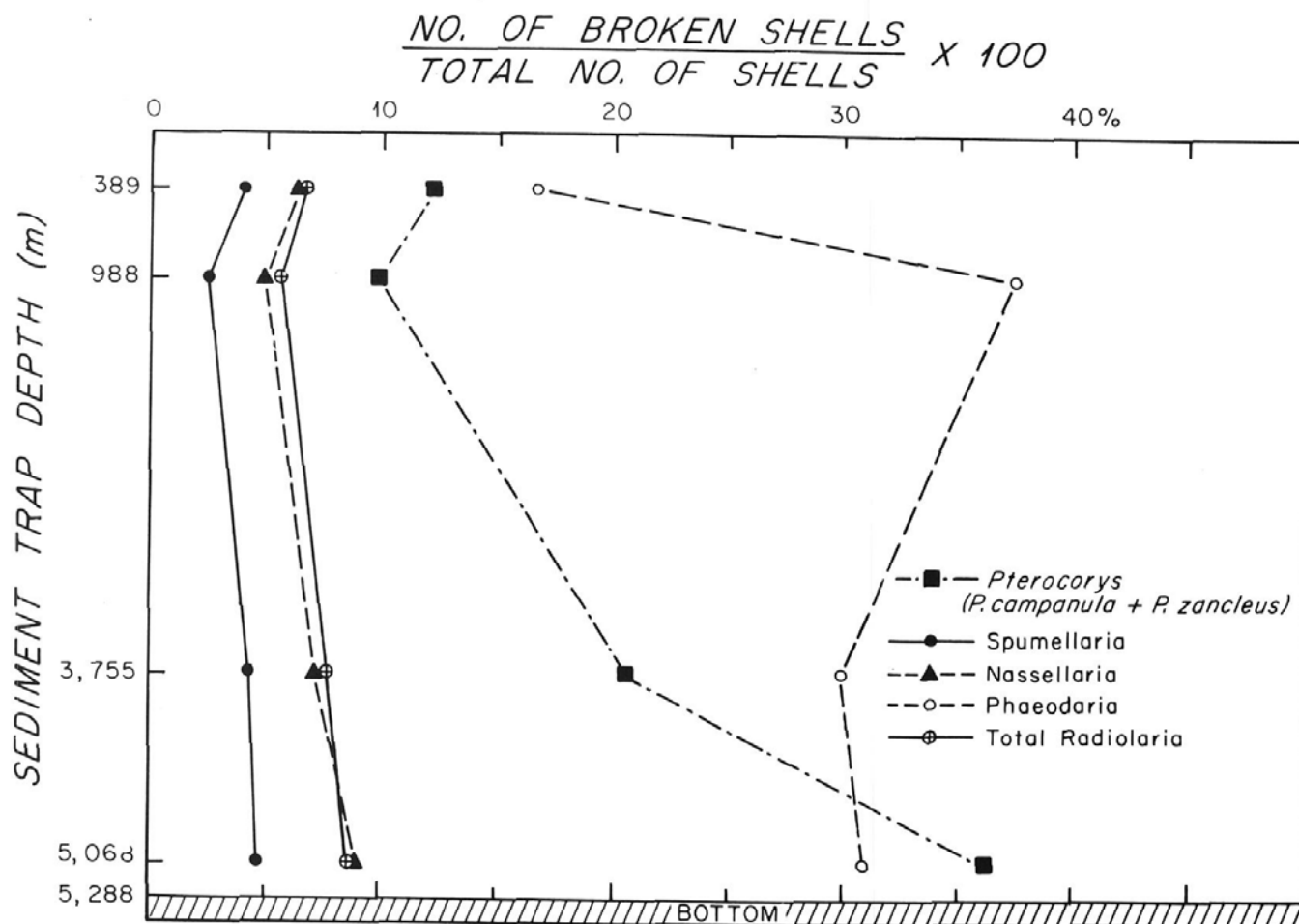
Fluxes of 3 suborders as well as Radiolaria as a whole were more or less uniform throughout the trap depths (table 3, text-fig. 1). An exception was at 3755 m where the fluxes were significantly greater than the others. This flux maximum at 3755 m was also true for biogenic opal (Honjo, 1980) and planktonic foraminifera (Thunell and Honjo, ms., in press) from the same trap samples.

PLATE 1

The scale bar in figure 2 equals 100 μm for all figures except 24.

- | | |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 1 <i>Rhaphidozoum pandora</i> Haeckel
3775 m. | 12 <i>Otosphaera polymorpha</i> Haeckel
389 m. |
| 2 <i>Collosphaera tuberosa</i> Haeckel
5068 m. | 13 <i>Styptosphaera</i> sp.
389 m. |
| 3 <i>Collosphaera polygona</i> Haeckel
988 m. | 14 <i>Plegmosphaera pachyplegma</i> Haeckel
988 m. |
| 4 <i>Cenosphaera compacta</i> Haeckel
988 m. | 15–16 <i>Plegmosphaera lepticali</i> Renz
15, 389 m; 16, 988 m. |
| 5 <i>Cenosphaera huxleyi</i> Müller
389 m. | 17 <i>Spongoliva</i> cf. <i>ellipsoides</i> Popofsky
988 m. |
| 6 <i>Acrosphaera spinosa</i> (Haeckel)
389 m. | 18–19 <i>Acanthosphaera actinota</i> (Haeckel)
389 m. |
| 7 <i>Acrosphaera murrayana</i> (Haeckel)
988 m; 2 shells linked together. | 20 <i>Acanthosphaera</i> sp. A
3755 m. |
| 8 <i>Siphonosphaera polysiphonia</i> Haeckel
5068 m. | 21 <i>Acanthosphaera</i> sp. B
5068 m. |
| 9 <i>Siphonosphaera martensi</i> Brandt
988 m. | 22 <i>Heliosphaera radiata</i> Popofsky
988 m. |
| 10 <i>Disolenia</i> sp.
988 m. | 23 <i>Liosphaera hexagonia</i> Haeckel
389 m. |
| 11 <i>Disolenia zanguebarica</i> (Ehrenberg)
389 m. | 24 <i>Heliosoma watkinsi</i> Keany
3755 m. Scale bar: 100 μm . |





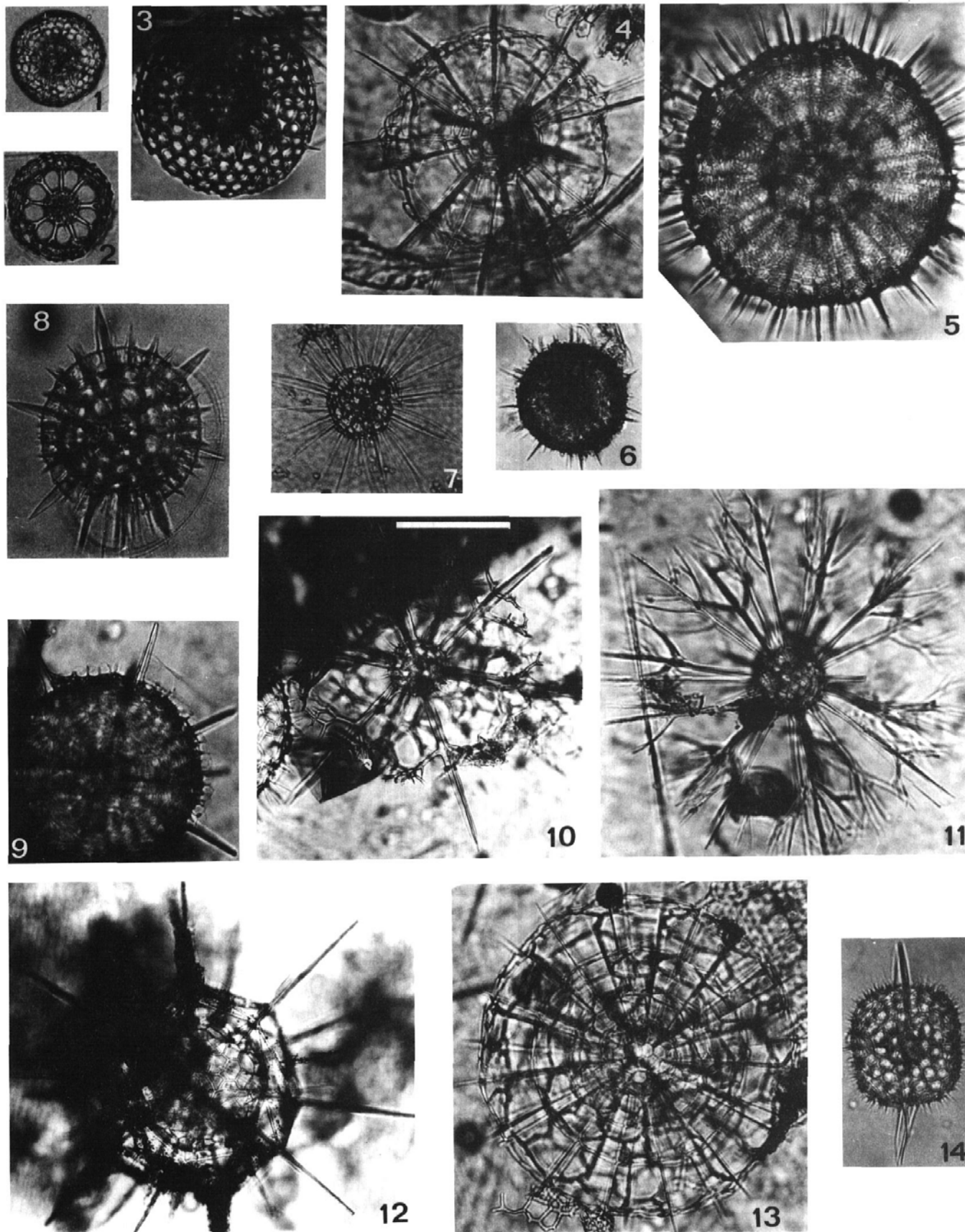
TEXT-FIGURE 3

Percentages of broken shells in radiolarian taxa from the western tropical Atlantic sediment traps.

PLATE 2

The scale bar in figure 10 equals 100 μm for all figures.

- | | |
|---------------------------------------------------------------------------------------------------------|----------------------------------------------------------|
| 1-2 <i>Thecosphaera inermis</i> (?) (Haeckel)
1, 988 m; 2, 5068 m. | 8 <i>Cromyechinus borealis</i> (Cleve)
5068 m. |
| 3 <i>Thecosphaera</i> sp.
389 m. | 9 <i>Heterosphaera tenuis</i> Campbell
988 m. |
| 4 <i>Actinomma</i> sp. A cf. <i>A. arcadophorum</i> Haeckel
and <i>A. medianum</i> Nigrini
389 m. | 10 <i>Cladococcus abietinus</i> Haeckel
5068 m. |
| 5 <i>Actinomma arcadophorum</i> Haeckel
3755 m. | 11 <i>Cladococcus scoparius</i> Haeckel
389 m. |
| 6 <i>Actinomma</i> sp. B
988 m. | 12 <i>Astrosphaera hexagonalis</i> Haeckel
389 m. |
| 7 <i>Trilobatum</i> (?) <i>acuferum</i> Popofsky
3755 m. | 13 <i>Arachnosphaera hexasphaera</i> Popofsky
5068 m. |
| | 14 <i>Stylosphaera melpomene</i> Haeckel
3755 m. |



Radiolarian shell flux as a whole showed no decreasing trend throughout the water column indicated by the population in traps at different depths. However a significant increase of shell fragmentation with increasing depth was noted; percentages of broken shells of *Pterocorys* [*P. campanula* Haeckel and *P. zancleus* (Müller)] shells were 12, 10, 20 and 36% at 389, 988, 3755, and 5068 m trap depths, respectively (text-fig. 3) (a broken but more than a half preserved shell was counted as 1 broken shell). The number of shells counted at each depth ranged from 289 to 540. Although less significant than the above, a similar trend in shell fragmentation with depth was observed in Spumellaria, Nassellaria, Phaeodaria, as well as total Radiolaria (text-fig. 3). The continuous increase in shell fragmentation with depth suggests that some continuous dissolution takes place while the shells are descending freely through the water column. Percentages of broken shells at 389 m were slightly higher than at 988 m for all the taxa shown in text-figure 3 except for Phaeodaria. Berger (1968) in the field and Hurd (1972) in the laboratory demonstrated much higher dissolution rates of biogenic opal above about 400 m than below in the tropical Pacific. It is

possible that some of the trapped radiolarian shells were dissolved within sediment trap receiving cups prior to retrieval. Thus, the higher percentage of broken shells at 389 m than at 988 m could be attributed to trap *in situ* dissolution rather than dissolution during their settling in the water column.

Phaeodaria, on the other hand, showed an opposite trend in the percentage of broken shells to other taxa between 389 and 988 m, although overall increase in the percentage of broken shells was consistent (text-fig. 3). Phaeodarian dissolution during their settling appeared to be greater than the trap *in situ* dissolution effect. Lower values of the percentages of broken shells at 3755 and 5068 m than at 988 m were due to the introduction of deep-water species (Reshetnyak, 1955) which can supply unbroken shells (table 2). *Challengeron willemoesii* Haeckel, *Protocystis xiphodon* (Haeckel), *Euphysetta pusilla* Cleve, and *Conchidium caudatum* (Haeckel) appear to decrease their fluxes significantly as they descend, suggesting their rapid dissolution.

A few radiolarian shells descended rapidly to the sea floor. This is substantiated by the observation that the

PLATE 3

The scale bar in figure 5 equals 100 μ m for all figures.

- | | |
|-------------------------------------------------------|-------------------------------------------------------------------------|
| 1 <i>Stylosphaera lithatractus</i> Haeckel
5068 m. | 11 <i>Stylacontarium bispiculum</i> Popofsky
3755 m. |
| 2 <i>Stylosphaera</i> group
3755 m. | 12 <i>Hexacladus</i> sp.
3755 m. |
| 3 <i>Amphisphaera</i> group
3755 m. | 13 <i>Hexacontium arachnoidale</i> Hollande and En-
jumeat
988 m. |
| 4 <i>Xiphatractus pluto</i> (?) (Haeckel)
988 m. | 14 <i>Hexacontium axotrias</i> Haeckel
389 m. |
| 5 <i>Druppatractus acquilonius</i> Hays
3755 m. | 15 <i>Hexacromyrum elegans</i> Haeckel
389 m. |
| 6 <i>Rhodosphaera</i> (?) group
389 m. | 16 <i>Hexalonche hystricina</i> Haeckel
3755 m. |
| 7 <i>Staurolonche</i> group
389 m. | 17 <i>Centracontarium hexacontarium</i> Popofsky
988 m. |
| 8 <i>Staurolonche</i> (?) sp.
3755 m. | 18 <i>Centrolonche hexalonche</i> Popofsky
5068 m. |
| 9 <i>Xiphosphaera tesseractis</i> Dreyer
3755 m. | 19–20 <i>Leptosphaera</i> sp.
3755 m. |
| 10 <i>Hexancistra</i> sp.
389 m. | |

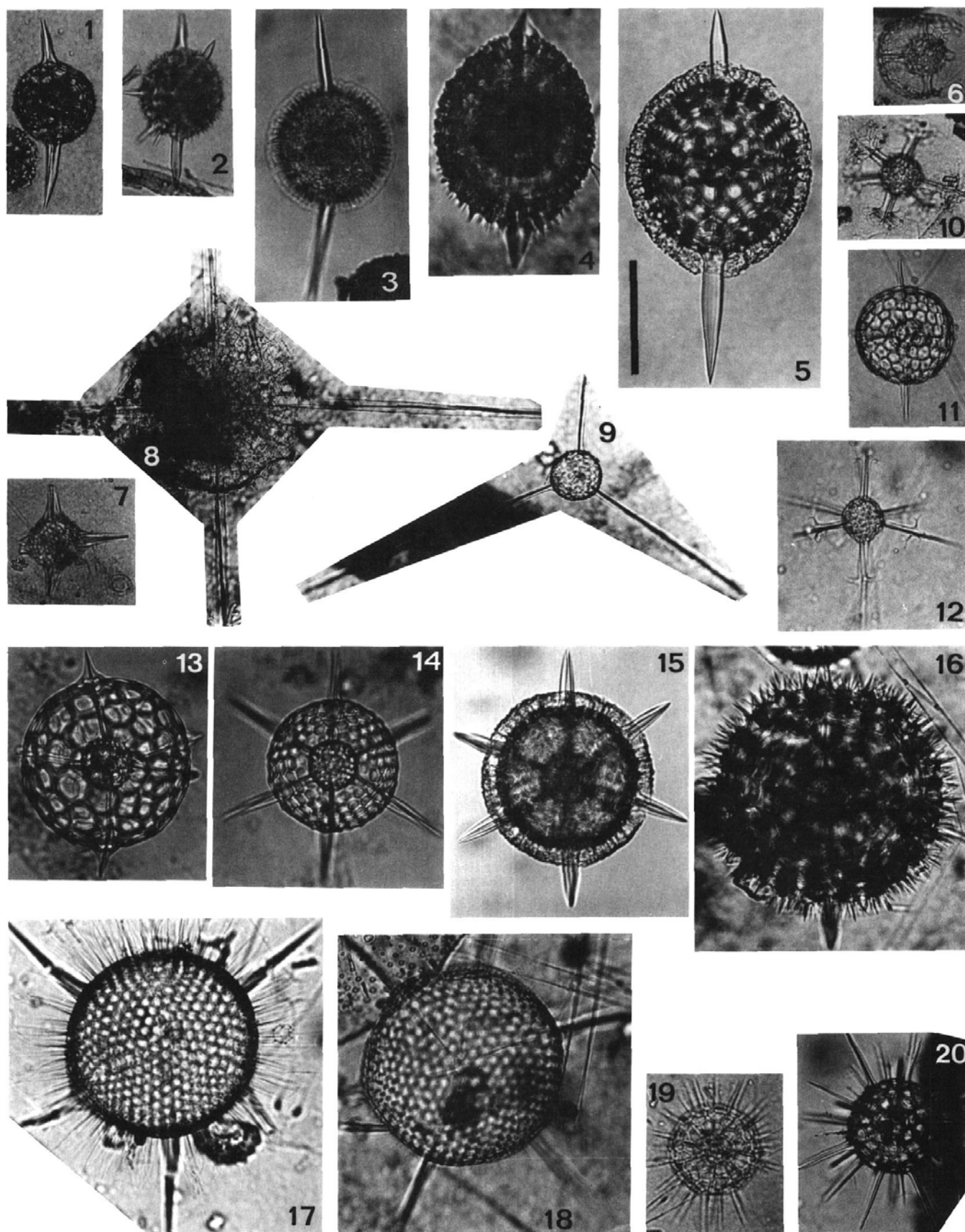


TABLE 6

Percent similarity between depths of Radiolaria and their subgroups in sediment traps deployed in the western tropical Atlantic.

Sediment Trap Depth (m)	Sediment Trap Depth (m)			
	389	988	3755	5068
Spumellaria				
389	100.0			
988	73.3	100.0		
3755	79.3	73.8	100.0	
5068	72.9	78.6	76.6	100.0
Nassellaria				
389	100.0			
988	75.3	100.0		
3755	69.5	86.3	100.0	
5068	70.1	80.8	84.3	100.0
Phaeodaria				
389	100.0			
988	50.2	100.0		
3755	34.5	59.7	100.0	
5068	27.8	62.2	77.7	100.0
Total Radiolaria				
389	100.0			
988	73.1	100.0		
3755	68.1	82.8	100.0	
5068	65.4	77.7	81.3	100.0

following types of radiolarian shells were counted in biogenic aggregates: (1) a shell that was incorporated in fecal material (pl. 15, figs. 8–11); and (2) an individual shell that was fully or partially wrapped by organic substance which most probably disintegrated from the fecal material. The examination of *Pterocorys*

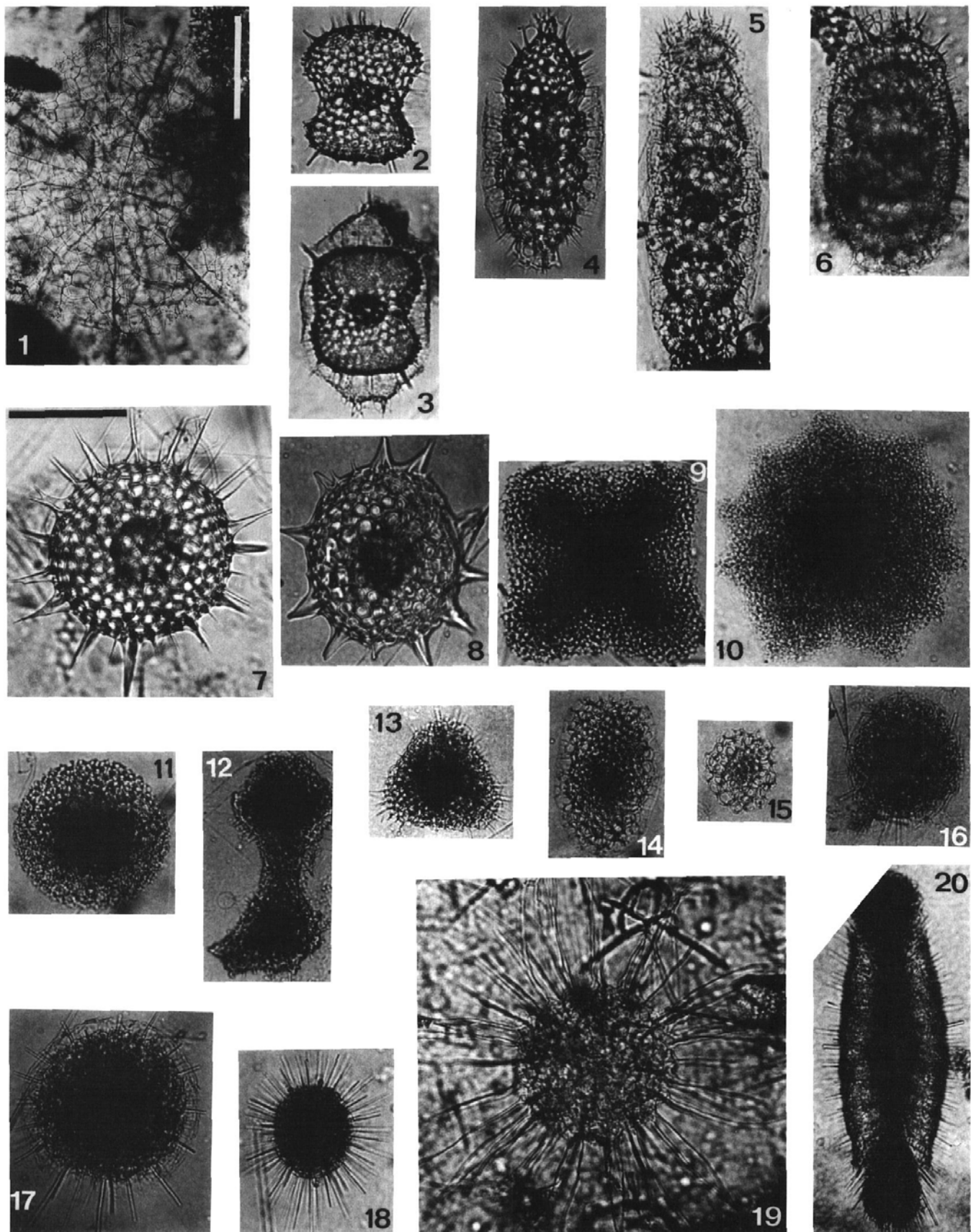
[*P. campanula* Haeckel and *P. zancleus* (Müller)] showed that the percentages of shells in biogenic aggregates were 13, 4, 2 and 1% at 389, 988, 3755, and 5068 m, respectively (text-fig. 4). Since the organic components of the samples were preserved *in situ* in the receiving cups by continuous diffusion of sodium azide (Honjo, 1980), decomposition of the biogenic aggregates was regarded minimal. Total counts used were the same as in the broken shell percentages discussed above. The decrease of the shells in biogenic aggregates with depth is probably due to the disintegration of fecal material during their descent through the water column. The decrease was most significant between 389 and 988 m. A similar trend was observed on all suborders of Radiolaria (text-fig. 4). The increasing values for Spumellaria and Phaeodaria between 988 and 3755 m were probably due to experimental errors, since the biogenic aggregates were rare.

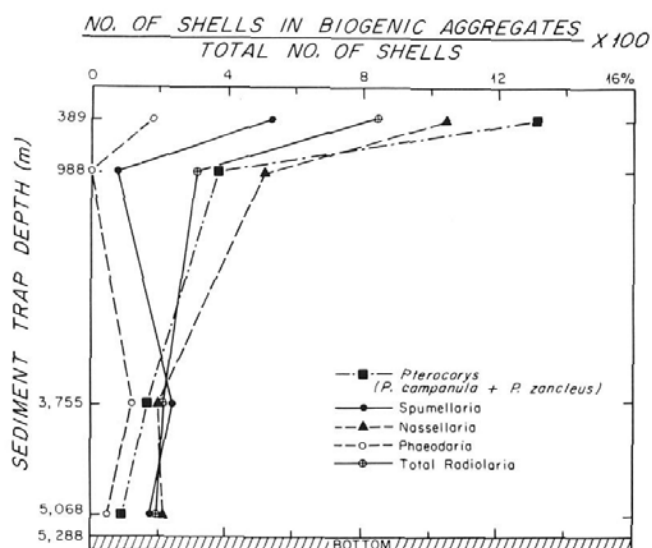
Table 3 shows percent flux of each suborder in total radiolarian shell flux as well as ratio between Nassellaria and Spumellaria (called N/S ratio in this paper). Nassellaria contributed more than 60% of the total radiolarian flux at all depths and hence this was the predominant suborder. Except from 389 to 988 m, the N/S ratio decreased with depth, indicating either an increase in relative spumellarian flux, or a relative decrease of the nassellarian flux, or both. The N/S ratio at 389 m was less than that at 988 m. This difference

PLATE 4

The scale bar in figure 7 equals 100 μ m for all figures except 1.

- | | |
|-----------------------------------------------------------------------------------|-------------------------------------------------------|
| 1 <i>Centroculus cladostylus</i> Haeckel
5068 m; scale bar: 100 μ m. | 12 <i>Spongodiscus</i> (?) sp.
389 m. |
| 2–3 <i>Ommatartus tetrathalamus</i> (Haeckel) subsp. A
2, 389 m; 3, 3755 m. | 13 <i>Spongodiscus</i> sp. A
389 m. |
| 4–6 <i>Ommatartus tetrathalamus</i> (Haeckel) subsp. B
4, 5, 5068 m; 6, 988 m. | 14–15 <i>Spongodiscus</i> sp. B.
389 m. |
| 7–8 <i>Heliodiscus asteriscus</i> Haeckel
7, 988 m; 8, 5068 m. | 16 <i>Spongopyle setosa</i> (?) Dreyer
389 m. |
| 9 <i>Spongaster tetras tetras</i> Ehrenberg
988 m. | 17 <i>Spongostrochus glacialis</i> Popofsky
389 m. |
| 10 <i>Spongaster</i> cf. <i>pentas</i> Riedel and Sanfilippo
5068 m. | 18 <i>Spongostrochus</i> sp. A
389 m. |
| 11 <i>Spongodiscus resurgens</i> Ehrenberg
988 m. | 19 <i>Spongostrochus</i> sp. B
5068 m. |
| | 20 <i>Spongocore puella</i> Haeckel
3755 m. |





TEXT-FIGURE 4

Percentages of shells in biogenic aggregates in radiolarian taxa from the western tropical sediment traps.

is significant and is reasonable considering more input of deep-water nassellarians than spumellarians between 389 and 988 m and a possibility of the *in situ* dissolution (Berger, 1968) within the receiving cups.

McMillen and Casey (1978) reported the standing stock of suspended Radiolaria using plankton tows from the surface to a few km depth in the Gulf of Mexico and Caribbean Sea. Our analysis based upon

their data showed that the N/S ratio decreased 3 orders of magnitude from the surface to a few km depth. Petrushevskaya (1971a) showed that N/S ratio decreased from her plankton samples to the surface sediments at 2 stations in the central tropical Pacific. The decreasing trend in N/S ratio with depth may be significant, although such generalization would be premature. The reported N/S ratios in the bottom sediments (Berger and Soutar, 1970; Kowsmann, 1973; McMillen, 1979) were generally lower than our observations in our deepest trap sample.

The flux of Phaeodaria was more or less uniform and it was between 6 and 8% at all depths. As stated previously, species composition of the Phaeodarian flux changed significantly with depth (table 2). The following species comprised the majority (>30 shells/m²/day) of phaeodarian flux in the bathypelagic zone: *Protocystis xiphodon* (Haeckel); *Euphysetta elegans* Borgert; *E. pusilla* Cleve; *Medusetta ansata* Borgert; *Borgertella caudata* (Wallich); *Lirella melo* (Cleve); *L. bullata* (Stadum and Ling); *Challengeron willemoesii* Haeckel; and *Conchidium caudatum* (Haeckel). Except for the last 2 species of medium size, all belonged to a small size category (pls. 10–14).

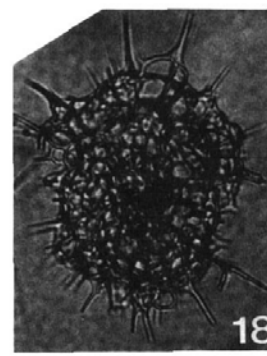
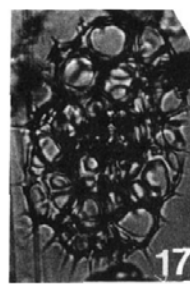
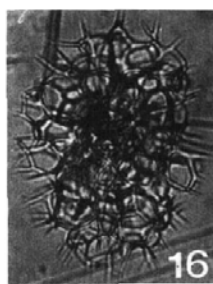
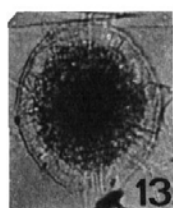
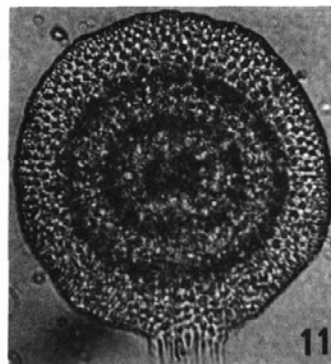
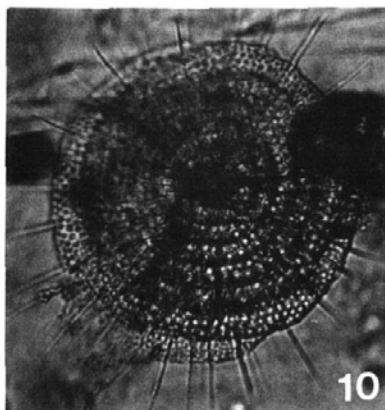
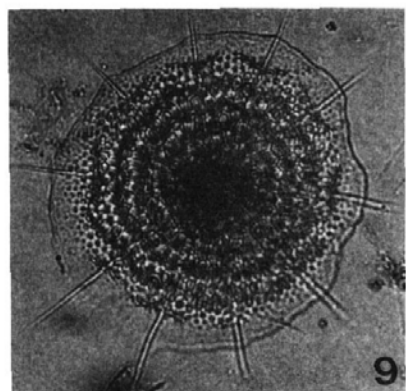
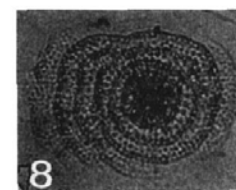
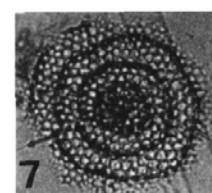
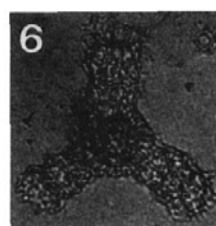
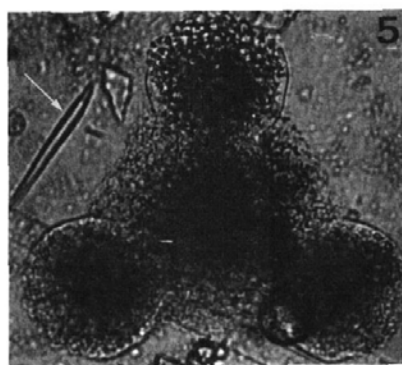
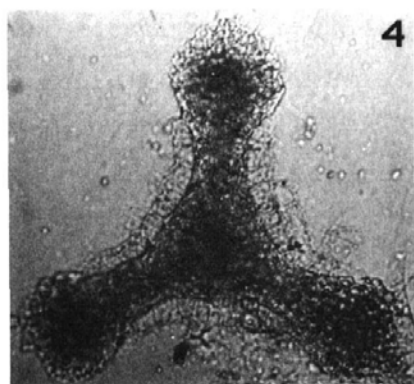
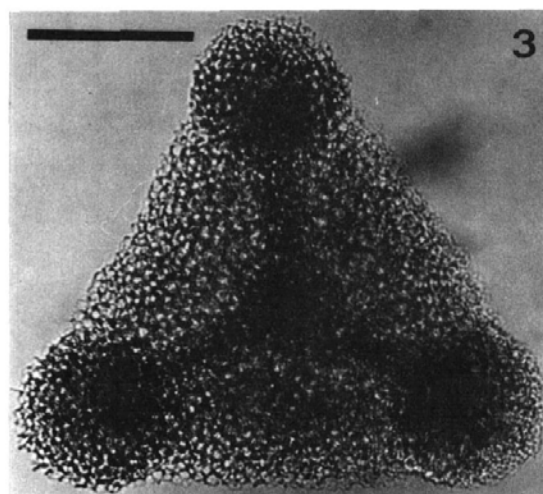
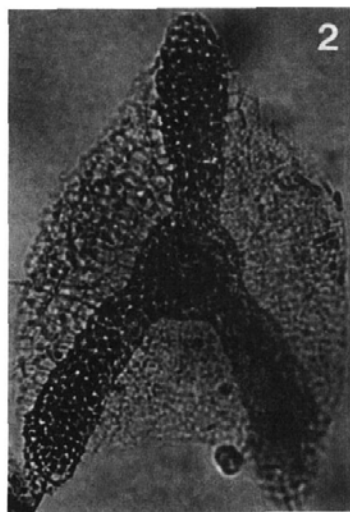
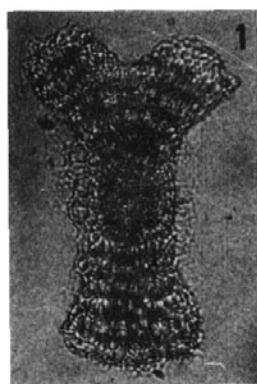
Comparison of the radiolarian flux with previous work

Total radiolarian flux ranged from 16.0×10^3 to 23.7×10^3 shells/m²/day (table 3). Of these, the flux in very coarse, medium size fractions constituted from 8.7×10^3 to 13.4×10^3 shells/m²/day. These corre-

PLATE 5

The scale bar in figure 3 equals 100 μ m for all figures.

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| 1 <i>Amphirhopalum ypsilon</i> Haeckel
5068 m. | 10 <i>Stylodictya multispina</i> Haeckel
3755 m. |
| 2 <i>Euchitonia elegans</i> (Ehrenberg)
988 m. | 11 <i>Ommatodiscus murrayi</i> Dreyer
5068 m. |
| 3–5 <i>Hymeniastrum euclidis</i> Haeckel
3, 389 m; 4, 3755 m; 5, 988 m. Arrow marks
a spine of <i>Sticholonche zanclea</i> . See plate 12,
figure 6 and plate 15, figure 5 for SEM. | 12 <i>Ommatodiscus fragilis</i> Stohr
3755 m. |
| 6 <i>Euchitonia furcata</i> Ehrenberg
389 m. | 13 <i>Stylodictya</i> sp.
988 m. |
| 7–8 <i>Porodiscus micromma</i> (Harting)
7, 988 m; 8, 389 m. | 14 <i>Discopyle elliptica</i> Haeckel
988 m. |
| 9 <i>Stylochlamydidium asteriscus</i> Haeckel
3755 m. | 15 <i>Larcopyle butschlii</i> Dreyer
389 m. |
| | 16–18 <i>Tholospira cervicornis</i> Haeckel group
16, 17, 389 m; 18, 3755 m. |



spend to 56 to 67% of the flux in all size fractions; the fine size fraction contained less than half of the radiolarian flux at all the depths.

Honjo (1978) placed a sediment trap at 5367 m during winter months in the Sargasso Sea which is known to be one of the least productive areas in the Atlantic (Ryther, 1963). Honjo's total radiolarian shell flux of 14.0×10^3 shells/m²/day included 10.0×10^3 shells/m²/day (71%) in the fine size fraction and 4.0×10^3 shells/m²/day (29%) in the very coarse, coarse and medium size fractions. Honjo's (1978) values were similar to ours in the fine size fraction but the very coarse, medium size fractions were smaller than ours by a factor of 2.

Hinga et al. (1979) measured material flux from sediment traps placed at 50 to 100 m above the sea floor in the slope and rise waters off the eastern United States. Their data included radiolarian flux of 2.0×10^3 to 6.0×10^3 shells/m²/day which did not discriminate fine size fraction. Considering the geographic regions and the deployment depths, it seems possible that their flux measured primary and resuspended radi-

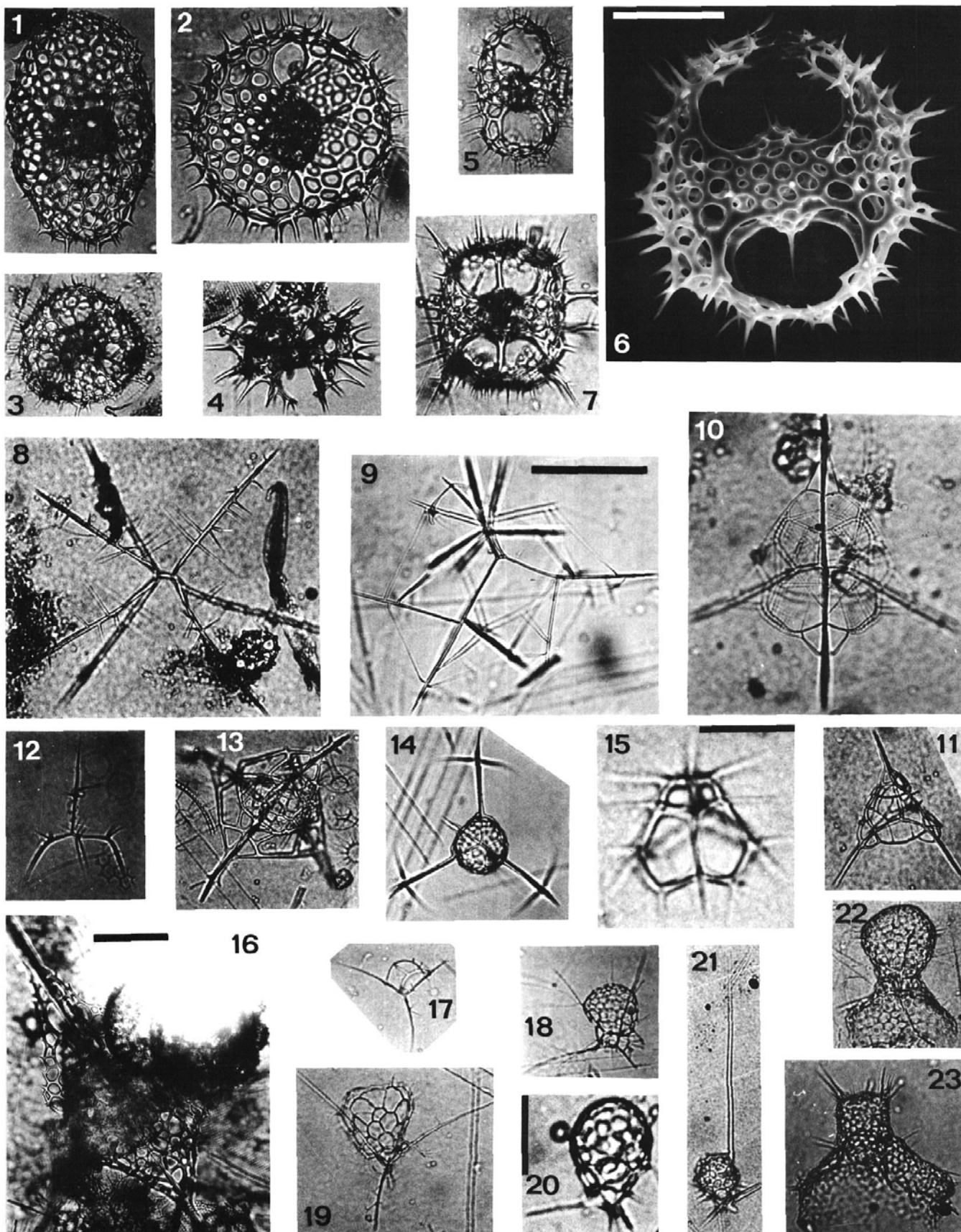
olarians as assumed by Rowe and Gardner (1979) in the same region. The radiolarian flux values of Hinga et al. (1979) are approximately one order of magnitude smaller than ours; however, their total mass and organic carbon fluxes were one order of magnitude greater than those in our samples (Honjo, 1980). Judging from their method cited in the text, it appears that their radiolarian fluxes were severely underestimated. It seems likely that they counted only visible specimens of all sizes on dry filters under a reflected light microscope.

Berger (1976) calculated supply rates of radiolarians, 0.5×10^3 to 1.1×10^3 shells/m²/day, to the surface sediments in the Santa Barbara Basin. This was based on Berger and Soutar's (1970) radiolarian counts in the fraction of surface sediments coarser than 62 μ m, assuming a sedimentation rate of 1 mm/yr (Emery, 1960). Emery's values are 1 to 2 orders of magnitude less than our values of very coarse—medium size fractions. Considering that carbon flux in the Santa Barbara Basin is 2 orders of magnitude greater (Soutar et al., 1977) than that of our Station E (Honjo, 1980), it seems

PLATE 6

The scale bar in figure 9 equals 100 μ m for all figures except 6, 15, 16 and 20.

- | | |
|----------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 1 <i>Larnacalpis</i> sp.
988 m. | 13 <i>Cladoscenum</i> sp.
5068 m. |
| 2 <i>Larcospira quadrangula</i> Haeckel
3755 m. | 14 <i>Cladoscenum anacoratum</i> Haeckel
3755 m. |
| 3 <i>Hexapyle dodecantha</i> Haeckel
988 m. | 15 <i>Obeliscus pseudocuboides</i> Popofsky
389 m; scale bar: 30 μ m. |
| 4 <i>Pyrolena armata</i> Haeckel group
389 m. | 16 <i>Clathromitra pterophormis</i> Haeckel
389 m; scale bar: 100 μ m. |
| 5–6 <i>Tetrapyle octacantha</i> Müller
389 m; 6, scale bar: 50 μ m. | 17–19 <i>Phormacantha hystrix</i> (Jørgensen)
17, 389 m; 18, 19, 3755 m. |
| 7 <i>Octopyle stenozona</i> Haeckel
988 m. | 20 <i>Peridium spinipes</i> Haeckel
389 m; scale bar: 30 μ m. |
| 8 <i>Plectanium</i> sp.
5068 m. | 21 <i>Peridium</i> sp.
3755 m. |
| 9 <i>Protoscenum</i> (?) sp.
389 m. | 22 <i>Lophophaena</i> cf. <i>capito</i> Ehrenberg
5068 m. |
| 10–11 <i>Archiscenum quadrispinum</i> Haeckel
3755 m. | 23 <i>Lampromitra circumtexta</i> Popofsky
5068 m. |
| 12 <i>Campylacantha</i> sp.
389 m. | |



reasonable to assume that radiolarian production in the former should be greater than at the latter. The radiolarians studied by Berger appear to be already significantly depleted through dissolution.

Comparison of Radiolaria from the sediment traps and in the Holocene sediments

When our radiolarian flux is converted to a different unit, $5.83\text{--}8.66 \times 10^5$ shells/cm²/10³ yr, it can be compared with Holocene sedimentation rates and radiolarian abundances in the surface sediments in our study area as cited in the literature. The comparison involves a sedimentation rate of <0.9 g/cm²/10³ yr (Lisitzin, 1972, fig. 72) and radiolarian abundance of 6000 shells/g of dry surface sediment (>44 μm : Goll and Bjørklund, 1971, pp. 437, 442). These figures combined to yield a radiolarian accumulation rate of <5400 shells/cm²/10³ yr. This rate is equivalent to $<0.8\%$ of our observed average radiolarian flux. Goll and Bjørklund (1971) stated that their <44 μm size fraction con-

tained only small broken fragments of Radiolaria which made the above comparison possible. Furthermore, they noted that the core (raised from 13°29'N, 55°59'W which was located nearest to our station E) contained mostly incomplete radiolarian specimens. The above crude comparison suggests that a high percentage of radiolarians supplied to the bottom sediments have not been preserved. This is in good agreement with general behavior of biogenic opal discussed by Heath (1974).

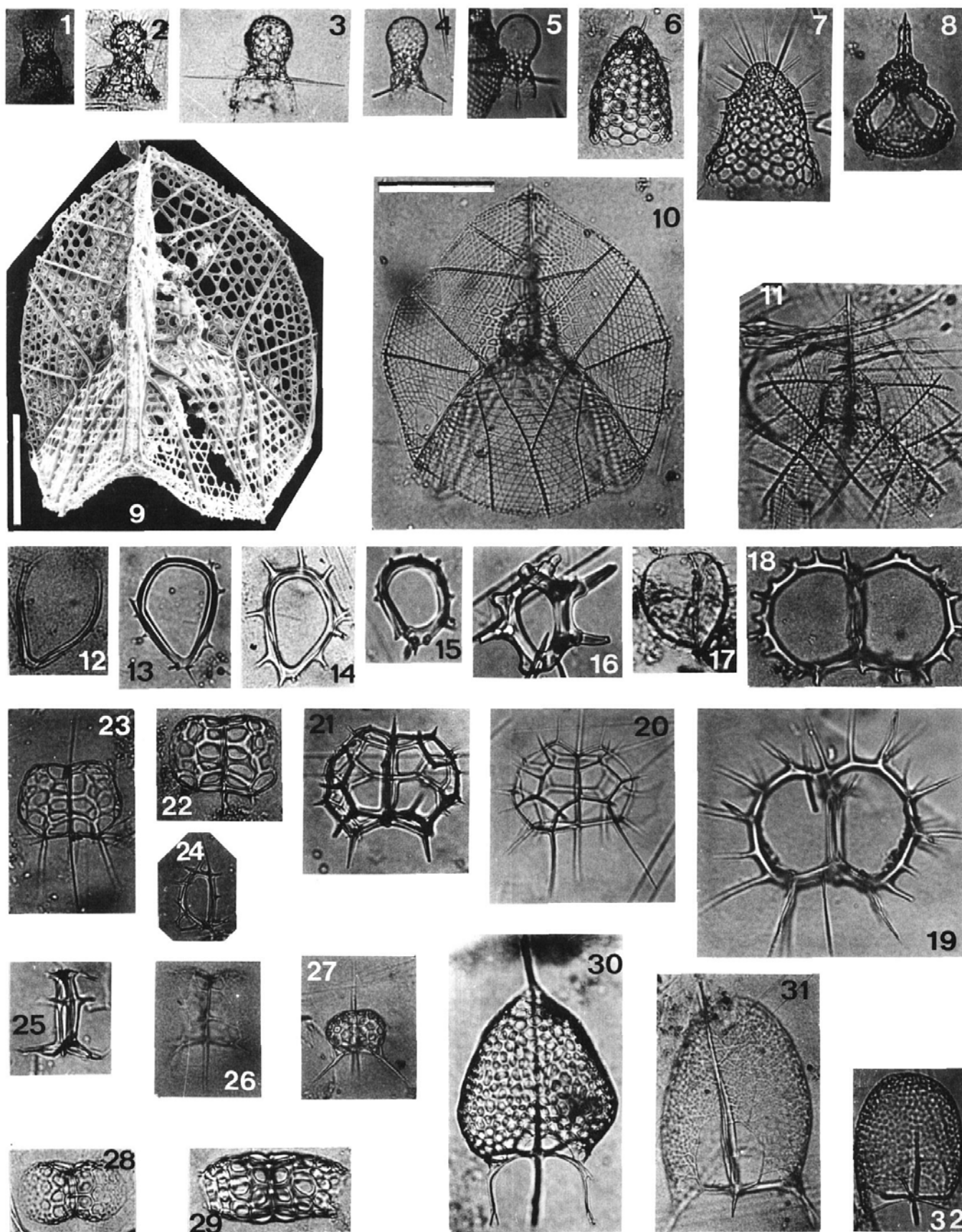
Radiolarian biogenic opal flux and estimated average weight of shells

Although comprehensive weight measurements for radiolarians in our samples have not been accomplished, we can obtain a crude estimation of radiolarian opal flux and an average weight of radiolarian shells. Microscopic examination of the sample slides indicates that Radiolaria contributed approximately one-half to three-quarters of the total biogenic opal mass flux. The remainder could be accounted for by siliceous

PLATE 7

The scale bar in figure 10 equals 100 μm for all figures except 9.

- | | |
|---------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 1 <i>Acanthocorys</i> cf. <i>variabilis</i> Popofsky
389 m. | 17 <i>Neosemantis distephanus</i> Popofsky
389 m. |
| 2 <i>Lophophaena cylindrica</i> (Cleve)
389 m. | 18–19 <i>Acanthodesmia vinculata</i> (Müller)
18, 988 m; 19, 3755 m. |
| 3–5 <i>Peromelissa phalacra</i> Haeckel
389 m. | 20–21 <i>Lophospyris pentagona pentagona</i> (Ehrenberg)
389 m. |
| 6–7 <i>Helotholus histicosa</i> Jørgensen
6, 988 m; 7, 3755 m. | 22–26 <i>Lophospyris pentagona hyperborea</i> (Jørgensen), emend. Goll
389 m. |
| 8 <i>Clathrocanium diadema</i> Haeckel
3755 m. | 27 <i>Tripodospyris</i> sp.
389 m. |
| 9–10 <i>Callimitra elisabethae</i> Haeckel
9, 988 m; scale bar: 50 μm . 10, 3755 m. | 28 <i>Dictyospyris</i> sp. A
389 m. |
| 11 <i>Callimitra emmae</i> Haeckel
389 m. | 29 <i>Dictyospyris</i> sp. B
389 m. |
| 12 <i>Zygocircus capulosus</i> Popofsky
389 m. | 30 <i>Tholospyris fornicata</i> Popofsky
988 m. |
| 13–14 <i>Zygocircus productus</i> (Hertwig)
389 m. | 31 <i>Cantharospyris</i> cf. <i>clathrobursa</i> (Haeckel)
389 m. |
| 15 <i>Zygocircus</i> cf. <i>piscicaudatus</i> Popofsky
389 m. | 32 <i>Cantharospyris platybursa</i> Haeckel
389 m. |
| 16 <i>Tholospyris</i> sp.
389 m. | |



phytoplankton shells whose predominant species were *Rhizosolenia styliformis* Brightwell and *Dictyocha messanensis* Haeckel.

Our averaged radiolarian flux of 18.3×10^3 shells/m²/day can be multiplied by an average weight of Quaternary radiolarian shells of 0.063 μg /shell (Moore, 1969) yielding 1.2 mg opal/m²/day which is equivalent to 14% of total biogenic opal flux measured by Honjo (1980: average value of 8.10 mg/m²/day). Furthermore, we also obtained an average radiolarian weight of 0.136 ± 0.009 μg /shell from a core, V24-58, 777 cm (~1 Ma: Hays et al., 1969) raised in the central tropical Pacific, by the methods used by Moore (1969). Use of this value in the same calculation as the above yields 2.5 mg opal/m²/day which is equivalent to 31% of the total biogenic opal flux. Both of the above percentages appear to be too small for the radiolarian biogenic opal flux. Our microscopic examination of the V24-58 sample indicated preservation of only medium size polycystines. Preliminary weight analysis of sediment trap large size radiolarians showed some phaeodarians were 2 orders of magnitude heavier (e.g. castanellids: 11.30 ± 0.01 μg /shell; $n = 115$ specimens) and some polycystines 1 order of magnitude heavier (e.g. *Actinomma arcadophorum* Haeckel: 0.95 ± 0.01 μg /shell; $n = 140$ specimens) than the above Quaternary fossil radiolarians. Therefore, an average weight of sediment trap radiolarians must be greater than 0.136 μg /shell.

Petrushevskaya (1966, cited in Lisitzin, 1971) reported that average weights of planktonic Radiolaria ranged between 0.33 to 1.00 μg /shell. Utilization of this range of values in the above calculation yields 6.0 to 18.2 mg opal/m²/day which is equivalent to 75 to 226% of the total biogenic opal flux. Clearly, only the lower end of Petrushevskaya's weight value is applicable to the present estimation of the radiolarian biogenic opal flux.

One can infer a range of the average radiolarian weights from our sediment traps by using the above information. By taking a range of 45 to 80% biogenic opal flux due to Radiolaria, the inferred average weight of Radiolaria appears between 0.22 and 0.33 μg /shell.

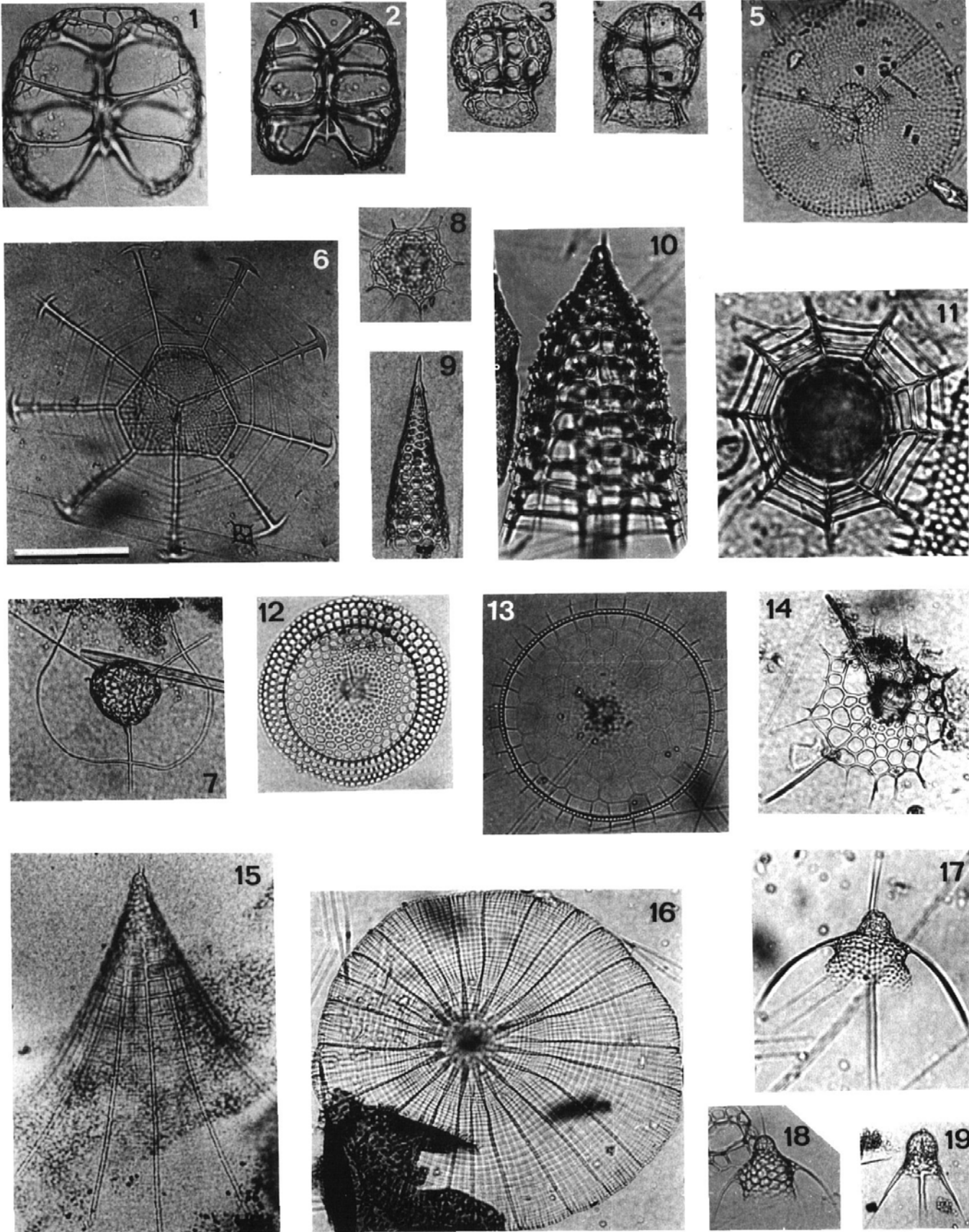
SUMMARY AND CONCLUSIONS

- (1) The number of species encountered in all samples in each group is: 89 Spumellaria; 84 Nassellaria; 34 Phaeodaria; 1 Sticholonchidae; and 208 total Radiolaria.
- (2) Of the above, on the average 67% of the species were quantified with regard to their flux. The vertical flux of individual radiolarian shells was on the order of 16×10^3 to 24×10^3 shells/m²/day.
- (3) A total radiolarian diversity index of 3.6 was obtained, and this is one of the highest ever reported.

PLATE 8

The scale bar in figure 6 equals 100 μm for all figures.

- | | |
|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 1–2 <i>Amphispyris costata</i> Haeckel
389 m. | 10–11 <i>Peripyramis circumtexta</i> Haeckel
10, 988 m, lateral view; 11, 5068 m, apical view. |
| 3 <i>Tholospyrus baconiana baconiana</i> (Haeckel)
389 m. | 12 <i>Theopilium tricostratum</i> Haeckel
389 m. |
| 4 <i>Tholospyrus baconiana</i> cf. <i>variabilis</i> (Haeckel)
389 m. | 13 <i>Clathrocyclas danaes</i> Haeckel
5068 m. |
| 5 <i>Sethophormis pentactis</i> Haeckel
389 m. | 14 <i>Dictyophimus butschlii</i> Haeckel
988 m. |
| 6–7 <i>Sethophormis rotula</i> Haeckel
6, 3755 m, basal view; 7, 988 m, apical view. | 15–16 <i>Litharacnium tentorium</i> Haeckel
15, 3755 m, lateral view; 16, 5068 m, apical view. |
| 8 <i>Sethophormis</i> cf. <i>dodecaster</i> (Haeckel)
988 m. | 17–18 <i>Dictyophimus</i> sp.
3755 m. |
| 9 <i>Cornutella profunda</i> Ehrenberg
988 m. | 19 <i>Dictyophimus plectaniscus</i> (?) Haeckel
3755 m. |



(4) Diversity indices of Spumellaria and Nassellaria were about the same between the 2 suborders except at 389 m, and uniform at 988 m and below.

(5) The diversity index of Nassellaria increased significantly from 389 to 988 m. This is mainly attributed to an introduction of deep-water species.

(6) Most of the radiolarian shells were observed to be single rather than in biogenic aggregates. They reach the bottom water without substantial modification to the species composition and standing stock. A few radiolarian shells descended rapidly to the sea floor.

(7) Fragmentation of radiolarian shells was interpreted as dissolution. Percent broken shell counts of *Pterocorys* as well as 3 suborders of Radiolaria suggest that slow dissolution of radiolarian shells may take place through the water column.

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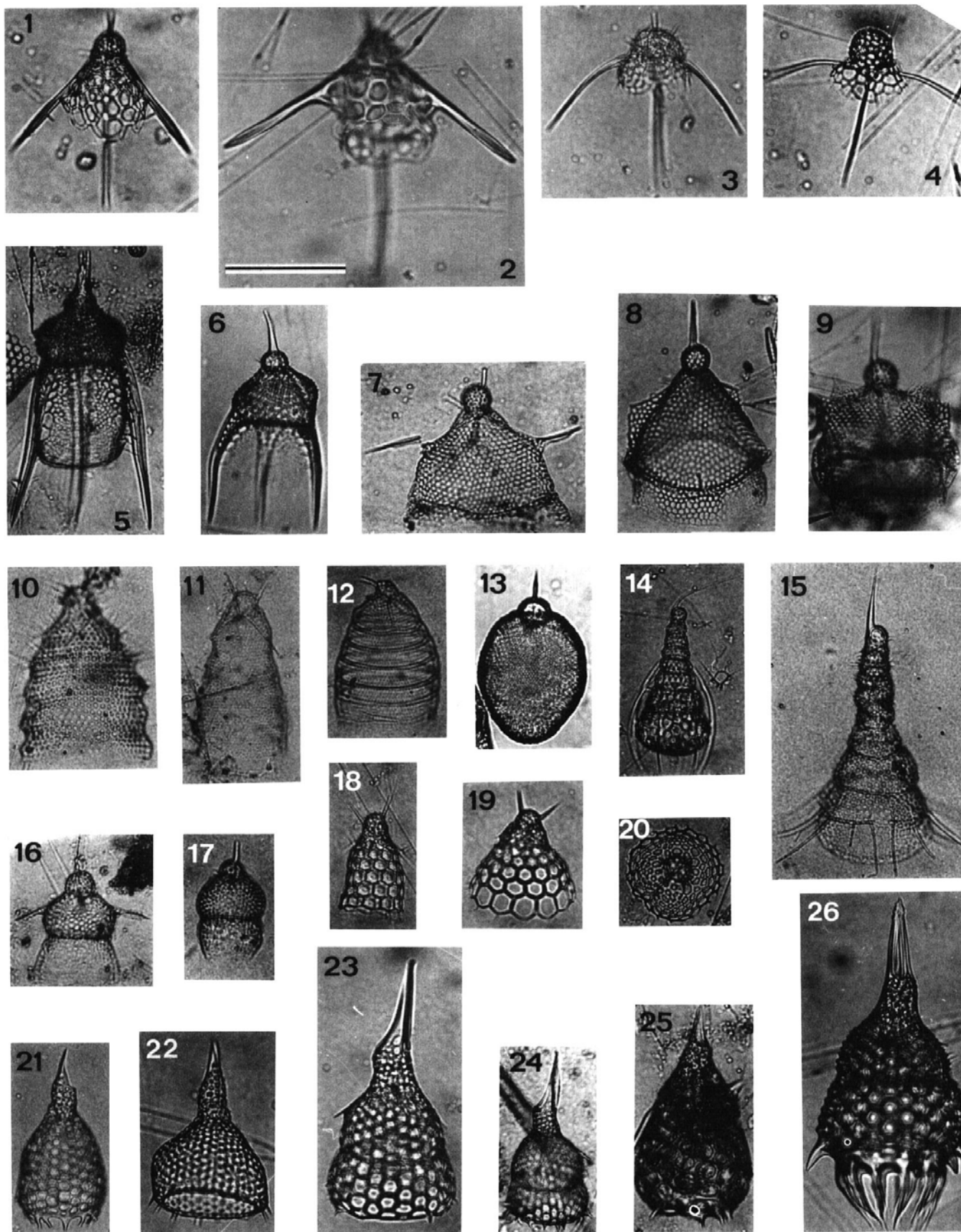
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PLATE 9

The scale bar in figure 2 equals 100 μ m for all figures.

- | | |
|----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 1–2 <i>Dictyophimus crisiae</i> Ehrenberg
3755 m. | 15 <i>Stichophormis</i> cf. <i>cornutella</i> Haeckel
3755 m. |
| 3–4 <i>Pseudodictyophimus gracilipes</i> (Bailey)
3, 5068 m; 4, 3755 m. | 16 <i>Corocalyptra columba</i> (Haeckel)
389 m. |
| 5–6 <i>Pterocanium praetextum</i> (Ehrenberg)
5, 389 m; 6, 988 m. | 17 <i>Theocorys veneris</i> Haeckel
3755 m. |
| 7–8 <i>Dictyoceras virchowii</i> Haeckel
3755 m. | 18 <i>Theocalyptra davisiana cornutoides</i> (Petrush-
evskaya)
3755 m. |
| 9 <i>Dictyoceras pyramidale</i> (Popofsky)
3755 m. | 19–20 <i>Theocalyptra davisiana davisiana</i> (Ehrenberg)
19, 988 m, lateral view; 20, 389 m, apical
view. |
| 10 <i>Lithostrobos hexagonalis</i> Haeckel
5068 m. | 21 <i>Anthocyrtdium zanguebaricum</i> (Ehrenberg)
3755 m. |
| 11 <i>Stichopilium bicornne</i> Haeckel
3755 m. | 22 <i>Anthocyrtdium ophirens</i> (Ehrenberg)
3755 m. |
| 12 <i>Eucyrtidium hexastichum</i> (Haeckel)
389 m. | 23–24 <i>Lamprocyclas maritatis polypora</i> Haeckel
3755 m. |
| 13 <i>Lithopera bacca</i> Ehrenberg
3755 m. | 25 <i>Lamprocyclas</i> (?) <i>hannai</i> (Campbell and Clark)
5068 m. |
| 14 <i>Cyrtopera languncula</i> Haeckel
3755 m. | 26 <i>Lamprocyclas maritatis maritatis</i> Haeckel
5068 m. |

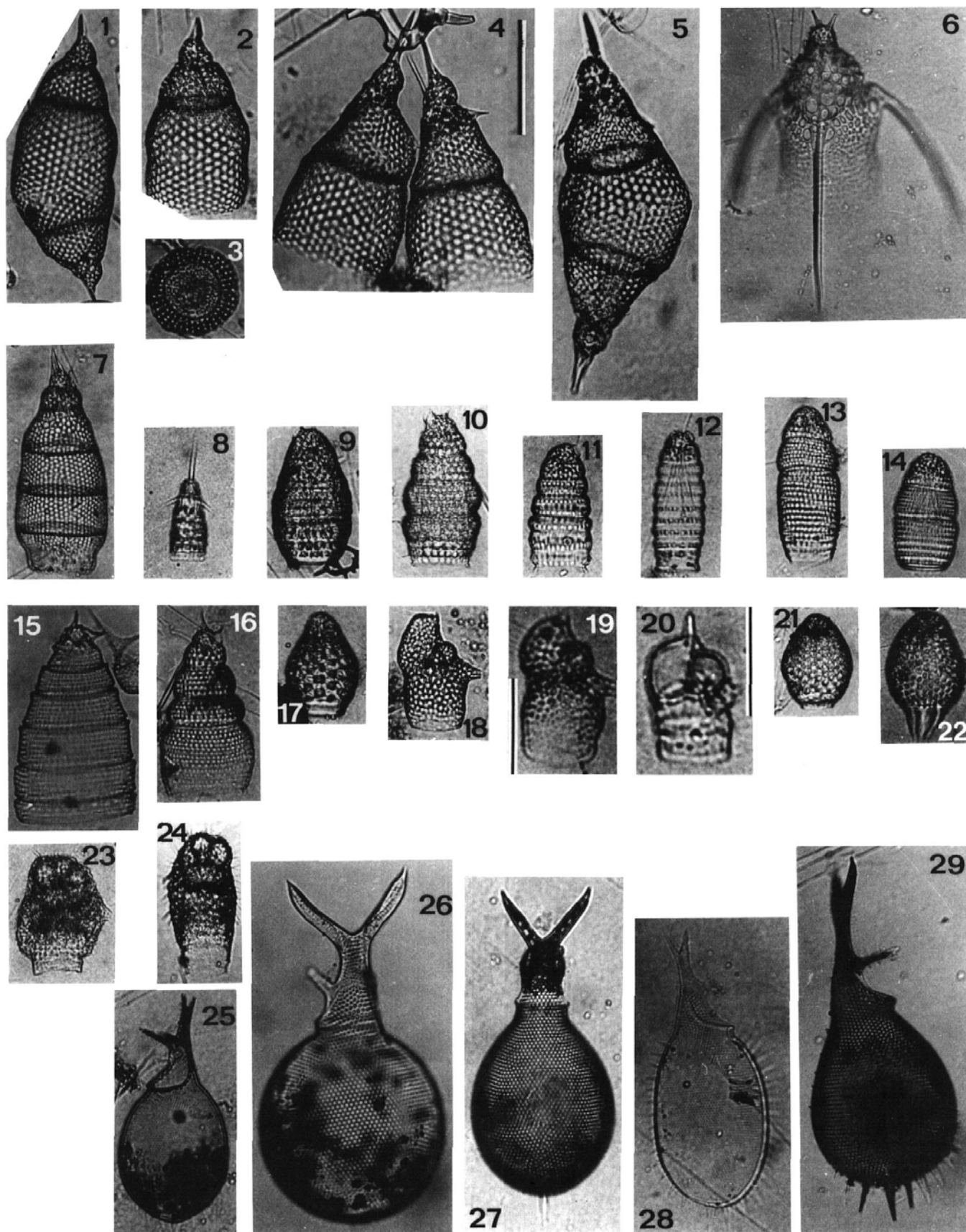


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PLATE 10

The scale bar in figure 4 equals 100 μ m for all figures except 19 and 20.

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| <p>1–3 <i>Pterocorys zancleus</i> (Müller)
1, 5068 m, specimen showing binary fission, lateral view; 2, 389 m, dorsal view; 3, 389 m, apical view.</p> <p>4–5 <i>Pterocorys campanula</i> Haeckel
4, 389 m, lateral view; 5, 988 m, specimen showing binary fission, lateral view.</p> <p>6 <i>Pterocorys hirundo</i> Haeckel
5068 m.</p> <p>7 <i>Eusyringium siphonostoma</i> Haeckel
3755 m.</p> <p>8 <i>Artostrobos annulatus</i> (Bailey)
988 m.</p> <p>9–10 <i>Botryostrobus aquilonaris</i> (Bailey)
5068 m.</p> <p>11–12 <i>Siphocampe nodosaria</i> (Haeckel)
5068 m.</p> <p>13–14 <i>Phormostichoartus corbula</i> (Harting)
13, 5068 m; 14, 3755 m.</p> <p>15 <i>Spirocyrts scalaris</i> Haeckel
389 m.</p> | <p>16 <i>Spirocyrts</i> sp. aff. <i>S. seriata</i> Jørgensen and <i>S. subscalaris</i> Nigrini
389 m.</p> <p>17 <i>Carpocanarium papillosum</i> (Ehrenberg) group
5068 m.</p> <p>18 <i>Acrobotrys</i> sp. A
389 m.</p> <p>19 <i>Acrobotrys</i> sp. B
389 m; scale bar: 50 μm.</p> <p>20 <i>Acrobotrys</i> sp. C
389 m; scale bar: 50 μm.</p> <p>21–22 <i>Carpocanistrum</i> sp. aff. <i>Carpocanistrum</i> sp.
D. Ling, 1975
5068 m.</p> <p>23–24 <i>Botryocyrts scutum</i> (Harting)
389 m.</p> <p>25–29 <i>Challengeron willemoesii</i> Haeckel
25, 389 m, oblique lateral view; 26, 988 m, oblique ventral view; 27, 389 m, ventral view; 28, 988 m, lateral view; 29, 389 m, lateral view.</p> |
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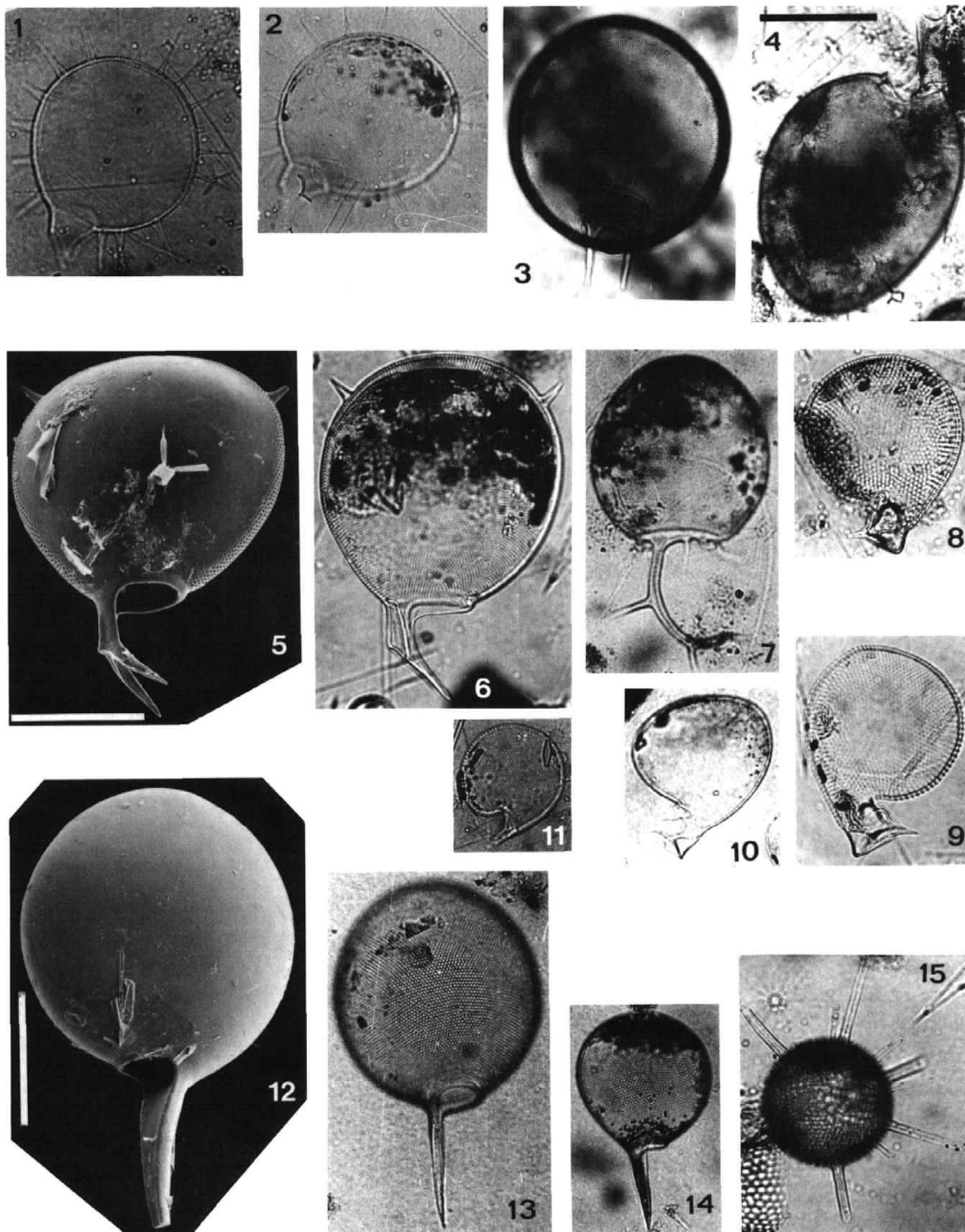


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PLATE 11

The scale bar in figure 4 equals 100 μ m for all figures except 5 and 12.

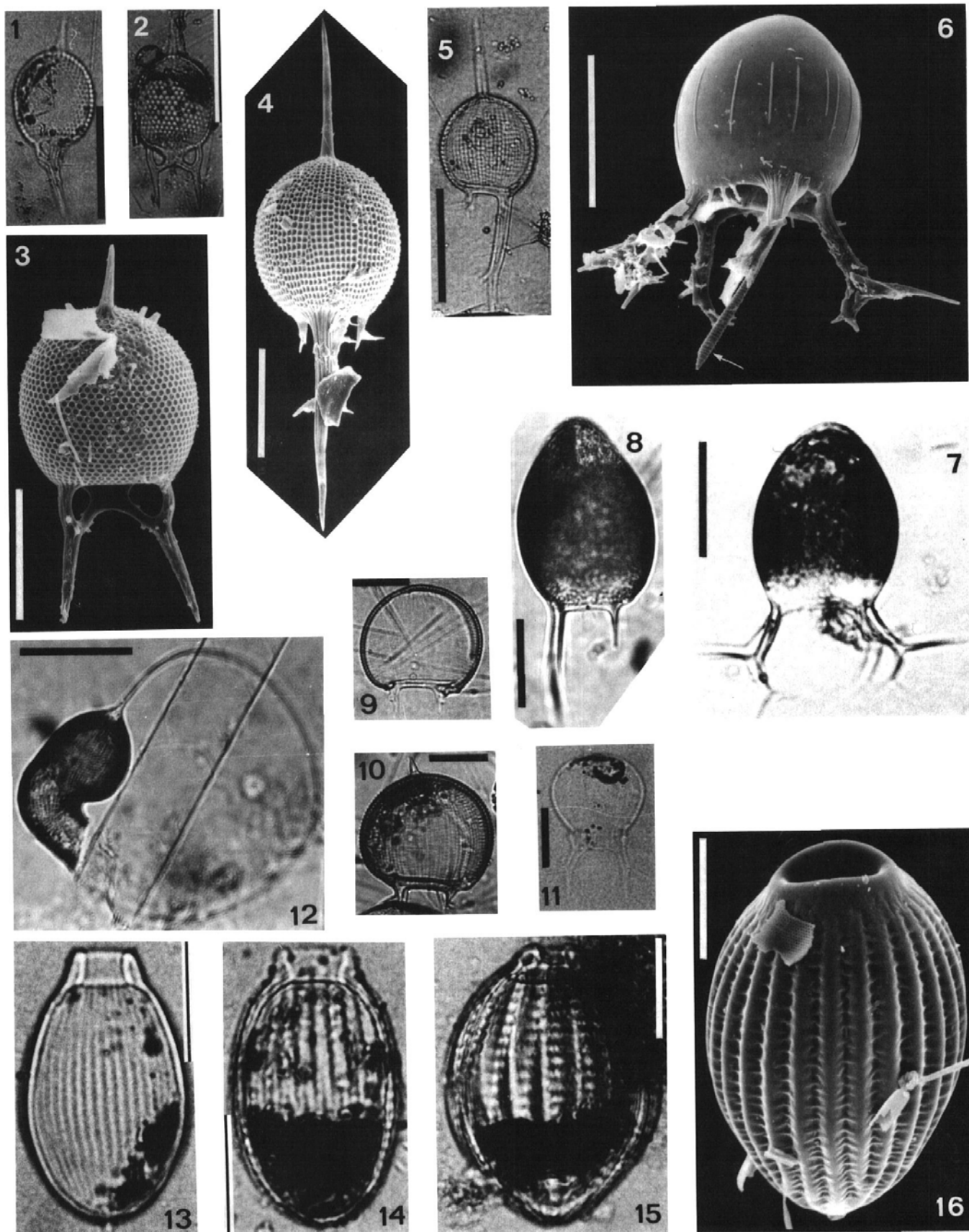
- | | |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| 1–2 <i>Challengeron radians</i> Borgert
1, 5068 m; 2, 389 m. | 11 <i>Protocystis harstoni</i> (Murray)
988 m. |
| 3–4 <i>Protocystis thomsoni</i> (Murray)
988 m. | 12 <i>Protocystis naresi</i> (Murray)
988 m, SEM, scale bar: 300 μ m. |
| 5–6 <i>Challengeron balfouri</i> (Murray)
5, 389 m, SEM, scale bar: 100 μ m; 6, 389 m. | 13 <i>Protocystis tritonis</i> (Haeckel)
5068 m. |
| 7 <i>Euphysetta lucani</i> Borgert
3755 m. | 14 <i>Protocystis xiphodon</i> (Haeckel)
389 m. |
| 8–10 <i>Protocystis</i> sp.
3755 m. | 15 <i>Porospathis holostoma</i> (Cleve)
3755 m. |



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PLATE 12

- | | |
|--------------------------------------------------|-----------------------------------------------|
| 1–3 <i>Challengeron diodon</i> Haeckel | 8 <i>Euphysetta pusilla</i> Cleve |
| 1, 988 m, lateral view, scale bar: 100 μ m; | 389 m, scale bar: 20 μ m. |
| 2, 389 m, dorsal view, scale bar: 100 μ m; | |
| 3, 988 m, SEM, ventral view, scale bar: | 9–10 <i>Medusetta</i> sp. |
| 50 μ m. | 389 m, scale bar: 50 μ m. |
| | |
| 4–5 <i>Euphysetta elegans</i> Borgert | 11 <i>Medusetta inflata</i> Borgert |
| 4, 3755 m, SEM, dorsal view, scale bar: | 988 m, scale bar: 50 μ m. |
| 50 μ m; 5, 3755 m, lateral view, scale bar: | |
| 100 μ m. | 12 <i>Borgertella caudata</i> (Wallich) |
| | 389 m, scale bar: 20 μ m. |
| | |
| 6–7 <i>Medusetta ansata</i> Borgert | 13, 14, 16 <i>Lirella melo</i> (Cleve) |
| 6, 389 m, SEM; arrow marks a spine of | 13, 3755 m, scale bar: 50 μ m; 14, 988 m, |
| <i>Sticholonche zanclea</i> ; see also plate 15, | scale bar: 50 μ m; 16, 3755 m, SEM, scale |
| figure 5; scale bar: 50 μ m; 7, 389 m, | bar: 50 μ m. |
| scale bar: 50 μ m. | |
| | 15 <i>Lirella</i> sp. |
| | 988 m, scale bar: 50 μ m. |

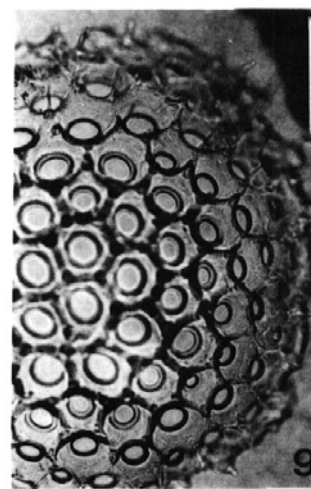
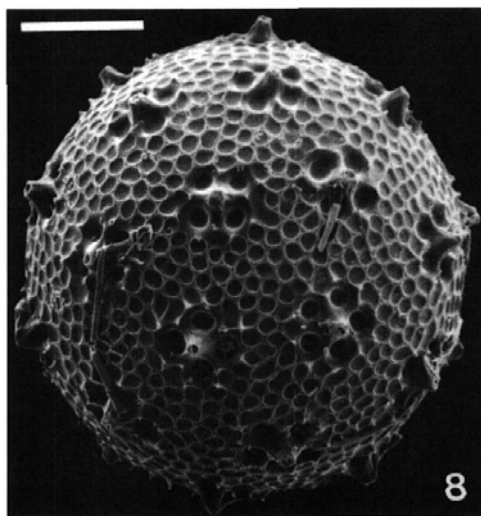
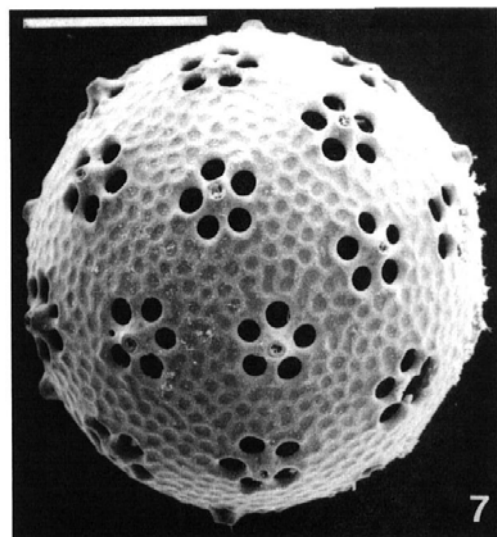
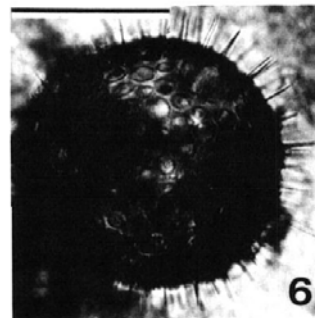
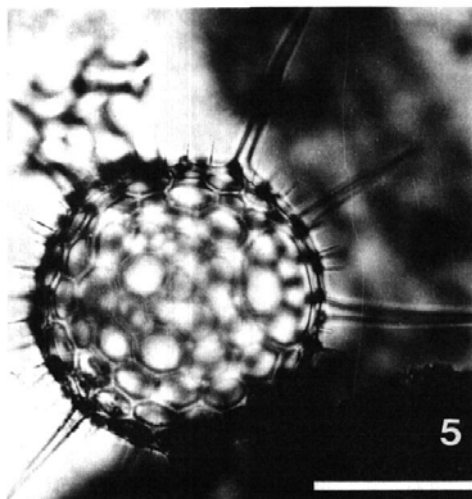
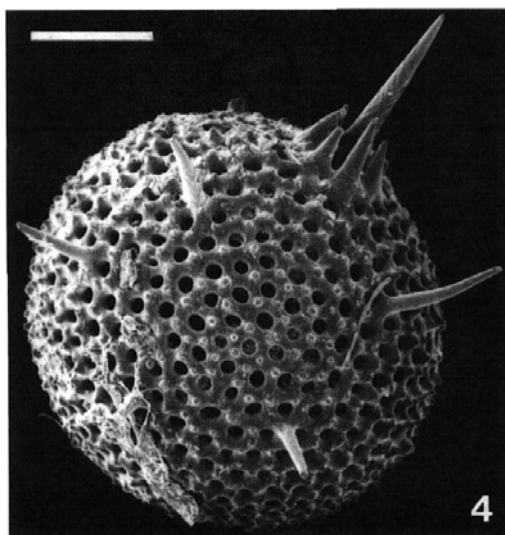
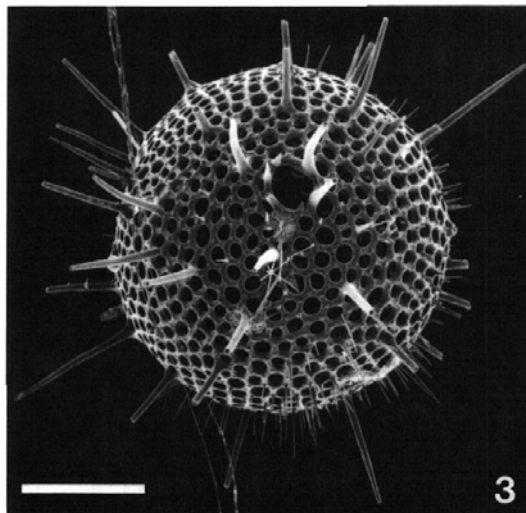
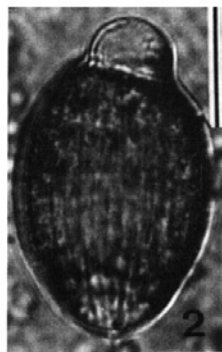
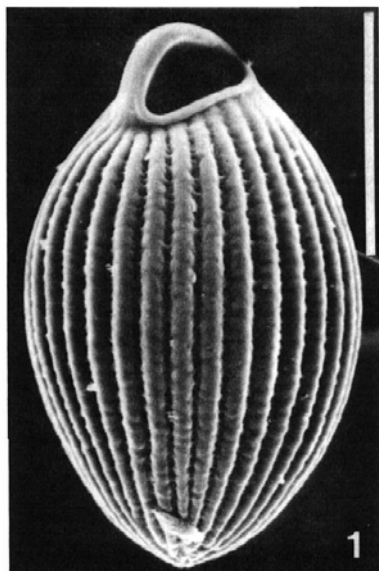


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PLATE 13

All scale bars equal 100 μ m except in 1 and 2.

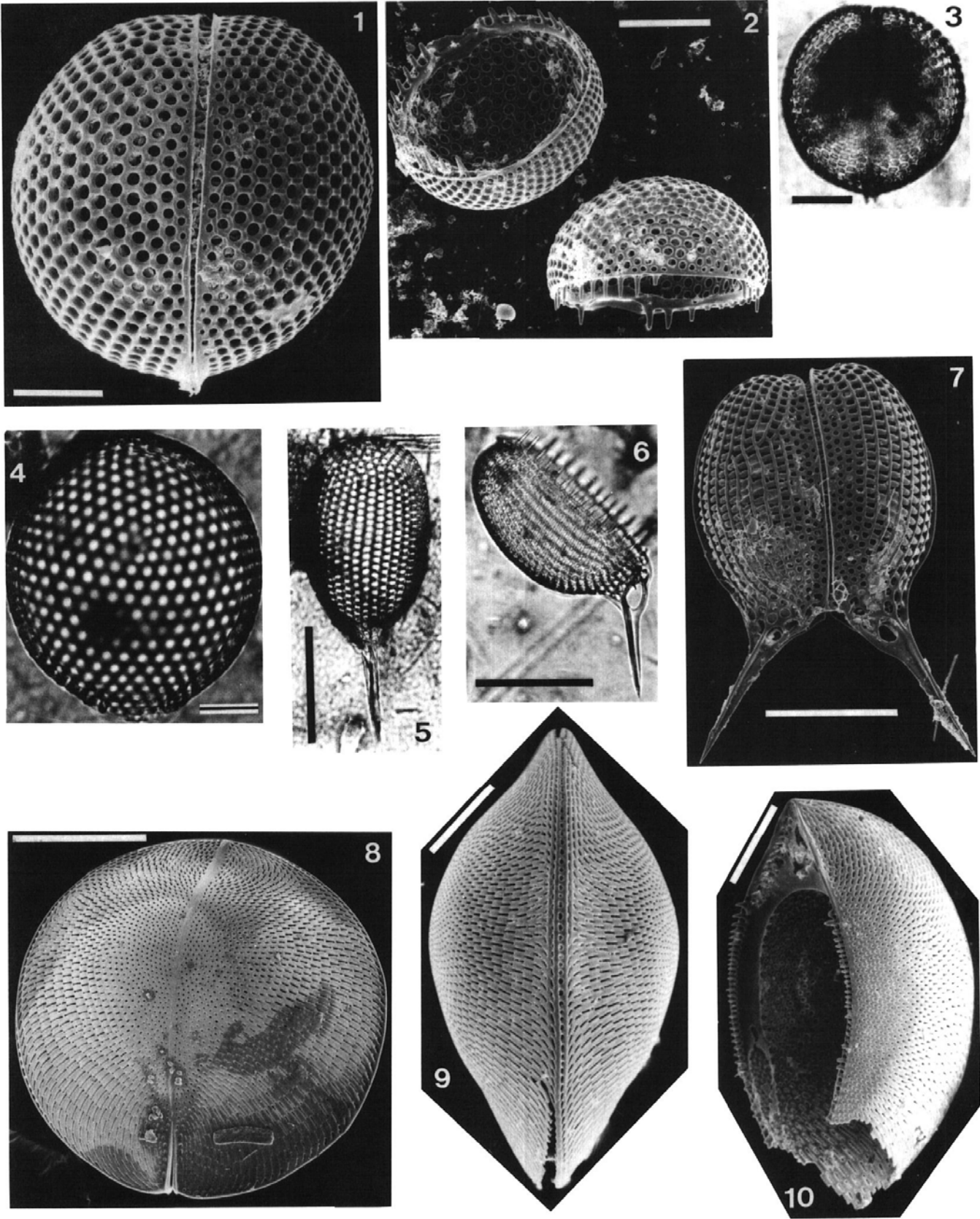
- | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1–2 <i>Lirella bullata</i> (Stadum and Ling)
1, 3755 m, ventral view, SEM, scale bar: 20 μm;
2, 5068 m, dorsal view, scale bar: 20 μm.</p> <p>3 <i>Castanissa nationalis</i> Schmidt
3755 m, SEM.</p> <p>4 <i>Castanissa circumvallata</i> Schmidt
389 m, SEM.</p> | <p>5 <i>Castanidium</i> sp.
988 m.</p> <p>6 <i>Castanarium</i> sp.
389 m.</p> <p>7–8 <i>Haeckeliana darwiniana</i> Haeckel
7, 988 m, SEM; 8, 3755 m, SEM.</p> <p>9 <i>Castanarium favosum</i> Haecker
988 m.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|



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PLATE 14

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|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1–4 <i>Conchellium capsula</i> Borgert
1, 389 m, SEM, scale bar: 50 μm; 2, 389 m, SEM, scale bar: 100 μm; 3, 389 m, scale bar: 50 μm; 4, 389 m, scale bar: 50 μm.</p> | <p>5–7 <i>Conchidium caudatum</i> (Haeckel)
5–7, 389 m, scale bars: 100 μm; 7, SEM.</p> |
| | <p>8–10 <i>Conchopsis compressa</i> Haeckel
8, 988 m, SEM, scale bar: 300 μm; 9, 10, 988 m, SEM. Scale bar: 100 μm.</p> |



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PLATE 15

- 1 *Conchopsis compressa* Haeckel
988 m, scale bar: 150 μ m.
- 2 *Conchophacus diatomeus* (Haeckel)
988 m, scale bar: 100 μ m.
- 3 *Conchellium* sp.
988 m, scale bar: 100 μ m.
- 4 Undetermined phaeodarian specimen, broken
988 m, scale bar: 100 μ m.
- 5 *Sticholonche zanclea* Hertwig
3755 m, SEM, distal end of a spine, scale bar: 5 μ m.
- 6–7 *Circoporus oxyacanthus* Borgert
389 m, scale bar: 100 μ m; 7, SEM.
- 8–11 Fecal aggregates composed mainly of polycystines
8–10, 389 m, scale bar: 200 μ m; 11, 389 m, SEM, scale bar: 100 μ m.

