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## EURORAD II, 1980 – Second European Meeting of Radiolarian Paleontologists: Current research on Cenozoic and Mesozoic radiolarians

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### ABSTRACT

This paper reports on current research in Cenozoic and Mesozoic radiolarian paleontology and summarizes contributions and discussions of EURORAD II, a meeting of radiolarian paleontologists held in Basel in 1980.

For fossil radiolarians, taxonomy primarily specifies morphological similarity. A later evaluation of the phylogenetic significance of morphologic characters will result in a revised, phylogenetically relevant taxonomy. The search for homologue skeletal elements is one way. A morphological taxonomy may be artificial and turn out to be invalid, when living radiolarians are considered (see colonial radiolarians).

Radiolarian abundance and distribution in surface and Late Cenozoic sediments and in the water column have been related to oceanographic parameters resulting in vertical and latitudinal biozonations. When interpreting abundances in sediments, the amount of dissolution and dilution of siliceous plankton by terrigenous sediment has to be considered. A minor part of all radiolarian taxa only has thus far been used in distributional studies and the inclusion of more taxa will certainly result in refined paleoceanographic interpretations.

Mesozoic radiolarian biostratigraphy has made much progress in the past few years in dating siliceous oceanic sediments. However, lithologies favourable to radiolarian preservation are restricted and certain taxa may be more affected than others by dissolution at the seafloor or during diagenesis. For worldwide correlations on the stage level future work has to be based on an integration of all available data with new correlation techniques (e.g. Unitary Associations) to allow for the incomplete preservation of radiolarian faunas.

Refined field and laboratory preparation techniques are explained.

### ZUSAMMENFASSUNG

In dieser Arbeit wird über laufende Forschung im Bereich der känozoischen und der mesozoischen Radiolarien-Paläontologie berichtet. Beiträge und Diskussionen des EURORAD II, des 2. Europäischen Treffens von Radiolarien-Paläontologen, werden zusammengefasst dargestellt.

Für fossile Radiolarien hat die Systematik hauptsächlich die Aufgabe, den morphologischen Verwandtschaftsgrad anzugeben. Bei genügender stratigraphischer Information kann später die phylo-

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netische Bedeutung von morphologischen Merkmalen erkannt und zur Erarbeitung einer phylogenetisch relevanten Taxonomie verwendet werden. Die Suche nach homologen Skelettelementen stellt einen Weg dar. Eine morphologische Taxonomie ist künstlich und kann sich als ungültig herausstellen, wenn Populationsstudien an lebenden Radiolarien beigezogen werden (z. B. kolonienbildende Radiolarien).

Radiolarienhäufigkeit und -verteilung in Oberflächen- und Neogensedimenten sowie in der Wassersäule selbst sind mit ozeanographischen Parametern (Temperatur, Salinität, Strömungsmuster usw.) in Beziehung gebracht worden und haben sowohl vertikale als auch breitenabhängige Faunenzonen ergeben. Es zeigt sich, dass bei der Interpretation von Radiolarienhäufigkeiten im Sediment, die unterschiedliche partielle Auflösung der Schalen und der Grad der Verdünnung durch terrigenes Sediment als wichtige Faktoren zu berücksichtigen sind. Nur ein kleiner Teil aller existierenden Radiolarienformen ist bisher in Verteilungsstudien berücksichtigt worden. Die Bearbeitung einer grösseren Zahl von Arten lässt noch präzisere palaeoozeanographische Interpretationen erwarten.

Die mesozoische Radiolarien-Paläontologie hat in den letzten Jahren entscheidende Fortschritte in der Datierung von kieseligen ozeanischen Sedimenten gemacht. Die für die Radiolarienerhaltung günstigen Lithologien sind jedoch in ihrer Verbreitung begrenzt und, zudem scheint es, dass bestimmte Arten der diagenetischen Auflösung mehr unterworfen sind als andere. Voraussetzung für eine weltweite stratigraphische Korrelation auf Stufenebene ist daher die Integration aller erhältlichen Radiolariendaten mittels neuer Korrelationsmethoden (z. B. Unitärer Assoziationen). Nur auf diese Weise kann der unvollständigen Erhaltung von Radiolarienfaunen in einzelnen Lokalitäten Rechnung getragen werden.

Im Kapitel 5 werden verfeinerte Feld- und Labor-Präparationsmethoden erläutert.

## 1. Introduction

During EURORAD I meeting, held in 1978 in Lille (France; DE WEVER et al. 1979a) it became clear that it would be desirable to continue to have regular meetings of radiolarian paleontologists in order to coordinate the efforts of a small scientific community dealing with an extremely diversified fossil group. The idea became reality when eleven scientists from six different countries gathered in 1980 in Basel (Switzerland) for EURORAD II.

The participants recruited from a variety of current research fields that may be divided into two categories by virtue of the nature of the fossil record and the state and methods of research: a) Cenozoic and b) Mesozoic radiolarians.

### a) Cenozoic radiolarians

Although radiolarian skeletons are amongst the more rapidly dissolved planktonic forms in the oceans, a vast amount of biogeographic and stratigraphic information from thousands of surface samples, piston cores and a few hundred drill-holes of the Deep Sea Drilling Project in all oceans is available. Thus, the understanding of Cenozoic radiolarian biostratigraphy has substantially advanced in the past decade, principally as the result of studies carried out in the frame of the Deep Sea Drilling Project (RIEDEL & SANFILIPPO 1970, 1971, 1973; MOORE 1971, 1973; GOLL 1972; BENSON 1972; PETRUSHEVSKAYA & KOZLOVA 1972; FOREMAN 1973a, 1973b; SANFILIPPO & RIEDEL 1973; DUMITRICA 1973; DINKELMAN 1973; LING 1973; JOHNSON 1974; BJØRKLUND 1976, etc.). A low-latitude Cenozoic radiolarian zonation was developed and has been successively refined to reach a certain stability (RIEDEL & SANFILIPPO 1978). Several high-latitude zonations have been proposed (KLING 1973; CHEN 1975; BJØRKLUND 1976) and their correlation with the "standard" equatorial zonation is being discussed (e.g. GOLL & BJØRKLUND 1980). Further stratigraphic research will probably add more precision to the established

zonal boundaries and provide a better resolution, if more species are considered for stratigraphy (WESTBERG & RIEDEL 1978).

Another field of research is concerned with the spatial distribution and the ecology of Cenozoic radiolarian species and the possible paleooceanographic implications. Numerous investigations have demonstrated, that the radiolarian assemblages preserved in the surface sediments of the oceans closely reflect the major zooplankton distribution provinces (HAYS 1965; PETRUSHEVSKAYA 1967; NIGRINI 1967, 1968, 1970; PETRUSHEVSKAYA & BJØRKLUND 1974; GOLL & BJØRKLUND 1971, 1974). Only more recently have comprehensive studies of radiolarian distribution in the water column begun to appear (PETRUSHEVSKAYA 1971a, b; RENZ 1976; KLING 1976, 1979; McMILLEN & CASEY 1978). They show distinct radiolarian assemblages not only depending on latitude but also varying with depth and general basin configuration. Thus the occurrences of many radiolarian species seem to be closely tied to certain hydrographic conditions such as temperature, concentration of nutrients, oxygen and other biota. Some radiolarian species have been successfully used as "tracers" for watermasses and changes in past circulation patterns could be traced in the sediments by changes in the presence or abundance of these species (CAULET 1979; LABRACHERIE 1980a, b).

However, caution must be applied when interpreting fossil radiolarian assemblages. They not only result from an accumulation of vertically and laterally varying faunas but are also the product of current distribution and selective dissolution in the water column, on the sediment surface and within the sediment (McMILLEN & CASEY 1978; KASTNER 1979).

In many of the Neogene and Quaternary sequences preservation is nevertheless extremely good and has permitted detailed stratigraphic, morphological and population studies, some of which are further discussed in this paper.

### b) Mesozoic radiolarians

Much of the early classic work on Mesozoic radiolarians was based on Triassic and Late Jurassic to Early Cretaceous radiolarian-rich sediments from Italy, Central Europe, Greece and Russia (RÜST 1885, 1898; PARONA 1890; SQUINABOL 1914, etc.).

In later decades, the interest in Mesozoic radiolarians declined and their stratigraphic value was questioned. The Deep Sea Drilling Project and new interest in dating siliceous sediments in Mesozoic oceanic sequences revitalized the research. Studies mainly based on Cretaceous DSDP-material (MOORE 1973; FOREMAN 1973b, 1975, 1978; RIEDEL & SANFILIPPO 1974) and on Late Jurassic and Cretaceous land samples from California (PESSAGNO 1976, 1977a, b) clearly demonstrated the biostratigraphic potential of Mesozoic radiolarians. The established zonations allowed a rough dating of otherwise unfossiliferous siliceous sediments.

Meanwhile, rich Triassic radiolarian faunas were discovered and systematically described from Austria (KOZUR & MOSTLER 1972, 1978, 1979), Greece, Sicily and Turkey (DE WEVER et al. 1979b), Baja California (PESSAGNO et al. 1979), Northern Italy and Roumania (DUMITRICA 1978a, b; DUMITRICA et al. 1980), and from Japan NAKASEKO & NISHIMURA, 1979). YAO et al. (1980) proposed a coarse, Middle Triassic to Middle Jurassic radiolarian zonation.

Only recently have systematic inventories on early and middle Jurrassic radiolarian faunas begun to appear (YAO 1972, 1979; ICHIKAWA & YAO 1976; PESSAGNO & BLOME 1980; PESSAGNO & POISSON, in press; PESSAGNO & WHALEN, in press; DE WEVER 1981b, c, in press).

All this work demonstrates not only the extreme morphological diversity of Mesozoic radiolarians, but also shows how fragmentary our knowledge of total ranges and of evolutionary relationships still is. The faunal associations revealed by new, well-preserved assemblages may always cause a modification of a hitherto established zonation. Radiolarians are highly susceptible to selective dissolution, both before and after burial in the sediment but especially during late diagenesis and deep burial. The extent of preservation of a radiolarian assemblage is strongly depending on the diagenetic microenvironment. Thus, lithologies favourable to good radiolarian preservation are generally of limited vertical extent. Changes in faunal composition in a vertical sequence that one tends to interpret as biostratigraphic always have a certain likelihood of being the result of incomplete preservation of the original assemblages.

To overcome this intriguing situation some of us (BAUMGARTNER et al. 1980) have used a method developed by GUEX (1977) that integrates co-occurrences of species from many sections to establish the synthetic total range of each species with respect to all other species considered. This method seems to have a great potential for Mesozoic radiolarian biostratigraphy. It has been fully discussed during the meeting and is summarized herein.

This paper is intended to provide information for non-specialists on current research in the field of radiolarian paleontology and to report on discussions of actual problems in this field. Informal contributions and discussions were centered around a number of themes which are given here as chapters 2 to 5. Each chapter includes summaries and discussions of one or several contributions and a general discussion and conclusions of the theme. Emphasis is put on concepts and methods of investigation. Thus the summaries are brief and give only examples of data to illustrate the problems discussed. For further detail, we refer to the original work by the authors (addresses given in the Appendix).

## 2. Radiolarian taxonomy (reported by J. P. Caulet)

### 2.1 Introductory remarks

Taxonomic problems appear to be of the most important concerns to all radiolarian workers, since clearly defined taxonomic groups are the basis both for stratigraphic and for paleoceanographic work. During the first EURORAD meeting we came to the conclusion that stratigraphic and paleoenvironmental interpretations can be made quite satisfactorily on the basis of morphotypes without considering whether or not they correspond to biological species. In fact, they can be defined more precisely and applied more uniformly than "species" which generally include some degree of subjective judgement. To illustrate the recent development of ideas and to initiate a general discussion, three contributions were presented at the meeting.

## 2.2 The taxonomical status of colonial radiolarians (presented by K. Bjørklund)

### a) Summary

This report on ongoing work is intended to draw attention to an until now insufficiently studied group of radiolarians. BJØRKLUND & GOLL (1979) used internal skeletal structures to demonstrate evolutionary lineages and repetitive evolution of Miocene collosphaerids. The study demonstrates that colonial radiolarians may yield both precise stratigraphic markers and insights in evolutionary processes. Their taxonomy, however, is in an early stage and needs to be revised.

The following is to illustrate the taxonomical problems that arise, when working with colonies that are referred to as *Collosphaera tuberosa*, *C. huxleyi* and *Trisolenia megalactis megalactis*. The problem is significant as *Collosphaera tuberosa* and *Collosphaera (Buccinosphaera) invaginata* are used as late Pleistocene index species (NIGRINI 1971). Living colonies of *C. invaginata* fortunately show little morphologic variation among the individual tests, whereas *C. tuberosa* causes more serious problems of identification. Specific discrimination is generally based on the morphology of isolated tests, whereas the range of morphologic variation within an entire colony is not well understood. The study of material collected in the equatorial Pacific by V. Reshetnyak shows an intriguing variation of morphologies within one colony. Figure 1 illustrates colonies with morphologies typical for *Collosphaera tuberosa*, as identified by STRELKOV & RESHETNYAK (1971). All figures clearly show the spherical shells with deep depressions characteristic for *C. tuberosa* (cf. NIGRINI 1971). In addition, smaller, smooth shell shapes, not related to *C. tuberosa* occur in the same colony (Fig. 1a-c, f). If found isolated in the sediment, these smooth shells would be identified as *C. huxleyi*.

Figure 2a, b illustrates a colony with a majority of shell shapes typical for *Collosphaera huxleyi*. HILMERS (1906) distinguished three varieties of this species, one with smooth shells only, a second with smooth and slightly undulated shells and a third with smooth and strongly undulated shells. Those shells with deep impressions (e.g. Fig. 2b, lower left corner) would, if found isolated in the sediment, easily be identified as *C. tuberosa*.

In conclusion it seems unrealistic to retain the present distinction between the two species. *C. tuberosa* may eventually be regarded as one of HILMER's (1906) varieties of *C. huxleyi*.

Figure 2c-e gives another example of a colony including several morphotypes. EHRENCBERG (1860) divided these tube-bearing spumellarians into five genera, *Disolenia*, *Trisolenia*, *Tetrasolenia*, *Pentasolenia* and *Polysolenia* according to the number of tubular extensions. HAECKEL (1887) synonymized them all under the genus *Solenosphaera* for which BJØRKLUND & GOLL (1979) used the name *Trisolenia* according to the rules of priority. All these morphotypes may just be variations (or growth stages?) of one single species, which is suggested by their coexistence in one colony.

Future studies of living colonies are required to understand the intra- and interspecific morphologic variations in this group. This understanding may greatly affect the interpretation of fossil colonial radiolarian assemblages.

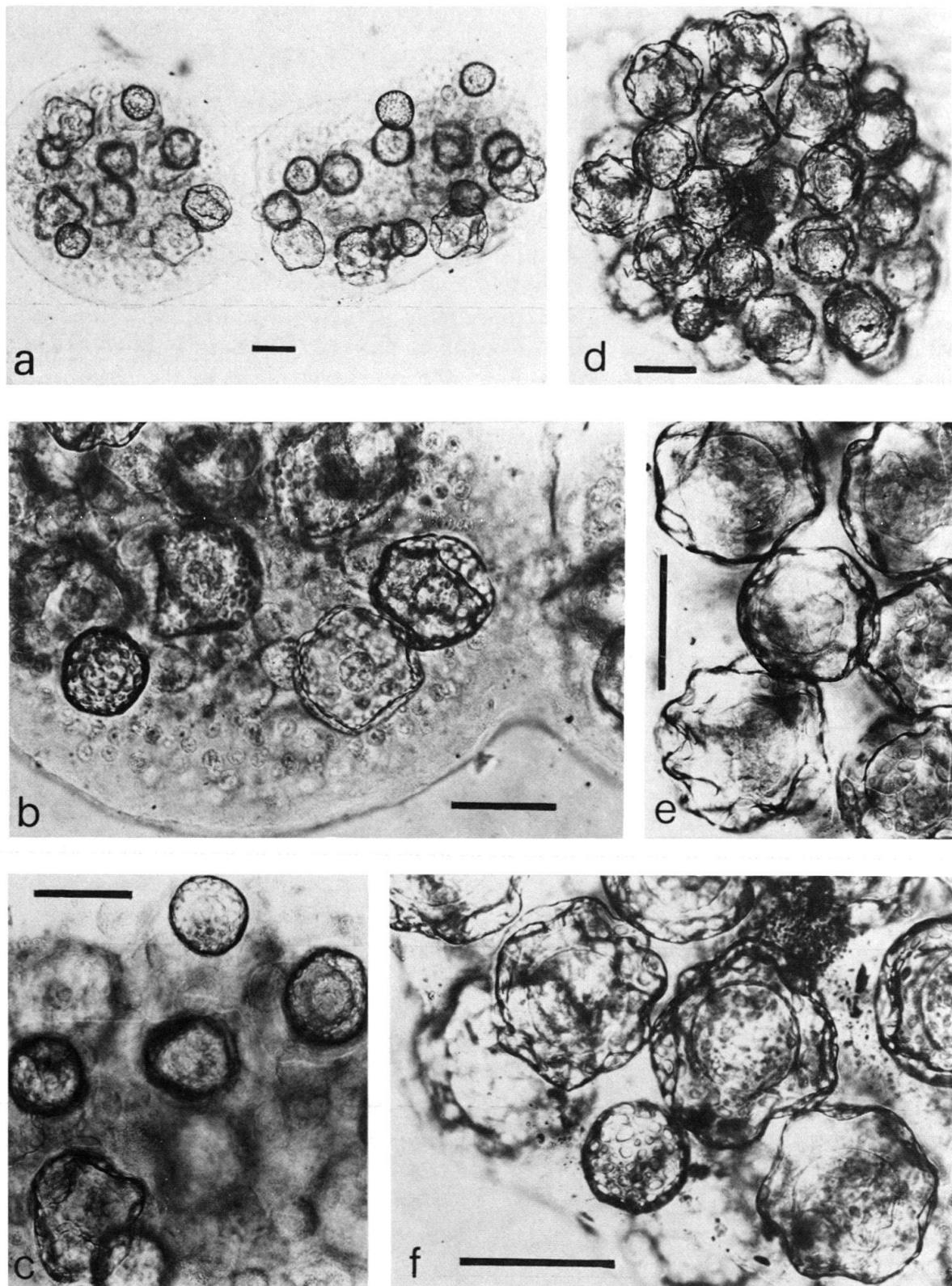


Fig. 1. Transmitted light photomicrographs of fixed living colonies of *Collosphaera tuberosa* collected by V. Reshetnyak in the equatorial Pacific. Scale bar represents 100  $\mu\text{m}$ .  
 a = Entire colony ca.  $\times 55$ ; b, c = details of a, showing the typical shells with deep depressions, but also smaller smooth shells, typical for *C. huxleyi*, ca.  $\times 130$ ; d = entire colony ca.  $\times 80$ ; e, f = details of d. Most of the shells show the typical tuberous shell surface. e: ca.  $\times 175$ , f: ca.  $\times 200$ .

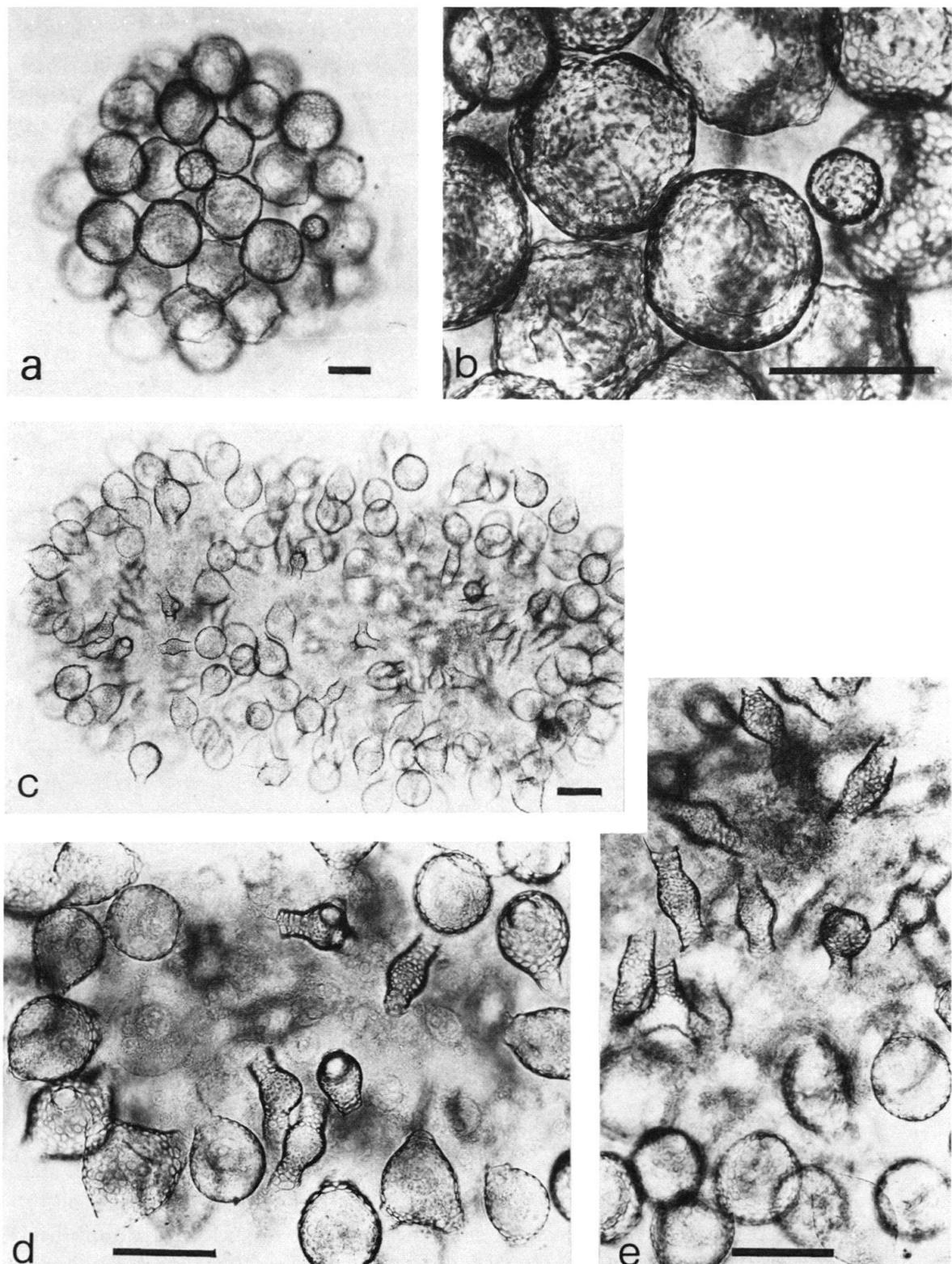


Fig. 2. Transmitted light photomicrographs of fixed living collosphaerid colonies collected by V. Reshetnyak in the equatorial Pacific.

a = *Collosphaera huxleyi*, entire colony ca.  $\times 80$ ; showing predominant spherical smooth shells, but also some with deperessions like *C. tuberosa* (compare to Fig. 1); b = detail of a, ca.  $\times 220$ ; c = *Trisolenia megalactis megalactis*, entire colony ca.  $\times 55$ . Shells may have one, two, three, four or more tubular extensions which led to EHRENBURG's (1860) classification of *Disolenia*, *Trisolenia*, *Tetrasolenia* and *Polysolenia*, seen here as morphologic variation of one species. d, e = details of c, ca.  $\times 130$ .

## b) Discussion

The contribution of K. Bjørklund has shown us that forms previously assigned to different genera or different species on the basis of test symmetry or other morphologic features can be found living together in one colony which suggests them to be conspecific. The question arises as to whether two or more biological species can form one symbiotic colony. This is unlikely, as the observed colonies seem to have one uniform cytoplasmic mass and include small specimens that appear to be juvenile forms.

When looking at fossil forms, we are not able to decide whether closely related morphotypes belong to the same species or not. All we need for biostratigraphy is an accurate description and stratigraphic record of all morphotypes. Closely related morphotypes may ultimately show the same ranges and co-occurrence in most samples, suggesting that they belong to one natural species. The incomplete knowledge of radiolarian biology does not exclude the possibility of sexual dimorphism. Perhaps biological species have to be conceived in a very conservative, broad sense.

### 2.3 The Poulpinae, spyrid-like forms of evolved Pylentonemidae (presented by P. De Wever).

#### a) Summary

Some Mesozoic radiolarian forms referred to as "spyrid, gen. et sp. indet" by RIEDEL & SANFILIPPO (1974) and described as *Saitoum* PESSAGNO (1977a; YAO 1979) are still of problematic supergeneric affinity.

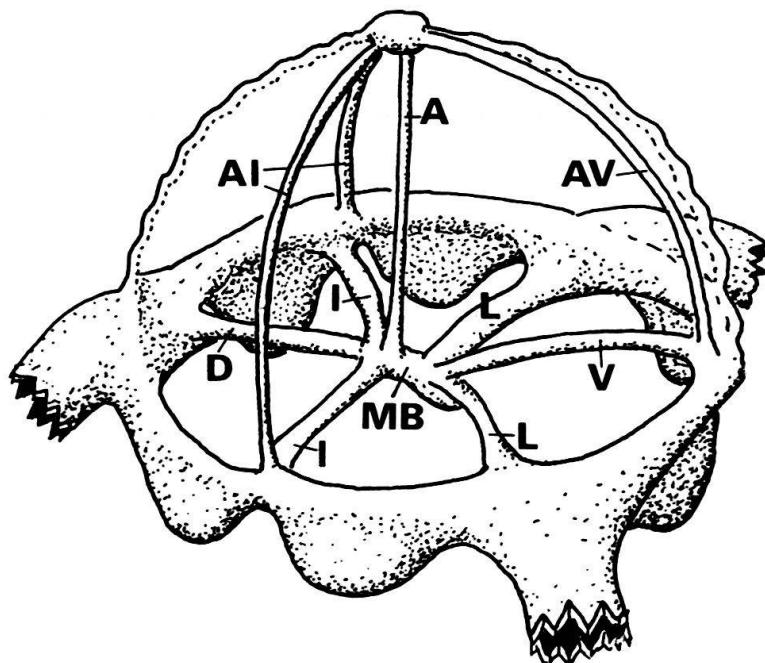


Fig. 3. Diagram illustrating the relations of arches and bars in the cephalis of the genus *Pouplus* (after DE WEVER et al. 1979b, Fig. 4). The following bars are present: A (apical), D (dorsal), L<sub>l</sub> and L<sub>r</sub> (left and right primary laterals), I<sub>l</sub> and I<sub>r</sub> (left and right secondary laterals), MB (median) and V (vertical). The two arches are AI and AV. The downwards directed knob in the center next to MB corresponds to the axial spine.

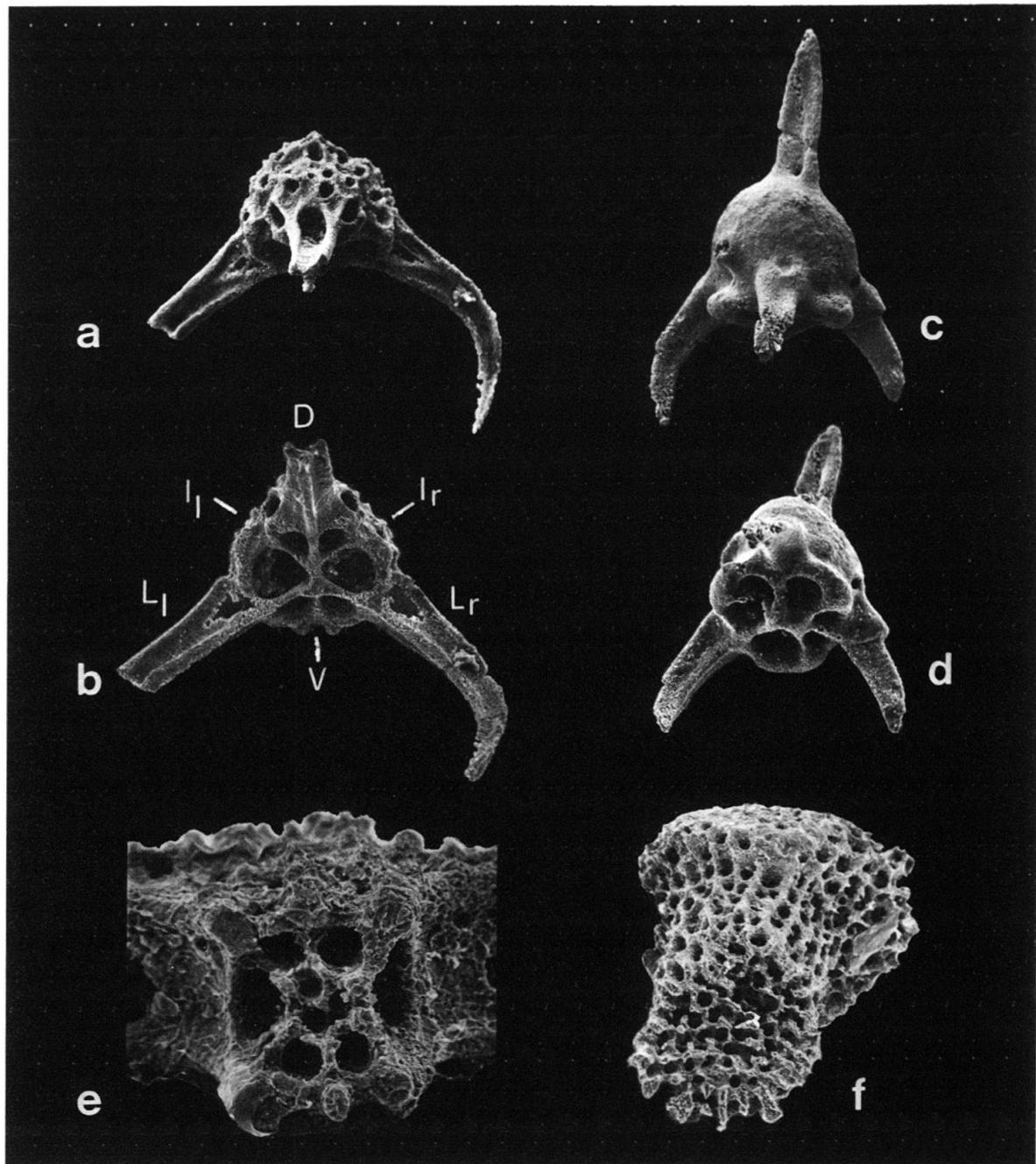


Fig. 4. Late Jurassic Poulopinae, Hagiastridae and Patulibracchiiidae from the Argolis Peninsula (Peloponnesus, Greece), collection P.O. Baumgartner, deposited at the Museum of Natural History, Basel. For sample localities see BAUMGARTNER 1980, p. 314.

a, b = *Saitoum pagei* PESSAGNO. POB 986/78/8172, C35293; ventral view (b) shows the cephalic bars common to all Poulopinae (same letters as in Fig. 3). The prolongations of D,  $L_l$  and  $L_r$  form the dorsal, the left lateral and the right lateral legs, respectively,  $\times 267$ . c, d = *Saitoum trichylum* DE WEVER. POB 986/78/8170, C35294,  $\times 267$ . e = Hagiastrid *Tetraditymya pseudoplena* BAUMGARTNER. POB 28/79/3582, C34764; ray cross section close to central area. Note arrangement of canals that are continuous through the entire ray (cf. BAUMGARTNER 1980, Pl. 1, Fig. 9),  $\times 500$ . f = Patulibracchiiid *Paronaella kotura* BAUMGARTNER. POB 899/79/1505, C35295; broken off ray tip showing uniform spongy meshwork in ray cross section,  $\times 250$ .

RIEDEL & SANFILIPPO (1974) envisaged a relationship to the spyrids because of the similarities in shape and of the collar apertures between *Saitoum* and Cenozoic spyrids. However, they did not see the sagittal ring, one of the diagnostic features of the spyrids (PETRUSHEVSKAYA 1971a). Owing to the absence of a sagittal ring, PESSAGNO (1977a) considered them to be cyrtids.

The detailed study of the cephalic structure of *Saitoum* and of the apparently related Triassic genus *Poulpus* DE EVER revealed several cephalic arches. The Triassic genus *Poulpus* shows three arches: AV, Al<sub>l</sub>, Al<sub>r</sub> (Fig. 3) which distinguishes it from the spyrids (see DE EVER et al. 1979b). *Saitoum* (Fig. 4a-d) on the other hand, has a velum that is spread out between the cephalic bars A, l<sub>l</sub> and l<sub>r</sub> and the dome-shaped cephalic wall. The intersection of the velums and the cephalic wall corresponds to the arches AV, Al<sub>l</sub> and Al<sub>r</sub>. The described cephalic structure is characteristic for the family Pylentonemidae DEFLANDRE (see DUMITRICA et al. 1980). However, in *Pylentonema* DEFLANDRE the cephalic structure is enclosed within the cephalis. The collar position of the described cephalic bars thus is one of the characters defining the subfamily Poulpinae DE EVER (1981a). The Pylentonemidae, thus far believed to be restricted to the Paleozoic, now have an extended range which includes most of the Mesozoic.

#### b) Discussion

The question arises as to whether the velum extends to the vertical bar and thus divides the entire cephalic space. This is very difficult to observe and would need either broken or partly dissolved specimens. Observation on partly dissolved specimens shows mainly the collar structures and the arches – which thus seem to be the primary structure. However, at the present stage of work it is nearly impossible to decide whether variably developed velums are the result of an evolutionary trend or represent different stages of ontogenetic growth or simply are the result of partial dissolution of the relatively delicate velums. More and better preserved material is needed to answer these questions.

### 2.4 Late Jurassic Hagiastridae – a taxonomy based on internal skeletal elements (presented by P. O. Baumgartner)

#### a) Summary

Well-preserved radiolarian faunas have been extracted from two otherwise unfossiliferous chert and deep-water clastic formations underlying allochthonous thrust sheets including ophiolites in the Argolis Peninsula (Peloponnesus, Greece, BAUMGARTNER 1980). The study of this material by both scanning electron and transmitted light microscopy showed the presence of most hagiastrid species described by PESSAGNO (1977a) from the Upper Jurassic of California as well as many new forms. Excellent preservation allowed the study of detailed internal structures visible on broken specimens. Many forms revealed a symmetrical disposition of internal skeletal elements including the presence of a discrete lattice medullary shell. The outer morphology appears to be closely linked to the internal architecture.

Two groups of entirely different internal structure have been observed. The first group has a test composed of concentric lattice cortical and medullary shells and of radially arranged arms (rays) with continuous longitudinal canals linking the interior of the medullary shell with the ray tip (Fig. 4e). The family Hagiastridae RIEDEL is emended to include this group. The second group has a central area and rays composed of a uniform spongy meshwork (Fig. 4f). The Patulibracchiidae PESSAGNO are raised to family level and emended to include this group.

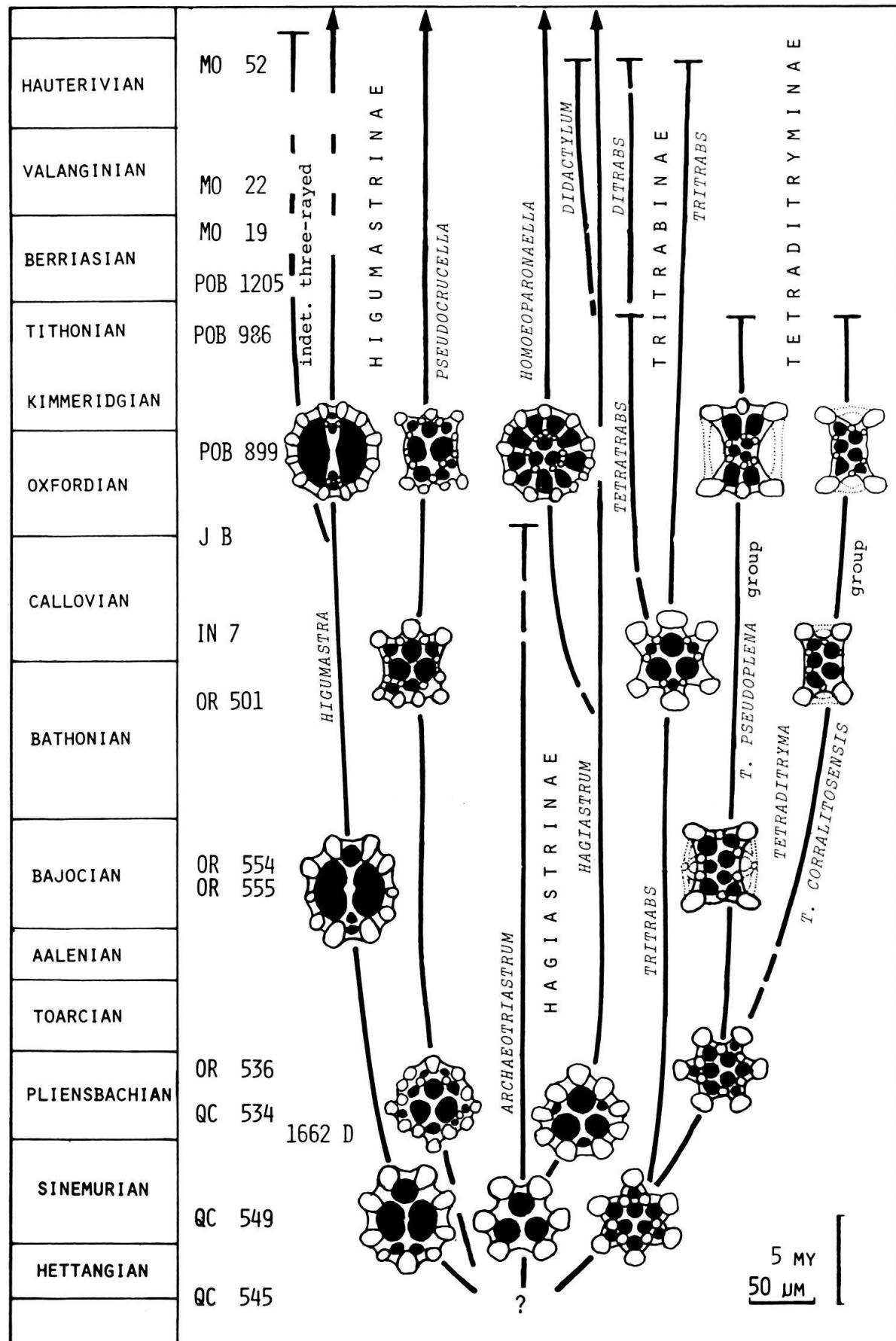
The morphology of the hagiastrids described compares to actinommiid spumellarians which leads to their inclusion with the Actinommacea HAECKEL, emended KOZUR & MOSTLER. Subfamilies based on the disposition of internal canals and external skeletal elements are established. Observations in Early and Middle Jurassic material showed the evolutionary differentiation of the hagiastrids, reflected by evolving ray cross sections (Fig. 5). This confirms the phylogenetic nature of the proposed classification. It seems that each established genus represents an independent evolutionary lineage, some of which became differentiated by cladogenesis from common ancestors during the Early and Middle Jurassic. DE WEVER (1981b) recently described middle Liassic hagiastrids and could successfully carry further the proposed classification.

The origin of the hagiastrids must be searched somewhere in the Triassic. KOZUR & MOSTLER (1979) introduced the family Hexaporobracchiidae and included various Triassic forms with a spherical or discoidal lattice shell with four or more porous arms. The porous arms show essentially the same structure as early hagiastrid rays. The hexaporobracchiids, however, have the arms arranged along tetraedric or orthogonal axes, whereas the hagiastrids always have them arranged in one plane. Thus, it is unclear whether these forms represent ancestors to the hagiastrids or an independent analog development. The proposed phylogenetic chart is by far not complete. New forms are being discovered and will complete the image of this complex group.

### b) Discussion

Would it be possible to adhere to a more radical solution and erect one genus for all forms with the same internal structure regardless of their number of rays? In some cases this may be justified (e.g. *Tritrabs* and *Tetratrabs*), where three- and four-rayed species have nearly the same range of outer morphology. In other cases it seems that the number of rays is a constant feature through the evolutionary development of a sequence of species and thus must be regarded as a superspecific classification argument. The erected subfamilies, on the other hand, group together a certain variety of internal structures based on their supposed or observed common origin (Fig. 5).

Another question is whether the medullary shells of the hagiastrids really come close to those of the actinommiids, or if hagiastrids could not have spongy ancestors. The spongy patulibracchiids exist at least from the Late Paleozoic to the Late Cretaceous, whereas the hagiastrids seem to be a short-lived family originating in the Late Triassic, rather from lattice shelled than from spongy ancestors. However, the homeomorphy of patulibracchiid and hagiastrid forms is striking and a change



from spongy to lattice shells cannot be excluded a priori. Perhaps the whole high-level distinction between Spongodiscacea and Actinommacea is somewhat artificial. There is, however, another argument: In analogy to observations made in foraminifera, one would assume the hagiastrid canals to be of biologic functional importance (e.g. preferred axes of protoplasma transport). One could then further argue that the hagiastrids, having other functional possibilities than patulibracchiids, would have occupied another environment. Thus, in a biologic sense, they would comprise an independent lineage at least since the Late Triassic/Early Jurassic. In order to be considered seriously, these speculations require further support from actual examples of living radiolarians.

## 2.5 General discussion and conclusions

When working with fossil radiolarians we have no way of knowing the original living radiolarian populations. Classificatory discrimination at species and at any higher level therefore must be entirely based on the morphology of the skeletons. The formal biological names thus have in this first step the function of specifying the extent of morphological similarity. Such a classification may be quite artificial and, as each author tends to have his own set of descriptors, a morphospecies may represent only a part of or several biologic species depending on the degree of splitting. The amount of splitting is of course also limited by the nature of the studied material such as preservation and abundance of the considered taxa, the amount of morphologic variation and the regionality of the study.

As more information on a set of morphotypes in stratigraphic succession becomes available, one can start to evaluate the phylogenetic significance of the morphologic characters. We have seen that, both for the colonial radiolarians and for the hagiastrids, the test symmetry seems to be of subordinate phylogenetic importance. Following the morphologic evolution of homologue skeletal elements such as the cephalic bars for the nassellarians (PETRUSHEVSKAYA 1971a) or the primary spines and pores/canals of the actinommaceans (see BAUMGARTNER 1980) seems to be more promising. In this second step, the biological names acquire a new function: they should indicate phylogenetic relationships through a hierarchical system of family, genus and species names. Conflicts between "morphologic" and "phylogenetic" taxonomies will be inevitable and as the ideas on evolutionary lineages develop, emendations of a large part of the hitherto established system will be necessary.

It is the consensus of all participants of the meeting that the base for all subsequent work is an accurate description and illustration of each considered morphotype, be it as formal species or subspecies or just as morphotype A, B, etc. In

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Fig. 5. Tentative phylogenetic chart for Jurassic and Early Cretaceous Hagiastridae illustrated with the change of ray cross sections (based on SEM observations, after BAUMGARTNER 1980, Fig. 7, modified in part with data from DE WEVER 1981b).

Samples: QC, Queen Charlotte Islands (British Columbia); OR, eastern Oregon (both Pessagno collection); IN 7, Inuyama area, Central Japan (Yao collection); JB, Jasper Beds (Romania, Dumitrica collection); POB, Argolis Peninsula and Southern Alps; MO, Murguceva Formation (Romania, Dumitrica collection). For further explanation see BAUMGARTNER 1980.

addition to the criteria by which each taxon is distinguished from the morphologically nearest other taxa, the limits of morphological variation of each taxon should be specified. Subsequent records of morphotypes or species should report how the specimens differ from the original definition, including differences caused by preservation.

### 3. Ecology and distribution of Recent and Cenozoic radiolarians (reported by P. O. Baumgartner)

#### 3.1 Introductory remarks

In the past decade significant advances have been made in relating radiolarian concentrations and the occurrence of index species in the sediments to physical and chemical properties of the overlying watermasses. Many workers determined the number of radiolarians per gram dry sediment and achieved good relations to watermasses delimited by the large current systems of the oceans. However, radiolarian concentrations in the sediment are, apart from being the result of the radiolarian production in the water column, controlled by a variety of other factors, such as silica dissolution and dilution by calcareous and terrigenous sediment. Two contributions presented during the meeting provided a stimulus for the discussion of these factors.

#### 3.2 Radiolarians in the surface sediments of the Norwegian Sea (presented by K. Bjørklund)

##### a) Summary

GOLL & BJØRKLUND (1971, 1974) reported on the distribution of radiolarians in the surface sediments of the northern and the southern Atlantic Ocean respectively. The following reports on a continuation of this work. Figure 6 gives concentrations of radiolarians per gram bulk sediment (for methods see GOLL & BJØRKLUND 1974) in the Norwegian Sea. It is noteworthy that higher radiolarian concentrations are restricted to the east side of the Mohns and Knipovich Ridges (MAR). Highest concentrations are found in the Norway Basin (between Norway, Iceland and Jan Mayen). This province also has the highest percentages of diatoms, phaeodarians and volcanic ash. There seems to be a relation between the presence of volcanic ash and good preservation of biogenic opal as also suggested by STADUM & LING (1969).

The highest species diversity can be observed in the eastern part of the Norwegian Sea and is clearly related to the northward drift of warmer watermasses due to the Norwegian Current, the continuation of the North Atlantic Current. About 50 to 60 species can easily be recognized in this part of the ocean, whereas on the Iceland Plateau the diversity is low. *Amphimelissa setosa* constitutes there about 76% of the total fauna.

Radiolarians are only found in a thin sediment blanket representing the postglacial deposits. These sediments are characterized by peak abundances of calcium-carbonate and are believed to represent the past 13,000 years.

In a forthcoming paper we will present a surface distribution/abundance map based on more than 300 stations, about 100 of them new. On the Norwegian

continental slope off Møre the postglacial sediments have accumulated to a thickness of up to five meters. Intended work on cores from that area should provide a detailed biostratigraphic and paleoceanographic record of the late Quaternary.

### b) Discussion

One of the main features of the distribution map (Fig. 6) is the decrease of radiolarian concentrations towards the north. K. Bjørklund concludes that the main reason for low radiolarian concentrations in the Greenland Sea sediments is the presence of a sea ice cover, at least during part of the postglacial period which did not permit the existence of a significant amount of plankton. It is generally accepted that the Greenland-Norwegian Seas were covered by sea ice during most of the glacial periods. The total absence of radiolarians in late Pleistocene sediments thus is concluded to be the result of low production under a sea ice cover in combination with opal dissolution due to silica absorption by clay minerals (JOHNSON 1976).

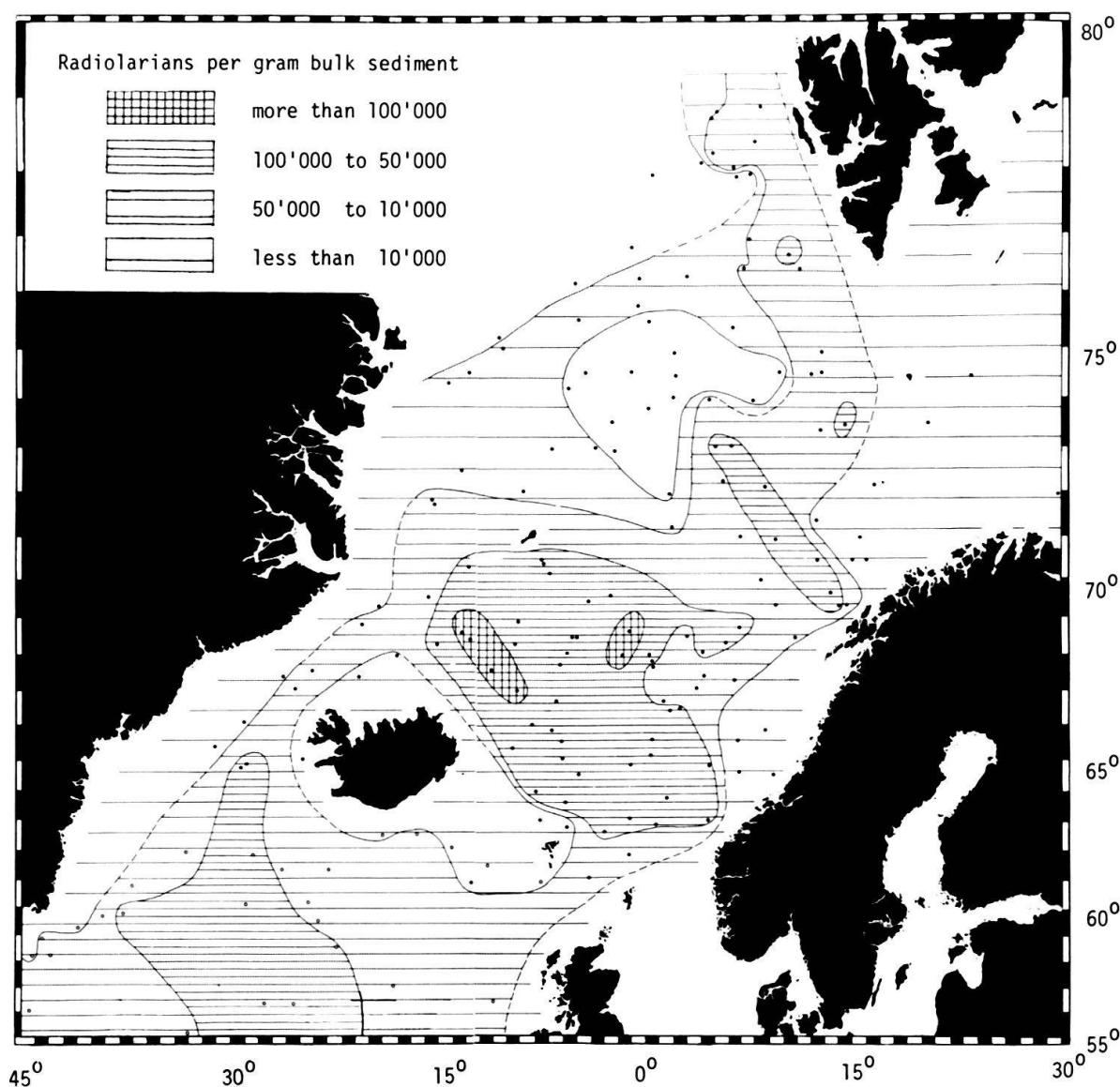


Fig. 6. Radiolarian distribution and abundance in surface sediments of the Norwegian Sea.

Several of us (J. P. Caulet, M. Labracherie, A. Schaaf) emphasize the effect of dilution by terrigenous sediment. Only by knowing the sediment accumulation rates, radiolarian concentrations per gram sediment can be transformed into radiolarian accumulation rates which allow conclusions on the primary productivity. The marked increase of radiolarian concentrations during interglacial periods coincides with increased carbonate concentrations. These trends may also be observed elsewhere in midlatitudes (see presentation of J. P. Caulet below) and certainly reflect higher plankton productivities during warmer periods. However, during glacial periods, a combination of three effects seems to be responsible for the observed low radiolarian concentrations: 1. Low productivity produces less plankton sediment. 2. High terrigenous input (ice rafting, ice erosion) dilutes the planktic sediment. 3. Dissolution is more pronounced due to cold, corrosive bottom currents and due to silica absorption by clay minerals in the clay-rich sediment.

For the Norwegian Sea the late Quaternary biochronology is poorly known. Thus it is almost impossible to give accurate sediment accumulation rates.

### 3.3 Reconstruction of Pleistocene paleohydrological fluctuations in the Crozet Basin (southern Indian Ocean, presented by J. P. Caulet)

#### a) Summary

Semi-quantitative compositions of radiolarian assemblages were obtained for 11 horizons of a mid-latitude core from the southern Indian Ocean ( $37^{\circ}55' S$  -  $67^{\circ}58' E$ ; 4260 m waterdepth). Nine horizons, dated from 175,000 to 300,000 years, were studied in addition to the top core and two reference samples: one corresponding to a maximum of *Diplocyclas davisiana* percentage, the other to a minimum.

Both calcium-carbonate and *D. davisiana* percentages were determined in all samples and the faunal data include the determination of nearly 4000 specimens for each level. The abundance of each taxon is classified as ++ (one or two specimens), R (less than 10 specimens), F (10 to 30 specimens), C (more than 30 specimens). Nearly 200 morphotypes were encountered, some of them are undescribed.

A correspondence factor analysis has been carried out with the faunal data from the 11 samples. The computation yields three axes with significant inertia. Temperature and depth of the watermasses appear to be the main controlling factors for the distribution of radiolarian species as illustrated by the two main axes of the analysis (axes I and II). Sedimentological processes seem to be responsible for the distribution along the axes II and III. All core levels obtain a location with respect to the three axes which allows paleoceanographical interpretations for the investigated area and time interval.

High percentages of *D. davisiana* and low calcium-carbonate contents support a northward shift of the antarctic polar front during the entire period. During an early interglacial, the faunal composition of the plankton indicates relatively warm subsurface waters and near-bottom velocities as existing today. Cold subsurface waters accompanied by strong undercurrents occur during the first stage of the following glacial interval corresponding to a probable northward migration of the polar front. Upsection, the faunal composition indicates deep and very cold waters without bottom circulation, probably related to a maximum stage of the ice cap.

After this cold peak, both the increasing velocity of bottom currents and the growing number of surface plankton indicate a retreat of the polar front and the establishment of a warm surface water layer, typical for the next interglacial period.

Correspondence factor analysis appears to be a promising tool for detailed paleoceanographic reconstructions.

### b) Discussion

One of the problems in this kind of studies is the relation of the statistically determined axes I to III with physical parameters controlling radiolarian distribution such as temperature, water depth, etc. This evaluation can be based only on the information obtained from species with known ecology. Furthermore, as there are many possible parameters, their separation along the three axes will never be complete. Thus, it is left to the intuition of the worker to weight the importance of each parameter along each axis. Nevertheless, this method may furnish detailed informations on many taxa not considered in distributional studies thus far.

#### 3.4 General discussion and conclusions

Cenozoic radiolarians have become increasingly important in paleoceanographic studies, especially in sediments of the deep, carbonate-poor ocean floors and the silica-rich high latitudes. Radiolarians offer a high morphologic diversity which has by far not been exhausted in recent distribution studies. Many radiolarian species show evident restriction to discrete depth zones (HÄCKER 1908; KLING 1976, 1979; McMILLEN & CASEY 1978) and to current-defined latitudinal settings. This knowledge has been used in paleoceanographic interpretations of fossil assemblages.

We have recognized some limitations to this procedure. TAKAHASHI & HONJO (1980) came to the conclusion that not more than a few percent of the total radiolarian flux to the deep sea is preserved in the surficial bottom sediments. Hence, even recent thanatocoenoses represent a solution-resistant residue of the original living faunal associations (KLING 1979). The more soluble forms and species with low abundances or long life spans may eventually disappear from a sediment assemblage, depending on the amount of dissolution. Thus, fossil sediment assemblages can only give a distorted image of past plankton distributions and paleoceanographic interpretations must take this into account.

Apart from the above natural limitations, there are methodical problems that need future improvement. The high morphological diversity has led to a selective treatment of those taxa for which a general agreement on their definition exists. Also low abundance species (not occurring in proportions greater than 2%) have not been considered. Therefore, a small group of species is commonly used in distributional studies. There is also a need for a more exhaustive taxonomy of modern radiolarians. The excellent guide by NIGRINI & MOORE (1979) gives about 100 species out of a possible 200 to 300. A critical review of some specific concepts will be necessary, as morphologic similarity does not necessarily mean similar ecologic needs. Quantitative population studies may resolve such problems. It is highly probable that the

inclusion of more taxa in distributional studies will help to refine paleooceanographic interpretations.

#### 4. Mesozoic radiolarian biostratigraphy (reported by P. De Wever)

##### 4.1 Introductory remarks

Research for a Mesozoic radiolarian biostratigraphy began only about 10 years ago; thus, the amount of published morphologic and stratigraphic data is still limited. However, the amount of good radiolarian material collected by each of us working in the Mesozoic, both in Japan and Europe, is immense and some coordination of efforts was obviously needed. The round-table discussions focused on two fields of problems.

The first problem was that of "paleontological semantics" – the use of specific names. We all agreed that it is desirable to use previously established species names as far as possible. However, each ones interpretation of earlier work is slightly different, especially when working with the early drawings from thin sections (RÜST 1885, 1898; PARONA 1890; HEITZER 1930, etc.). As long as the range of morphologic variation is not given in an original description of a species, each subsequent reference to that species will cover a slightly different field of morphologies. This has resulted in some cases in an uncontrolled broadening of specific concepts; a few of many examples are *Parvingula boesii* (RÜST), *Sethocapsa rotunda* (HINDE), *Xitus spicularius* (ALIEV) and *Pseudodictyomitra carpatica* (LOZYNIAK). The ultimate solution will be to create neotypes for these species, as it will be very difficult to ever retrieve the holotypes or even to obtain topotypic material. Many of the early locality descriptions are unprecise or holotypes were described from pebbles of conglomerates (e.g. RÜST 1885, 1898: "Jaspis der Westschweiz", or FISCHLI 1916: Rigi-Molasse conglomerate). Thus, it will be almost impossible to ever recollect a similar assemblage. Our preliminary solution consisted in comparing all our various illustrations and in achieving an oral consensus on the use of certain names. A further step would be the selection and careful description of neotypes – a task for future EURORAD meetings.

The other intensively discussed field was the methods used for establishing a biozonation. Three recent papers on this subject were presented and discussed: BAUMGARTNER et al. (1980), ICHIKAWA & YAO (1980) and NAKASEKO et al. (1979).

##### 4.2 Correlation of Tethyan Late Jurassic–Early Cretaceous radiolarian events (presented by P. O. Baumgartner)

###### a) Summary

In a recent paper (BAUMGARTNER et al. 1980) we have established Unitary Associations (GUEX 1977) based on co-occurrences and exclusions of selected species observed in sequences from the Southern Alps, Tuscany (R. Kocher), Sicily, Romania (P. O. Baumgartner) and Eastern Greece (P. O. Baumgartner and P. de Wever).

Faunal comparisons prove that the fossil record is generally incomplete due to sedimentary and diagenetic processes. From the late Callovian to the late Valangian we can establish 12 radiolarian unitary associations; at least 4 of them are well

reproducible in several sections and allow to define 5 biochronologic intervals. In the Late Jurassic, an exact age allocation of these intervals is hampered by the absence of ammonites in the radiolarian-bearing rocks. Late Tithonian to Valanginian samples are well dated by co-occurring calpionellids.

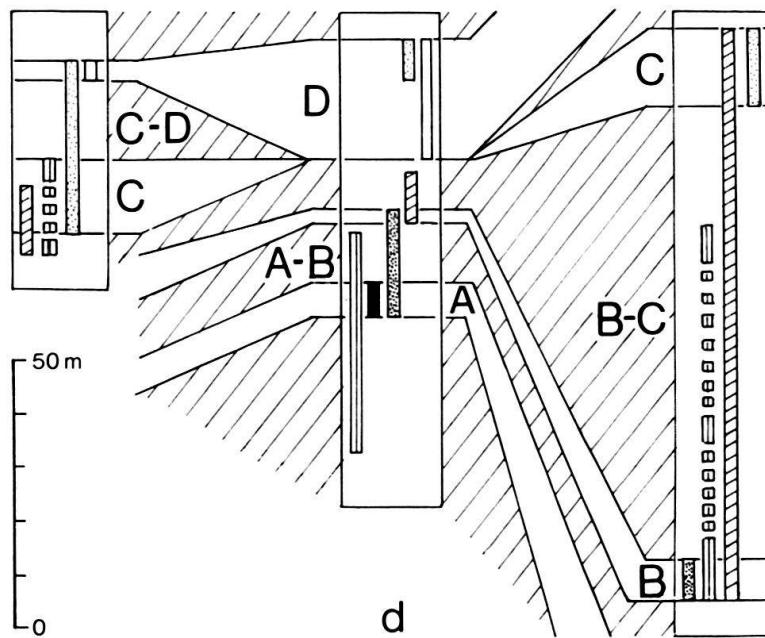
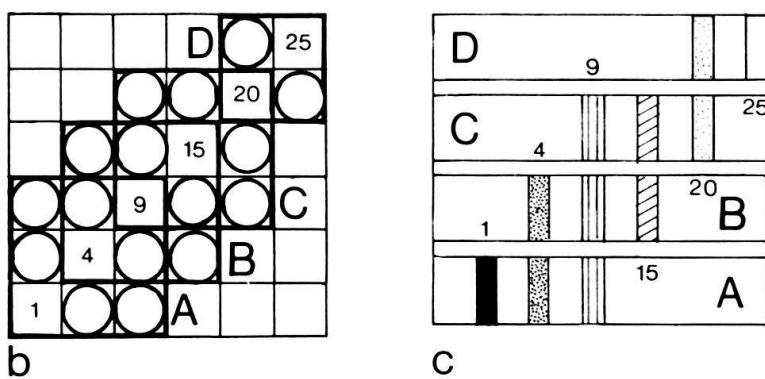
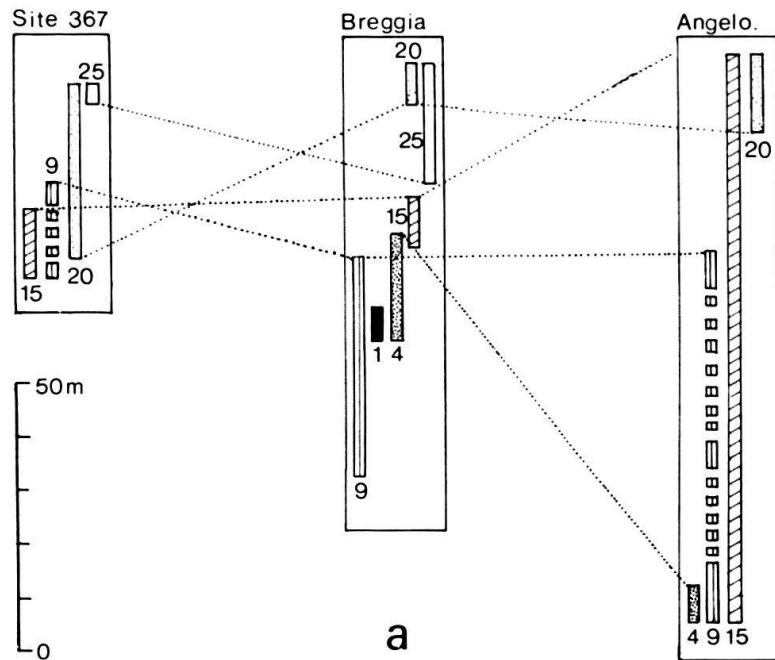
Our Zone A is of late Callovian to Oxfordian age (possibly including the earliest Kimmeridgian), Zone B is of Kimmeridgian to early Tithonian age, Zone C is of early or middle to late Tithonian age, Zone D is of latest Tithonian or early Berriasian to late Valanginian age and Zone E is of late Valanginian and younger age.

The concept of the *Sphaerostylus lanceola* Zone (RIEDEL & SANFILIPPO 1974) has been abandoned because *S. lanceola* and its "ancestor" largely co-occur in the Late Jurassic. Little of PESSAGNO's (1977a) zonation is confirmed by our material: most of his zonal species have longer and partly overlapping ranges. The final appearance of *Mirifusus guadalupensis* and the first appearance of *Acanthocircus dicranacanthos* in the middle Tithonian and the final appearance of *Parvingula altissima* in the late Tithonian are the only events that can be confirmed. We recommend a redefinition of the *Eucyrtis tenuis* Zone as this form is difficult to separate from *E. micropora* which occurs already in the late Callovian. The presence of *Sethocapsa trachyostraca* in the Late Jurassic makes it difficult to apply the *S. trachyostraca* Zone.

### b) Explanatory review of the method

The high susceptibility of radiolarians to dissolution results in a large variation of the number of identifiable morphotypes from one sample to another. This is especially the case in land based samples which underwent deep burial diagenesis. Well-preserved samples may contain easily over 100 morphotypes, whereas poorly preserved samples contain as few as 10 or less. This demonstrates that the absence of certain morphotypes in part of a section does not necessarily have a chronologic significance. To some extent, the list of morphotypes of a certain level can be extended by searching through more material. However, documentary gaps are inevitable as certain morphotypes are affected more easily than others by diagenetic processes and selectively disappear from an assemblage. Nonpreservation is controlled by factors such as the nature of the test (geometry, shell thickness, size of pores, chemical composition?) and by the diagenetic microenvironment (lithology, pore fluids, pH-Eh, etc.). The result of the documentary gaps is obvious: The sequence of events (i.e. first and final appearances of morphospecies) is generally not the same in two compared sections. Thus, the events themselves will not be useful for correlation.

Figure 7a shows the vertical distribution of six radiolarian species in three sections. These data are extracted from BAUMGARTNER et al. (1980) as a simple but real example of the radiolarian fossil record. The dotted lines connecting first and final appearances illustrate that there is no way of making a useful correlation by these means. Nevertheless, the three sections contain valuable information on the mutual coexistence and exclusion, as well as on the superposition of the species. GUEX (1977, 1978, 1979, 1980) has developed and refined the method of establishing Unitary Associations which adequately treats the above information and results in a



chronologically significant biozonation. For the detailed theoretical background as well as for the procedures, we refer to GUEX' work. The focus of this review is to elucidate the fundamental differences between the "event thinking" and the "association thinking" and the differences in the resulting zonation.

The information on co-occurrence and mutual exclusion from all species and all sections is reported to a species/species matrix showing the association spectra of every species (Fig. 7b). This matrix has to be permuted to show a maximum of submatrices in which all species are compatible, submatrices that equal Unitary Associations. GUEX (1977, 1978) has given examples of "manually" performed permutations with a small number of species. DAVAUD (1978) has presented a FORTRAN computer program that uses the occurrence data of the sections and searches for the Unitary Associations and their stratigraphic sequence. A major problem in this procedure are indeterminate relations of association and superposition caused by documentary gaps. DAVAUD's program avoids the problem by eliminating the "perturbatory" species, which has the inconvenience of losing valuable stratigraphic information. GUEX (1980) has more recently used modern concepts of the Graph Theory (cf. e.g. HARARY 1969) to establish a mathematical framework for the calculation and identification of Unitary Associations.

In our example, the lines of thinking for organizing the association matrix are relatively simple. For instance, species No. 1 is found below species No. 15, 20 and 25. Thus the association containing species 1 must be the lowest in the matrix. A further step would be: species 4 is co-occurring with species 15 but never with 20 or 25, which are found above 4. Thus, the Unitary Association containing both species 4 and 15 must be above the one containing species 1 (as 1 and 15 do not co-occur, but are superposed) and below the ones containing species 20 and 25 ... and so on. For a large number of data this process must, of course, be formalized.

Figure 7b gives the permuted matrix for our example, with the indicated Unitary Associations A to D. It is the character of these associations to represent

Fig. 7. Example of correlation of three sections with the help of Unitary Associations based on radiolarian occurrence data.

a = Radiolarian occurrence data of six species in three sections extracted from BAUMGARTNER et al. 1980. Site 367: Deep Sea Drilling Project Site 367, Cap Verde Basin, Eastern Atlantic. Breggia: Lower Breggia Gorge, Mendrisiotto, Southern Switzerland. Angelo: Section near Angelokastron, Prov. Korinthos, Argolis Peninsula (Peloponnesus, Greece). Species numbers are taken from BAUMGARTNER et al. (1980): 1: *Stylocapsa oblongula* KOCHER, 4: *Parvingula procera* PESSAGNO, 9: *Mirifusus guadalupensis* PESSAGNO, 15: *Emiluvia orea* BAUMGARTNER, 20: *Podocapsa amphitreptera* FOREMAN, 25: *Acanthocircus dicranacanthos* SQUINABOL. Dotted lines connect first and final appearances of species; crossed lines show the uselessness of this operation. b = Permuted species/species association matrix showing co-occurrence of pairs of species (squares filled with circles) and mutual exclusions (void squares) based on the data of Figure 7a. The number in the main diagonal serves as label both for the line and the column. The heavy lined squares A-D indicate complete submatrices = Unitary Associations. c = Chart of Unitary Associations A-D obtained for the 6 species from matrix b. The range of each species is given with respect to the other species. The double line between Unitary Associations symbolizes the interval of separation. No vertical scale is implied. d = Correlation of the three sections of Figure 7a based on the recognition of Unitary Assemblages A-D. Hachured fields designate indeterminate correlations. These represent intervals of separation assignable to either one of the two bracketing Unitary Associations.

maximal sets of compatible species (based on the given data). Figure 7b also gives their stratigraphic superposition. This information is easily transferred to the chart in Figure 7c. This chart looks like a range chart but has some fundamental differences: 1. The vertical axis represents neither time nor thickness, but simply superposes intervals of real coexistence of species resulting from a synthesis of all considered data. 2. The "range" of each species is not given with respect to a vertical scale, but only with respect to all other considered species. This implies that there is an interval of separation (GUEX 1979) between each two adjacent Unitary Associations which is of unknown duration. The first and final appearances of the species characterizing each of the adjacent Unitary Associations may lie anywhere within this interval. Such a zonation is in theory indefinitely perfectible (GUEX 1979). The consideration of more species in more sections with closer spaced sampling will both allow a further subdivision of the established Unitary Associations and eventually permit the insertion of new ones between the established ones to reduce the intervals of separation.

Figure 7d shows the correlation of the three sections based on the recognized Unitary Assemblages. As the number of considered species is small and their occurrence patchy, only thin, discrete parts of the sections can be safely correlated. The hachured fields show the large intervals of separation that may be part of either one of the adjacent Unitary Associations. It is interesting to see that the inclusion of more species (see BAUMGARTNER et al. 1980) considerably reduces the intervals of separation but does not alter the superposition of Unitary Associations. Crossed lines of correlation are excluded by this way of data integration.

Another step in the process of finding a chronologically significant biozonation is the evaluation of the reproducibility of each Unitary Association. In our example, U.A.A. is only found in the Breggia section. Thus, it is not useful for correlation to the other sections. More data are needed to demonstrate its reproducibility elsewhere. The principles are explained in GUEX (1979) and applied in BAUMGARTNER et al. (1980).

### c) Discussion

The discussion during our meeting was long and intense and also involved comparisons with the "conventional" biostratigraphic methods. The following points represent a brief summary:

*Reworking.* - As pointed out several times by GUEX (e.g. 1980), there is no way to identify reworking of a species except by sedimentological evidence. Generally, reworking will cause apparently longer ranges. If reworking occurs at a single locality of many, it will result in Unitary Associations which are found only in that locality and thus are not reproducible. The same problem exists when working with final appearances of species.

*Relative abundance of species.* - The relative abundance of species is not considered in the identification of the Unitary Associations. However, when defining zones on the basis of reproducible U.A. one should tend to include only the more abundant and morphologically distinctive species in the formal definition. The rarer the defining species are, the more limited the application of the zone will be.

*Identification of the chart of Unitary Associations.* – To distinguish a chart of Unitary Associations from a usual range chart, it is desirable to place a double line delimiting a blank space between two adjacent Unitary Associations (cf. Fig. 7c) to symbolize the interval of separation. (Table 3b in BAUMGARTNER et al. 1980 is drawn with solid “range”-lines which is misleading).

*Interval of separation.* – For some of us, it may appear irritating to deal with intervals of separation instead of “exact” correlations based on “datums”. As a matter of fact, intervals of separation exist in every biostratigraphic study – they are merely not mentioned. A “base” or a “top” of an occurrence may always lie between the sample containing the first or the final occurrence and the adjacent sample. Thus, the interval of separation is, in any kind of study, determined by the spacing of the samples. Very closely spaced sampling often reveals biostratigraphic limits falling together with minor condensations or hiatuses. In such cases, the interval of separation is given by the discontinuous nature of the sedimentary record.

#### 4.3 Triassic an Jurassic radiolarians from Southwest Japan (presented by A. Yao)

##### a) Summary

In two recent papers (YAO et al. 1980, ICHIKAWA & YAO 1980) we have distinguished four radiolarian assemblages of Ladinian to Middle Jurassic age. These assemblages occur in chert and mudstone sequences in the Inuyama area and other areas of Southwest Japan. The lower three assemblages occur superposed in one section along the Kiso River in Central Japan (YAO et al. 1980, Fig. 1, 2) and can be dated by co-occurring conodonts. Thus, the *Dictyomitrella* sp. A assemblage is of Ladinian to early Carnian age, the *Dictyomitrella* sp. B assemblage is of late Carnian to “Rhaetian” age and the *Dictyomitrella* sp. C-*Archaeodictyomitra* sp. A assemblage is of post-conodont early Jurassic age. The *Unuma echinatus* assemblage is found in a mudstone sequence which is in faulted contact with the sequence mentioned above. A late Middle Jurassic age can be deduced for this assemblage from the occurrence of the ammonite *Choffatia (Subgrossouvreria)* (SATO 1974) in the same sequence.

The *Dictyomitrella* sp. B assemblage is characterized by an abundance of capnuchosphaerids (DE EVER et al. 1979b) and compares well to Carnian or early Norian assemblages from Greece. The *Unuma echinatus* assemblage contains more than 150 radiolarian species, many of which were described by YAO (1972, 1979) and ICHIKAWA & YAO (1973, 1976). The study of Mesozoic radiolarians has proved to be one of the most effective ways of deciphering the complicated geologic structures of the oceanic complex of Southwest Japan.

##### b) Discussion

Although the description of Triassic and Early Jurassic radiolarians from European localities has made progress (see introduction) no continuous sections have been described. It is therefore too early to attempt a correlation of the proposed zonation to the European localities. The *Unuma echinatus* assemblage on the other hand, seems to be one of the best preserved Jurassic assemblages thus far

collected. Many of its radiolarian forms are very characteristic and have never been observed in Late Jurassic assemblages. P.O. Baumgartner has most recently found the *Unuma echinatus* assemblage near the base of the Koliaki Chert in a basinal sequence of eastern Greece (Argolis Peninsula, BAUMGARTNER 1981) and near the top of the Sogno Formation in the Lombardian Alps of northern Italy. At the last locality, a Callovian age is indicated by aptychi occurring in the same stratigraphic position (PASQUARÈ 1965).

#### 4.4 Mesozoic radiolarians in Southwest Japan (presented by K. Nakaseko)

##### a) Summary

In two recent papers (NAKASEKO et al. 1979, 1980) we have reported on our progress in radiolarian biostratigraphy from the Late Jurassic and Cretaceous of the Shimanto, the Sambosan and the Mino belts in Southwest Japan. In the northern part of the Shimanto belt we recognize seven assemblages that are considered as equivalents of FOREMAN's (1977) revised zonation: The *Mirifusus mediolatatus-Parvingula altissima* assemblage corresponds to the *Sphaerostylus lanceola* Zone sensu FOREMAN (1977). The *Obesacapsula rotunda* assemblage corresponds to the *Sethocapsa trachyostraca* Zone. The *Eucyrtis micropora* assemblage corresponds to the *Eucyrtis tenuis* Zone. The *Acaeniotyle umbilicata-Ultranapora praespinifera* assemblage corresponds to the *A. umbilicata* Zone. The *Holocryptocanium barbui-H. geysersensis* assemblage corresponds to the *Dictyomitra somphidia* Zone. The *Patellula planoconvexa-Artostrobium urna* assemblage corresponds to the *A. urna* Zone and the *Amphipyndax enesseffi* Zone remains unchanged.

In addition to Late Jurassic-Cretaceous assemblages we also found Middle Jurassic and Late Triassic ones. The Middle Jurassic faunas are characterized by the presence of *Parvingula hsui*, *Hsuum maxwelli*, *Tricolocapsa plicarum*, *Mirifusus* sp., etc. The Late Triassic assemblages are dated by co-occurring conodonts and contain *Triacyclia* cf. *T. acythus*, *Capnuchosphaera theloides*, *C. triassica*, *Capnodoce anapetes*, *C. sarisa* and *Dictyomitrella* sp.

##### b) Discussion

Some species defining the proposed assemblages such as *Obesacapsula rotunda*, *Eucyrtis micropora* and *Acaeniotyle umbilicata* occur also in the Late Jurassic. This may cause difficulties in applying the proposed zonation. However, if the assemblages are defined by the co-occurrence of two or more species they become widely applicable. The Middle Jurassic assemblage has been compared by the authors with radiolarians given in an early description of Tethyan Middle Jurassic by HEITZER (1930) which, however, represents weak evidence for this age. On the other hand, many of the observed species are common in the *Unuma echinatus* assemblage discussed above and seem to support a Middle Jurassic age.

#### 4.5 General discussion and conclusions

Mesozoic radiolarian biostratigraphy has made much progress in the past few years and has significantly contributed to the dating of siliceous oceanic sediments

both in the oceans and mountain belts. As the critical mass of data for a universally applicable biozonation has yet to be obtained. Many of the now available results may need future precision or correction, much like we have seen it for other fossil groups. In contrast to other microfossils, radiolarians offer an immense diversity of morphotypes (probably a few hundred at any time during the Mesozoic) to biostratigraphic investigation. However, as the lithologies favourable to radiolarian preservation are relatively restricted, it will take another ten years of research, to know all the total ranges and to get an idea of the phylogenetic relationships within this complex fossil group. Many radiolarian morphospecies may be less resistant to dissolution than others and therefore be very rare or absent from certain environments or lithologies. Considering the ecologic specialization of Recent radiolarians one would suspect that the biostratigraphic record is, apart from being affected by dissolution, the result of both phylogenetic evolution and biogeographic distribution changing through time. Once a stratigraphic framework based on cosmopolitan species is consolidated, we can start evaluating the effects of biogeography and selective dissolution.

### 5. Sampling and preparation techniques (reported by R. Schmidt-Effing)

This chapter is a summary of experiences, preparation hints and techniques that were exchanged between the attendants of the meeting. The idea is to carry further the inventory of methods worked out during EURORAD I (DE WEVER et al. 1979a, p. 208-213).

#### 5.1 Field techniques

In Mesozoic sequences, radiolarian preservation widely varies within one lithological section and well-preserved radiolarians may be found in only thin laminae of some millimeters or centimeters thickness out of a several meter thick section. It is therefore essential for successful sampling to do some field preparation in order to be able to select the good lithologies and the good horizons.

The following method has been successfully used by P.O. Baumgartner in Greece and the Lombardian Alps and by P. De Wever in Morocco. The "field laboratory" consists of a working table with a stereomicroscope (magnifications  $\times 30$  to  $\times 100$ ) with a battery or gas driven illumination for overcast weather, storage bottles for concentrated hydrochloric and hydrofluoric acids, plastic trays in which samples may be etched and washed, a pair of acid resistant tongs to handle the samples, a camping gas stove to dry the samples, sufficient water containers to carry water for cleaning and washing the samples (daily consumption 20 to 30 liters), and what is most important for the worker's security are safety goggles and rubber gloves.

The field laboratory is set up as close as possible to the section to allow a frequent comparison between the outcrop and the etched samples. In a first step, closely spaced, small samples (about 50 to 100 grams every 20 to 50 cm) of a variety of lithologies are collected, marked on the outcrop with chalk (in dark lithologies) or marker and treated in groups of ten or twenty. Carbonate-free lithologies are etched for several minutes in concentrated HF. Calcareous cherts and siliceous limestones

are first etched with concentrated HCl, examined and in case of insufficient result, etched with HF as above. The preliminary HCl treatment surficially removes the carbonate and thus prevents the formation of a fluorite crust in HF. After etching the samples are totally submerged in water and thoroughly washed for several minutes. Drying on a stove helps to evaporate remaining acid (observe wind direction). The samples are allowed to totally dry and cool and are then examined under the stereomicroscope (or a high power hand lens). Good samples should then show abundant radiolarian tests appearing in relief on the etched surfaces. In some cases preliminary determinations are possible.

The obtained results will soon guide the worker to the best lithologies in the particular section and further sampling will show an improved success rate. The final sampling, including measurements, drawings, etc. is only made for the successful samples. It is essential to collect exactly the piece of rock which furnished the preliminary, good sample as lateral sampling along one bed has shown that good preservation is generally of patchy occurrence. In one day up to one hundred samples may be treated and examined by this method.

The inconveniences of this method are the weight of the equipment and the amount of time spent on the section. However, the method allows to search systematically for well-preserved assemblages which have thus far been a matter of good luck.

## 5.2 Laboratory extraction techniques

A number of methods for the extraction of radiolarians from rocks have been reported by DUMITRICA (1970), PESSAGNO & NEWPORT (1972), PESSAGNO (1977a), DE WEVER et al. (1979a) and have become standard procedures. Some additional remarks may be useful. Many siliceous rocks contain a minor percentage of carbonate. During treatment with hydrofluoric acid this carbonate is dissolved and reprecipitates as fluorite crust which effectively prevents any further reaction of the sample. Boiling of the sample in concentrated hydrochloric acid prior to the HF treatment removes most of the carbonate, boiling of the HF-residues cleans them from precipitated fluorite.

Radiolarians replaced by pyrite or iron hydroxides are highly resistant to short treatment in cold concentrated acids (HF and HCl) but get partly destroyed by hydrogen peroxide. The use of detergents (Calgon, phosphates, Ternary-O, etc.) is recommended.

For the sieving of radiolarian residues the use of nylon sieve cloths<sup>3)</sup> suspended in a plastic funnel (Fig. 8a) has been very convenient to P.O. Baumgartner. The main advantages are: Nylon is completely resistant to hot and concentrated acids and oxidizing agents. The cloths are easily cleaned (by stretching them diagonally to the woven pattern). The material is cheap (SFr. 30.- to 60.- per square meter) and can be replaced whenever necessary. It is possible to work with very small quantities of residue without any loss: The residue is centered with a gentle water beam (Fig. 8b). Then the cloth is brought in contact with a paper towel to adsorb most of

<sup>3)</sup> Sieve cloth of suitable quality and precision can be obtained under the name "polymon PES" with all possible mesh sizes (from 2 microns to 5 mm) from Schweizerische Seidengazefabrik AG, CH-8002 Zürich, Grütlistrasse 68.

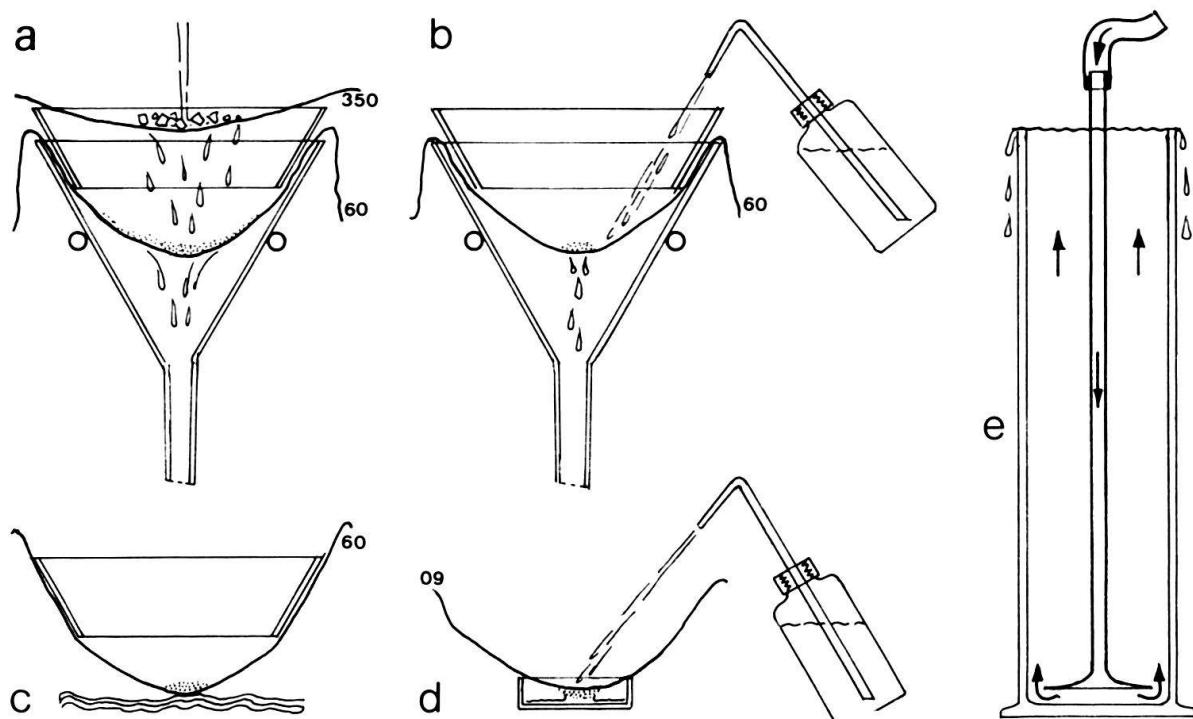


Fig. 8. Techniques for extraction of radiolarians from residue.

a = A 60  $\mu\text{m}$ -mesh sieve cloth (60) is suspended in a plastic funnel with a cut-off upper part of a similar funnel. A 350–500  $\mu\text{m}$ -mesh sieve cloth (350) withholds coarse residue and rock fragments which are gently washed. b = The residue is centered in the depression of the cloth with deionized water. c = The sieve cloth is transferred to a paper towel which adsorbs most of the water. d = The cloth is then overturned and the residue washed off into a dish or picking tray. e = Apparatus used for floating radiolarians from heavier residue.

the water (Fig. 8c). The residue now firmly sticks to the sieve cloth which can be overturned, placed over a picking tray or petri dish, where the residue can be washed off with a small quantity of distilled water (Fig. 8d). One drop of wetting agent is added to destroy the surface tension of the water for easy observation and wet picking.

### 5.3 Floating techniques

Radiolarians are often rare in the acid residues. They can be concentrated by using their contrast in density and hydrodynamic properties with respect to other particles of the residue. Tests preserved as pyrite or iron hydroxides may be separated with the help of heavy liquids. Tests with spines and/or porosity have a lower bulk density than similar sized sand grains. They can be separated by floating techniques. A. Schaaf uses an apparatus as illustrated in Figure 8e. Water flows through the central tube to the bottom of a glass cylinder and gets evenly distributed by a trumpet-shaped lower end of the tube. In that way, a laminar flow is maintained in the cylinder which carries the lighter tests upwards and eventually over the rim of the cylinder. The intensity of the water flow has to be experienced for each sample. These separation methods do not work at a 100% efficiency. Both fractions have to be kept and examined for exceptionally large or small radiolarian specimens, respectively.

#### 5.4 Mounting radiolarians for scanning electron microscopy (SEM)

A wet picking technique for radiolarians submerged in water has recently been described by DE WEVER (1980). Nail varnish is used as mounting medium on SEM-stubs. When the picking is complete, the stubs are exposed to acetone vapor to soften the varnish and thus to fix the specimens firmly. To remove them acetone is used again.

P.O. Baumgartner, after having experienced with film emulsion and cellulose glue, came back to a dilute solution of polyvinyl acetate in methyl alcohol as described by McCANDLESS et al. (1971) and CLANTON & LADLE (1975). The radiolarians are placed on the dry polyvinyl acetate film which has a limited hygroscopic property that allows to adjust the specimens in a drop of water into any desired position. When the picking is complete, the acetate film is heated to about 100 °C to melt it and glue the radiolarians to the stub. On polished and completely degreased aluminium stubs one can work with films as thin as five to ten microns. Thus, there is no fear of filling pores with glue or of drowning the radiolarians in the mounting medium. To remove the specimens, the stub is gently heated to make the acetate plastic, which allows to remove single specimens with a wet brush.

Tempfix (by Neubaur Chemicals, Münster, Germany) is used as mounting medium by R. Schmidt-Effing (SCHMIDT-EFFING 1980, Fig. 9-33). The resin is spread on a thick aluminium foil which has been heated to about 120 °C. At this temperature the resin is completely molten and can be scraped off with a spatula leaving a thin film on the foil. After cooling the foil is cut into small sheets of about 10 × 10 mm size. They can be placed into the picking tray, immediately next to the material to be picked, which allows picking and arrangement of specimens on the foil under the stereomicroscope at the same observation level. When the picking is complete, the foil sheets are briefly heated to about 40 °C which securely fixes the specimens to the foil. After sputtering the foil sheets are attached to a SEM stub by means of a small screw (supplied with the Tempfix set) and are ready for SEM work. The foil sheets can easily be stored in a very small space. A certain disadvantage is that the specimens cannot be removed from the foil when once mounted with Tempfix.

#### 5.5 Orientation during SEM-work

Radiolarians are usually placed in rows on the stubs and oriented in a way that no or little rotation around the vertical stage axe is necessary. The specimens may then be observed at different angles simply by tilting the stub around the horizontal axis of the stage. A drawing of each stub, magnified ×15 is produced by P.O. Baumgartner with the help of a mirror stereomicroscope. Negative numbers and remarks on tilting angle and orientation can be put on the drawing. A photograph of the entire stub is used for the same purposes by K. Bjørklund.

#### 5.6 Storage and access to prepared radiolarian material

Clean radiolarian residue is stored either wet or dry in small glass vials, plastic dishes or Plummer cells. Glass vials require the spreading of the sample in a picking tray for each examination. P.O. Baumgartner spreads out residue on wet photo-

graphic paper on which a system of coordinates has been copied. The specimens stick to the emulsion after drying and can easily be removed by a drop of water. Counting and the location of particular specimens is eased by the coordinates. This method allows only for reflected light observation and is particularly recommended for the examination of opaque assemblages.

## 6. Synthesis and general perspective

EURORAD II has initiated a number of discussions essential to the future advance of radiolarian paleontology as a whole. The dialogue between people working in the Cenozoic and those working in the Mesozoic proved to be very instructive for both sides. Ideas on radiolarian zoogeography have to be carried into the stratigraphically oriented research on the Mesozoic, and a joint effort in the field of taxonomy may result in a consistent application of morphologic descriptors and thus in a more transparent taxonomy. Because we deal with the same zoological group, we are faced with similar problems with respect to incomplete preservation of the fossil record due to dissolution. Both in the Mesozoic and Cenozoic we have to investigate the specific dissolution resistance in order to know how reliable our stratigraphic or paleoceanographic interpretations are. Among the hundreds of radiolarian morphospecies available at any time, there are certainly some that meet the requirements of being both temporally or ecologically restricted and solution resistant. Methods have to be developed to discriminate faunal differences caused by the dissolution facies from those resulting from biogeographic or biostratigraphic change.

It is tempting to apply the paleoceanographic models developed for the Neogene and Quaternary oceans to the Mesozoic radiolarian occurrences. However, the Mesozoic fossil record is by far not as complete as the Cenozoic one, both in areal coverage, number of samples and general preservation. Beyond that, there are indications for fundamental differences between the two eras. During the entire Cenozoic, radiolarians exhibit a high rate of faunal change. Much of this change is seen to be the result of rapid evolution (cf. RIEDEL & SANFILIPPO 1978) another part of it may be due to frequent biogeographic redistributions. Both phenomena are certainly related to frequent large scale climatic changes also documented by many other fossil groups as well as by the evolution of stable isotopic compositions of fossil shell material.

In the Mesozoic, a preliminary evaluation of the data suggests much longer ranges for most morphospecies than for average Cenozoic forms. This may in turn be the result of more stable paleoceanographic conditions resulting in less environmental stress and thus in slower speciation processes. However, for many Mesozoic taxa there is yet little fossil evidence to document phylogenetic relationships. This may result from the still poor areal coverage of the samples. With a few exceptions (e.g. FEARY & HILL 1978) the recently investigated radiolarian samples all come from low and middle paleolatitudes (for North American samples see discussion in PESSAGNO & BLOME 1980). Thus, we may have to investigate high paleolatitude samples to find some of the ancestors and descendants to the mid-latitude species, if we assume allopatric speciation.

The worldwide abundance of Middle to Late Jurassic radiolarites leads to speculations on a high radiolarian prosperity in the Jurassic ocean (GARRISON 1974; HSÜ 1976). We have some reasons to speculate also on a different silica budget for the Middle to Late Jurassic. Modern radiolarians are slow feeders and have low reproduction rates compared to phytoplankton. They occupy a wide variety of habitats, including medium fertility, middle and deep water zones. Modern sea water is highly undersaturated in silica, which may explain the Cenozoic evolutionary trend to thinner and more surface-to-volume effective shells (MOORE 1969; SCHAAF 1980). The undersaturation in silica is also responsible for the dissolution of a major part of opaline tests prior to their burial. Although the values for the accumulation of biogenous silica widely vary from ocean to ocean (and from author to author), they appear to be modest compared to Jurassic estimates. Similar high values are actually found in the high latitudes only, but there, diatoms constitute the major portion of the siliceous sediment (e.g. CAULET 1978). Values for the radiolarian flux to the deep sea given by TAKAHASHI & HONJO (1980) equally show a wide variation, but compare by the order of magnitude to the accumulation rates of Jurassic radiolarites.

We do not know, whether the Jurassic ocean was equally undersaturated in silica. However, the above mentioned values may suggest that the dissolution rate was distinctly smaller, which would be due to a certain saturation in silica, at least of the bottom waters and/or due to a less pronounced turnover as a result of reduced vertical and latitudinal temperature gradients (BERGER & VON RAD 1972). An alternate interpretation of the Jurassic peak abundances of siliceous deposits would be a high prosperity of radiolarians occupying the high fertility surface water zone which was, at that time, only sparsely populated by other zooplankton competing for nutrients. Both interpretations are now highly speculative and a combination of them or a more complex set of factors may become evident, when more exact stratigraphic data and more quantitative work both on Mesozoic and Cenozoic siliceous sediment accumulation will be available.

It is only by the way of interdisciplinary collaboration that we can solve such problems. The EURORAD meetings have initiated some of this collaboration and we hope that these meetings will continue to be a platform for future joint research programs in the field of radiolarian paleontology. EURORAD III will be held in Bergen, Norway, in July 1982 organized by K. Bjørklund.

## 7. Appendix: Participants and their current and intended activities

Baumgartner, Peter O.

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Mesozoic radiolarian biostratigraphy: present projects: Neocomian of Tethys (together with P. Dumitrica). - Callovian-Berriasian of Blake Bahama Basin (DSDP Leg 76). - Correlation of Tethyan and Atlantic radiolarian events and deep water facies evolutions. - Early-Middle Cretaceous off Morocco (DSDP Leg 79).

Bjørklund, Kjell R.

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Cenozoic zoogeography and oceanography of the Norwegian Sea. - Evolution, stratigraphy and

taxonomy of Cenozoic and Recent collosphaerids in the Pacific. - Cenozoic radiolarians in the Zaire Deep Sea Fan area.

Caulet, Jean Pierre

Laboratoire de Géologie, Muséum National d'Histoire Naturelle, 43, rue Buffon, 75005 Paris, France. Relation of biogenic silica accumulation and paleocurrent activity (dissolution). - Detailed Pliocene-Quaternary radiolarian stratigraphy of the Indic for the location of Mn-nodule pavements. - Paleoclimatic interpretations of changing radiolarian assemblages, displacement of the antarctic polar front during the Neogene and Quaternary.

De Wever, Patrick

CRNS-Laboratoire de Géologie Structurale, Université des Sciences et Techniques de Lille, 59655 Villeneuve d'Ascq Cedex, France. Evolution and taxonomy of the Poulpinae. - Liassic radiolarians from Turkey. - Mesozoic radiolarian biostratigraphy in Alpine-Mediterranean sequences.

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Labracherie, Monique

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Mesozoic and Paleozoic radiolarian biostratigraphy of Japan. - Especially Late Jurassic-Cretaceous zonation of the Shiman Peninsula calibrated with ammonites, nannofossils and foraminifera.

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Neogene and Mesozoic radiolarian biostratigraphy and taxonomy of Japan.

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Schmidt-Effing, Reinhard

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Mesozoic radiolarian biostratigraphy of Panama and Costa Rica. - Jurassic radiolarians from the Subbetic of southern Spain correlated to ammonite stratigraphy.

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