UTRECHT MICROPALEONTOLOGICAL BULLETINS

W. J. ZACHARIASSE, W. R. RIEDEL, A. SANFILIPPO, R. R. SCHMIDT, M. J. BROLSMA, H. J. SCHRADER, R. GERSONDE, M. M. DROOGER and J. A. BROEKMAN

Project no. 1

MICROPALEONTOLOGICAL COUNTING METHODS AND TECHNIQUES – AN EXERCISE ON AN EIGHT METRES SECTION OF THE LOWER PLIOCENE OF CAPO ROSSELLO, SICILY

17

UTRECHT MICROPALEONTOLOGICAL BULLETINS

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MICROPALEONTOLOGICAL COUNTING METHODS AND TECHNIQUES – AN EXERCISE ON AN EIGHT METRES SECTION OF THE LOWER PLIOCENE OF CAPO ROSSELLO, SICILY

I.G.C.P. Project no. 1

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95 figures, 23 plates

The **I.G.C.P. project 74/I/1** "a systems approach to accuracy in time", aims at a quantification of the refinement that may be attained with various methods of stratigraphic correlation.

A considerable part of the pilot studies carried out by the "Dutch" working group deals with the application of numerical methods in biostratigraphy, in which one of the lines of research aims at a better understanding of counted numbers of specimens of individual taxa in suites of samples, as presented in so-called distribution charts or range charts. The biozonations constructed from such charts, from which in practice the more general zonation schemes are compiled, are commonly based on entries and exits of indivual taxa or groups of taxa. The corresponding datum levels based on single or multiple presence-absence criteria (as well as relatively high frequencies of taxa, so-called acmes) determine the zones recognized in the vertical successions.

These methods and the actual counting on which they are – often unconsciously – based are being evaluated by the Utrecht team for several sections of the Mediterranean Neogene.

The **purpose** of the present investigation was only to obtain a better documented insight in the reliability of different methods of collecting quantitative data. The Capo Rossello section, i.e. part of the Lower Pliocene Trubi formation of southern Sicily, was selected for such a test of various counting methods for several reasons:

1. The well-exposed sediments belong to the neoclassical section of the stratotype of the Lower Pliocene Zanclean Stage, overlying at this place the recently defined Miocene-Pliocene boundary stratotype (Cita, 1975). The chronostratigraphic position thus is unambiguous.

2. In recent years the section received much attention from several capable geologists and micropaleontologists, especially Italian colleagues, among whom Mrs. M. B. Cita (1973, 1975) may be cited for her outstanding reports and opinions.

3. For various purposes the section will be investigated over and again for the next few years, which furthers the chance that our work will be critically examined by others.

4. The Utrecht team has been interested for several years in the region on account of its investigations of the Messinian salinity crisis (Brolsma, 1978). A fair knowledge of sediments and microfossils was available before initiating the present investigation.

5. The Trubi marls (or limestones) may be classified as calcareous oozes with subordinate admixtures of terrigenous material. The good preservation of the fossils suggests deposition well above the levels of lysocline and carbonate compensation depth.

6. The lithology in the section suggests that the Trubi marls are the result of continuous or para-continuous sedimentation in one and the same type of environment, which is commonly appreciated as bathyal (Cita and Gartner, 1973; Brolsma, 1978).

7. The 8 meter section selected, starting about 29 meters above the base of the 45 meters of Trubi, was expected to cover about 250,000 years, which means that evolutionary changes of the faunas and floras in this interval may be considered to have been slight or absent.

As a consequence, neither paleoecological trends nor evolutionary development was expected to have affected the faunal and floral composition from the bottom to the top of the section, and if so, to a slight extent at the most.

The sample suite of these eight meters thus was considered optimal to check the results of various counting techniques against the theoretical models for such methods. Several checks on subjectivity in determination could be added as well.

The selection of the Capo Rossello section had yet another reason, which at first sight seems to be in contradiction with the conditions outlined above. The sedimentological approach during the field survey learned that the eight meters did not show a monotonous lithology from bottom to top. Homogeneous or homogenized marls of the usual Trubi type were found to alternate with six fairly well-delimited laminated intervals, which in some layers seem to contain a distinctly higher percentage of silica, due to abundant well-preserved radiolarians and diatoms. Because of the repetitive character of the sediment changes, this complication was considered an extra advantage rather than a drawback. Specialists on siliceous microfossils could participate in the investigation, thus enlarging the experience and the number of methodological tests.

The additional need to explain the sedimentary alternation stimulated the participants to complete the tedious routine work. It made the investigation of the scarce benthonic fossils more rewarding.

The preliminary field surveys and sampling (MJ numbers) were carried out by M. J. Brolsma. The section was described and sampled (CRP numbers), together with J. A. Broekman, in September 1975. Broekman compiled sedimentological laboratory data that we thought were needed. Preparation

of the samples and preliminary taxonomic studies were completed during the 1975–1976 winter season.

The actual counting followed from March 15 to April 15, 1976, all specialists being present in Utrecht during that time. Radiolarians, calcareous nannofossils, diatoms, silicoflagellates, planktonic and benthonic foraminifera were dealt with by W. R. Riedel, R. R. Schmidt, H. J. Schrader, R. Gersonde, W. J. Zachariasse and M. J. Brolsma. Statistical checks on the results were carried out by M. M. Drooger. Writing and re-writing of the reports continued until the end of 1977. The research was coordinated by J. E. Meulenkamp, balancing of the papers was the duty of C. W. Drooger. The major part of the illustrative work was carried out by the technical staff in Utrecht (J. P. van der Linden, P. Hoonhout and A. van Doorn).

The entire investigation was made possible by generous financial support of the Netherlands Organization for the Advancement of Pure Science, Z.W.O. (The Hague).

There is a wealth of information in the reports of this volume, from which it is hard to summarize the major **conclusions.** Many of the results seem to be trivial, but others may be as unexpected to the reader as they were to us.

As to the paleoecological problem of the alternation of laminated and non-laminated sediments, the composition of the benthonic foraminiferal faunas suggests that less favourable, low oxygen, bottom conditions caused the lamination. Although the composition of the planktonic associations is hardly affected, it seems likely that extremely high plankton productivity coincided with the deviations in the benthonic assemblages in the laminated sediments. These conclusions are dealt with in the elaborate paleoecological interpretation by Brolsma (1978).

For the quantitative methods that were tested, it appears that the statistical theory and the actual counting results repeatedly show a satisfactory convergence. No single counting method appears useful for the various relative frequency ranks. Taxa represented in the associations by more than 5–10% can be best dealt with on the basis of fixed number total counts of 200–600 individuals. For less frequent taxa and especially for those which are rare (less than 1%) various "logarithmic" methods, based on additional density estimates, give the better results. Attention is drawn to the fact that frequent taxa with fluctuating relative numbers cause a squeezing effect that is expressed in all second order correlations. This shows that indiscriminate multivariate analyses of all data together may easily lead to erroneous results and misleading interpretations.

Independent counts in the same slide or split, from one sample, and from different samples of the same layer show increasing but not too serious deviations, as to be expected. Numerous compositional differences along the eight meter column reflect ununderstood paleoecological fluctuations superposed on those which caused the alternation of both sediment types. Apart from faint indications in the diatom and calcareous nannofossil floras, no evolutionary changes were found in the section.

Another interesting result is that the theoretical maximum objectivity in species determination in terms of Linnean nomenclature, based on the subjectivity of a single investigator, is a less constant factor than expected, especially with increasing periods of time between successive counts. The disappointing results in comparing species determinations by different specialists may contain avoidable exaggeration, but these results do show that errors caused by subjective appreciation of the observations may widely overshadow the effects of all statistical errors and sampling irregularities. For a detailed quantitative analysis of fossil assemblages, the combination of the data from different observers seems to be a senseless effort.

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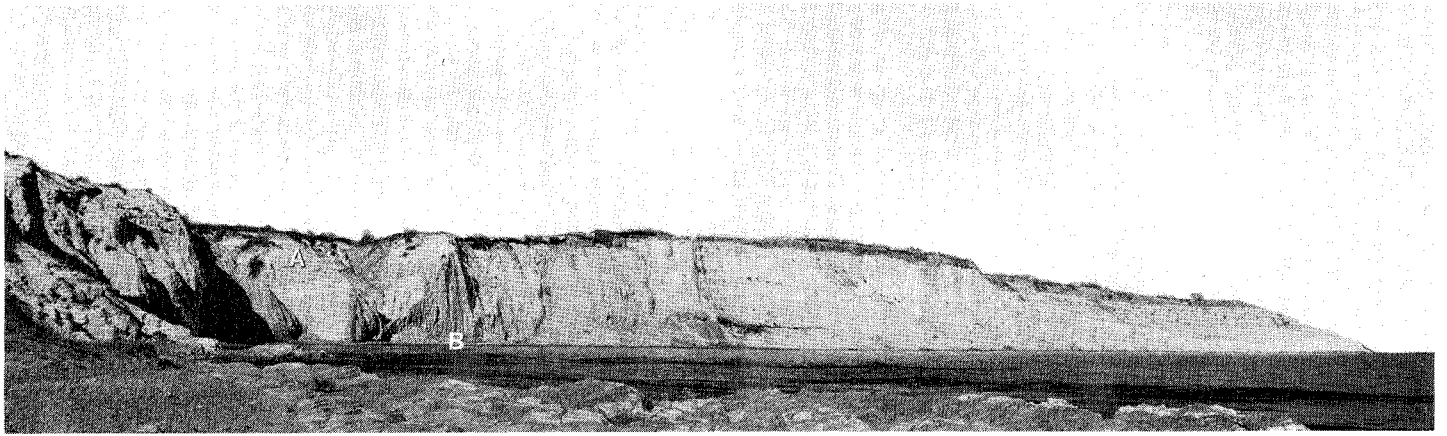


Fig. 1 The cliffs of Capo Rossello looking to the east. A: position of the sampled section; B: contact of Arenazzolo and Trubi.

THE SECTION AND THE SAMPLES

M. J. BROLSMA and J. A. BROEKMAN

INTRODUCTION

In October 1975, an eight-meter section in the lower part of the Pliocene Trubi limestones was sampled in detail east of Capo Rossello, Sicily.

The section is situated on the south coast of Sicily, near Lido Rossello, west of Porto Empedocle and south of the village of Realmonte (fig. 2). The Trubi is exposed along the beach in some 4 km of continuous cliff-like outcrops, in which the lower contact with the Upper Miocene Arenazzolo is locally visible (fig. 1, and Brolsma, 1975). The cliff-face is dissected by numerous NW-SE trending normal faults, interspaced about 50 meters and with displacements of up to 15 meters. Within each block a reliable profile can be sampled; correlation between adjoining blocks may prove more difficult.

The sampled section (fig. 3) starts at about 29 meters above the base of the Trubi and is easily accessible both from below and above along the eastern slope of a gully, the location of which is indicated in figures 1 and 2. The gully ends at the beach some 100 meters west of section 2 of Brolsma

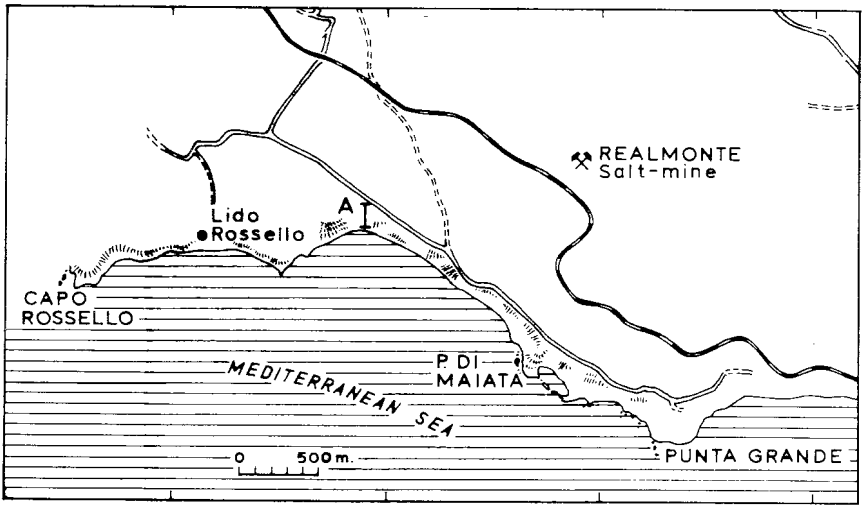
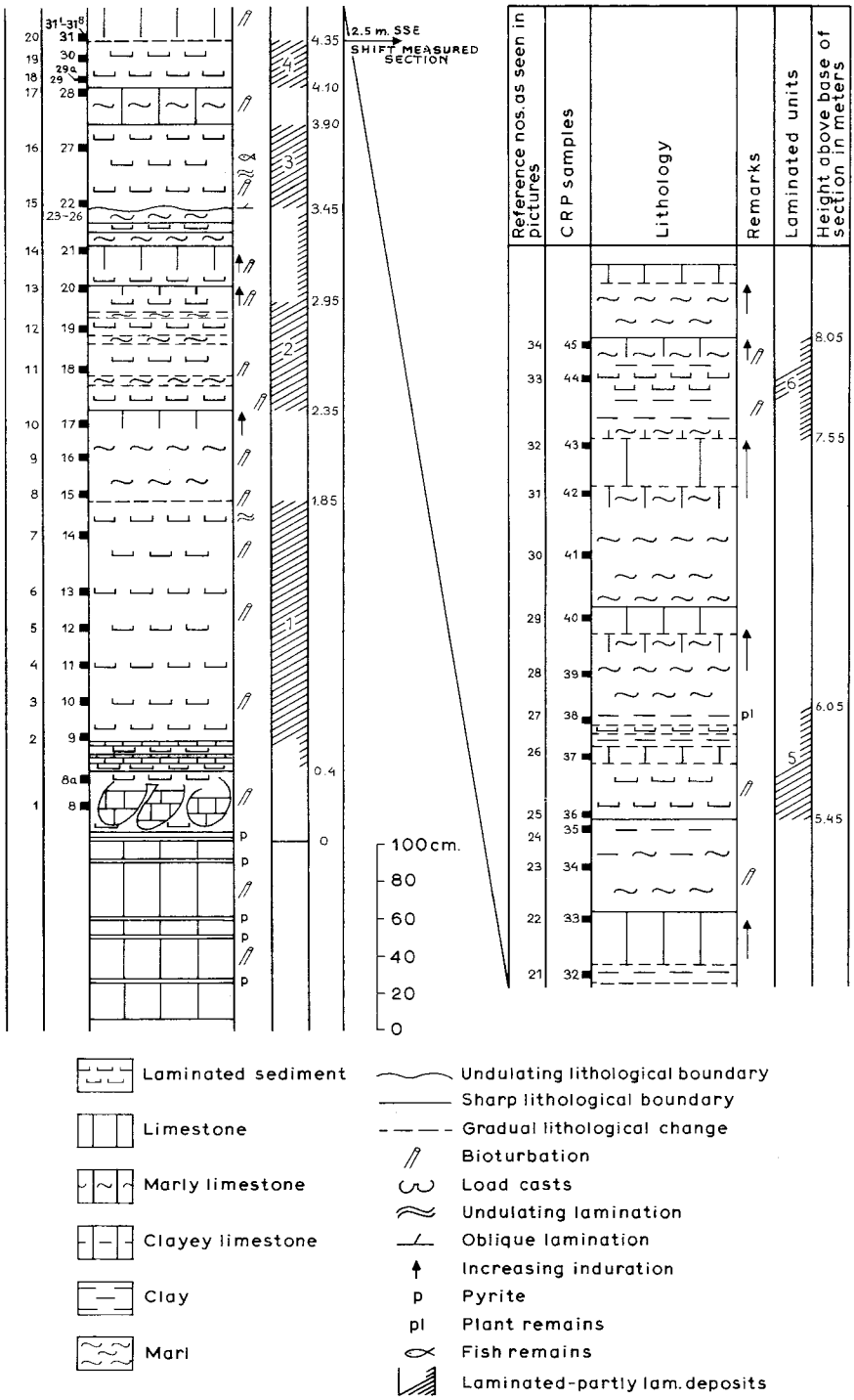


Fig. 2 Location of the Capo Rossello section (A).

Fig. 3 Lithostratigraphic details of the Capo Rossello section.



(1975). The section is continuously exposed in a near-vertical sense. The strata are subhorizontal.

THE TRUBI

This informal formational unit of the Lower Pliocene, known from Sicily and the south Italian mainland, has characteristic whitish colours. The rocks consist of some 75% of carbonates and 25% clay admixture (Cita, 1975). They are commonly referred to as limestones, but the degree of induration in the outcrops is variable. The carbonate material is of organic origin, consisting mainly of calcareous nannofossils and planktonic foraminifera. If the limestones are relatively soft and friable, they have been named marly limestones or even marls. In places the colour seems to indicate a somewhat higher percentage of clay, and such layers have been called clayey limestones.

The basal part of the Trubi at Capo Rossello

The investigated 8 m section starts about 29 m above the local base of the Trubi. The lowermost 6 to 7 m, immediately above this base, are generally cream coloured, and consist of vaguely bedded, intensely burrowed, compact limestones.

Upwards, the appearance changes because of the rapid alternation of relatively soft and marly limestones, and more indurated limestone beds. The greyish marly limestones grade upwards into the more compact limestones, which show brown, relatively indurated and apparently more strongly burrowed surfaces at their top. The thickness of the smaller sequences varies from some 30 to 70 cm; on a total thickness of 10 m, 25 of such repetitions may be distinguished. Farther upwards, the well-bedded appearance of the Trubi tends to vanish, the marly levels becoming more compact.

The next higher 10 m consist of limestones with a thickness of 1.00 to 1.20 m, separated by somewhat marlier beds of 20 to 40 cm. The upper 1.60 m shows marly limestones alternating with more compact limestones. The thickness of the marly beds is 35 to 60 cm, and that of the compact limestones 20 cm.

A limestone bed of about one meter, just below the section sampled in detail, is characterized by several subhorizontal thin layers of brown relatively indurated material that is black on the inside. Oblique U-shaped burrows filled with similar resistant material are abundant; the black core is supposed to be pyrite; the outer coating contains a mixture of gypsum, calcite and jarosite (Brolsma, 1975).

The investigated 8 meter section

This stratigraphic interval of special interest (fig. 3) is characterized by six intercalations of brownish-rose, finely bedded limestone, some of which are rich in silica, interbedded in a succession of marly and indurated limestones (fig. 3). The exact position of the sampling spots has been marked by long spikes. Each sample represents an interval of 5 cm, unless indicated otherwise. In one layer five samples (CRP 22 to CRP 26) were collected with a horizontal spacing of 5 m.

CRP 8–8A. The lowermost 40 cm show indurated pyritic thin layers at the base and finely laminated, rose-coloured sediment on top. Within this bed, semiglobular, asymmetrical bodies of homogeneous limestone are embedded in the laminated deposits. These structures are interpreted as the result of loadcasting with a slight lateral component. Sediment movement probably was toward the southeast, which is concluded from the orientation of the axial planes of the loadcasts. Burrows are numerous and some of them are composed of the same brown-black material as described above. Sample 8 was collected from a semiglobular body, 8A from the surrounding laminated sediment. Within the upper 6 cm of this bed, a rose coloured, finely bedded stratum with a thickness of 2 to 3 cm is intercalated.

CRP 9–14. The lowermost laminated to finely bedded interval of substantial thickness (about 140 cm) shows at its base a gradual transition over a few centimeters with the underlying deposits; the transition consists of an irregular alternation of non-laminated and finely laminated, brownish beds. In an upward sense, the limestone beds decrease in thickness from 2 cm to less than 0.5 cm over an interval of 10 cm.

The fine lamination is traceable by the differences in induration of the laminae, probably caused by different iron-content. Burrowing has not disturbed the lamination; the upper part of this unit, however, is distinctly burrowed, without substantial distortion of the original lamination. In this upper part the lamination is more delicate and wavy and the sediment is somewhat more brownish. The burrows reach a length of 10 cm; they are oblique to subparallel to the original lamination, and are filled with contrasting greyish material derived from the overlying marly limestone. Samples 9 to 14 were collected with a vertical spacing of 20 cm.

CRP 15–17. The basal part of the overlying grey marly limestone is burrowed as well, causing a gradual transition. These burrows are filled with rose sediment, corresponding in colour to that of the underlying bed. The lower marly limestone passes upwards into brownish and indurated limestone. The total thickness of this unit amounts to 50 cm. Samples 15 and 16,

and sample 17 correspond to the respective subunits.

CRP 18–21. The lower boundary of the second finely laminated unit is marked by a rapid change in colour to rose-brown. The sediment seems to be clayey; burrowing is present but rare. Some less distinctly laminated interbeds have a thickness of up to 4 cm. Samples 18 and 19 were collected in this part of the succession.

At about 60 cm from the base, the sediment changes into a light brown, less distinctly bedded limestone, containing burrows filled with white limestone of pelletoidal texture. This sediment passes in turn into homogeneous limestone (sample 20), which is overlain by a laminated bed with a thickness of 6 cm and a compact, indurated limestone of 15 cm (sample 21). The unit ends with a marly, partly laminated limestone of 20 cm thickness.

CRP 22–27. The undulating lower contact of the third laminated unit of rose-coloured sediment (thickness 45 cm) is rather sharp and well traceable horizontally. Over a horizontal distance of 5 m, samples 22 to 26 were collected from the same level in the basal part of this unit, CRP 27 from the top part.

The sediment is remarkably light in weight and shows delicate lamination with small-scale undulations, draping over larger specimens of *Orbulina,* which in turn seem to depress the laminae underneath. Fish remains are common.

The variation of colours from white to brown shows that the lamination is discontinuous in a lateral sense. Inclusions of greenish clay may be the result of burrowing but since the lamination seems to follow the outlines of the inclusions, these may at least partly be pebbles (diameter up to 2 cm).

The lamination shows internal unconformities as well as wavy stretches with a height of 0.5 cm. The lower contact of this unit is irregular due to folded structures and the presence of oblique lamination, visible over a horizontal distance of up to 20 cm. The folded structures have a width of some 10 cm. Internal small scale, zig-zag folding of laminae has been observed as well.

CRP 28. The third laminated unit is covered by 20 cm of marly limestone with a distinct lower contact and intense internal bioturbation. Sample 28 was collected from this layer.

CRP 29–30. The fourth laminated bed has a thickness of only 25 cm. Upwards, it changes gradually but rapidly into a burrowed limestone. Sample 29 was collected near its base; sample 29A, from the same level represents only two successive thin beds with a total thickness of 2 cm. Sample 30 is located near the transition to the overlying burrowed limestone.

CRP 31–35. The lower part of this unit is a compact, burrowed limestone of 20 cm (sample 31), followed by a relatively clayey layer of brown colour (10 cm, sample 32), which gradually passes into an indurated limestone of 30 cm (sample 33). The pronounced top of this limestone is covered by 30 cm of marl to marly limestone (sample 34), which shows an upward increase in clay-content and a change to brownish hues (sample 35). The total thickness of this non-laminated unit is 110 cm.

At the level of sample 31, the investigated section had to be shifted 2.5 m to the SSE, for reasons of accessibility. At the top of the first part of the measured section, samples 31^1 and 31^2 were collected; at the base of the second part, 31^3 to 31^8 are located in the same level.

CRP 36–38. Upwards, the fifth laminated intercalation attains a thickness of 60 cm. Burrowing is present without destroying the delicate bedding; the thin beds are homogeneous and white. In the lower part sample 36 was collected. About halfway, a relatively indurated, thin bedded intercalation is represented by sample 37. Towards the top, burrowing and clay content are increasing; lamination is restricted to some levels, and the colour changes to brown. In one layer plant-remains are common. Sample 38 is located in this upper clayey part.

CRP 39–43. The clayey top part of the fifth laminated intercalation gradually changes into a marl and marly limestone of grey colour (sample 39). This grades upwards into a somewhat more indurated limestone (sample 40), overlain by marls and marly limestone with an upward increasing induration (sample 41 to 43). The total thickness of this unit is 150 cm.

CRP 44–45. At the top of the section there is a sixth interval of about 50 cm with laminated sediments. The internal bedding is disturbed by burrowing in its lower and upper parts. About half way, less intensive organic activity allowed the preservation of discontinuous laminae. Sample 44 was collected from this middle part. Upwards the sediment passes rapidly into a relatively indurated, brown-coloured and burrowed limestone (sample 45).

The upper part of the Trubi at Capo Rossello

The sampled section is overlain by 2 m of soft and marly limestones with intercalations of some more indurated beds. Towards the top of the exposure, the marly intercalations disappear and the rather vaguely bedded and massive character of the sediments resembles that in the basal few meters of the Trubi (thickness 6 to 7 m). At its top the Trubi is unconformably overlain by gravels and soil.

Near Lido Rossello to the west, the Trubi reaches a greater thickness,

of more than 100 m. Upwards it grades into the more clayey sediments with brownish intercalations (Monte Narbone formation), which at this place are unconformably covered by Quaternary calcarenitic sands.

CHEMICAL, SPECTROPHOTOMETRICAL AND X-RAY ANALYSES

The carbonate, silica and pelite contents were determined for ten of the samples by means of chemical and spectrophotometrical analyses (fig. 4). The differences between the samples are not impressive, and but few of them give suggestions for correlation with the observed lithological changes along the column.

The carbonate content varies from 57 to 84%, and has a minimum value in the fifth laminated interval. Fluctuations across the other two laminated interbeds have not been observed.

The silica content varies between 9 and 20% and shows a slight overall upward increase. The maximum value is reached in the fifth interval; the samples from the other two laminated sequences are not clearly different from those of the adjoining homogeneous beds. The silica content in the non-laminated limestones (samples 15 and 28) is as high as in the first and fourth laminated interbeds. The most clayey intervals, from which samples 35 and 40 had been taken even show a higher silica value than the first

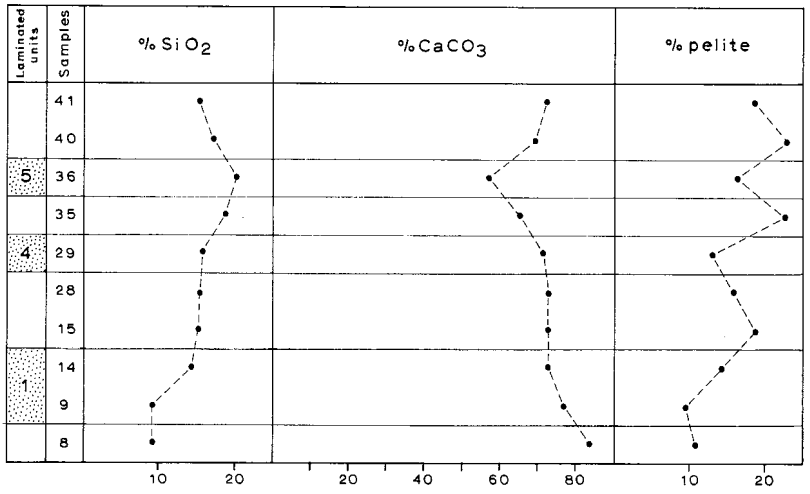


Fig. 4 SiO_2, $CaCO_3$ and pelite contents of ten of the samples from the Capo Rossello section. Dotted fields correspond to samples from laminated intervals.

and fourth interbeds. The abundance of diatoms and radiolarians in some of the laminated intervals is not clearly reflected in the silica values.

The pelite content shows an overall increase from approximately 10 to 20% and minimum values in the laminated interbeds. The samples 35 and 40 contain equal percentages. The lower level had been classified in the outcrop as clayey but the upper sample is from a homogenized limestone bed, according to the field observations.

The qualitative composition of the clay-fraction was investigated by means of X-ray analysis. It appeared that the clay mineral assemblages did not show appreciable variation. Smectites (probably predominantly montmorillonite), illite and small amounts of quartz were found in all samples; some kaolinite may be present in samples CRP 9 and 40.

Acknowledgements

The authors wish to thank C. W. Drooger and J. E. Meulenkamp for their critical remarks and valuable suggestions in the field as well as in the laboratory. The various analyses were carried out at the Department of Sedimentology of the State University of Leiden. The X-ray results were kindly interpreted by H. N. de Rooij of the Department of Soil Science of the State University of Utrecht.

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STATISTICS

M. M. DROOGER

STATISTICAL ERRORS

1.1 General remarks about statistical errors

There appeared to be a need for a critical review of the current statistical treatment of range chart data. The data gathered by the group of micropaleontologists who studied quantitatively the 38 Capo Rossello rock samples, could not be handled with a single procedure. Although the information was collected by various methods, the methods have one feature in common – all the observations were or could be expressed in numerical form, i.e. in values that bore some relation to the statistical population to which they belonged.

Any numerical value obtained from an "experiment", whether it be in the form of a simple number, a percentage, a mean or a ratio, contains a *statistical error* if by applying an appropriate statistical model one can deduce from the data an interval within which a desired number of the values from repeated experiments can be expected to fall. The value of the statistical error is equal to the standard deviation in any such hypothetical series of values. In other words, any numerical statement can be accompanied by a deduced *confidence interval* which contains the "real" parameter of the statistical population at a pre-determined probability level.

The term "statistical error" is used in this paper to distinguish the mathematically based errors from various possible geological errors, the effect of which cannot be calculated. This term statistical error is identical to the statistical term "standard error". An example of the latter is the term "standard error of the mean", which indicates the statistical error of a mean value calculated from a series of values, the real parameter being the mean of the population from which the series of values has been drawn. The relation between the parameters of the population and those of the statistical sample are shown in figure 1.

The statistical models used in our investigation are the Poisson model (numbers of repeated haphazard occurrences per unit of time, length, area or space) and the binomial model (random sampling from a population, each element of which has or does not have some property).

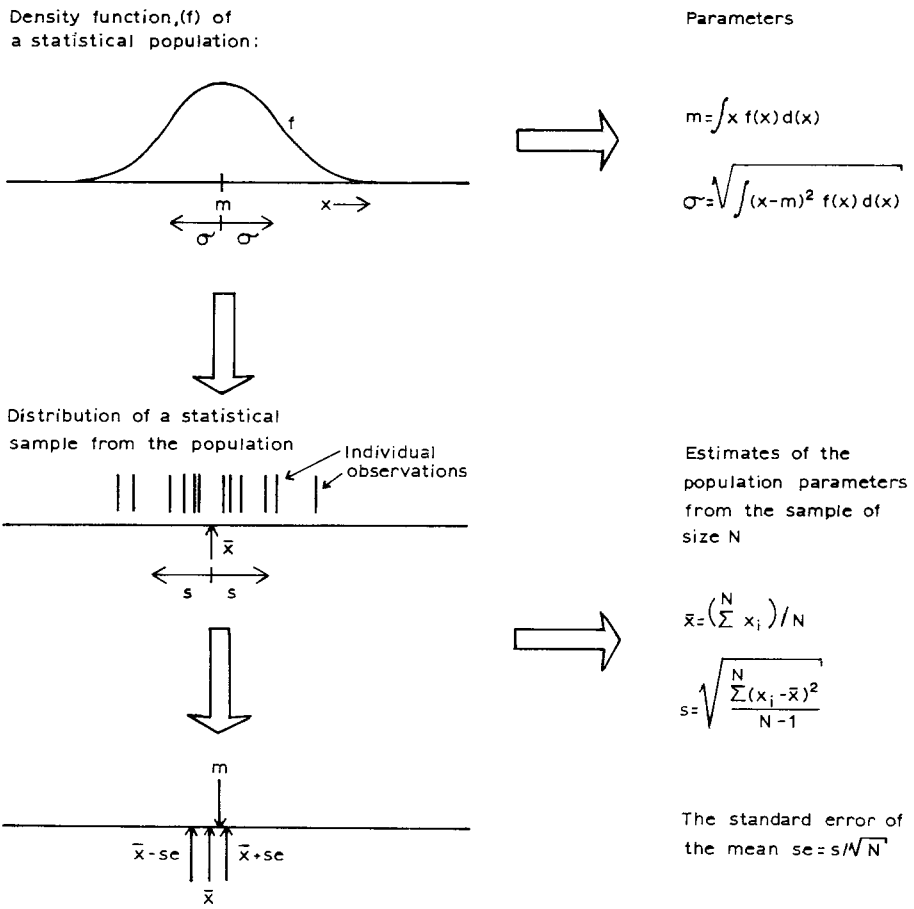

Fig. 1 Parameters of a statistical population and parameters of a random sample from such a population.
m = mean value of the pupulation
σ = standard deviation of the population
$\bar{x}$ = mean value of the sample
s = standard deviation of the sample
SE = standard error of the mean value $\bar{x}$.

1.2 Presentation of statistical errors

In the texts of this bulletin the statistical error of a value is given as

(value) ± stat. error

As shown in figure 2, the statistical error can be presented graphically as

the interval [value − stat. error, value + stat. error] which is a 68 per cent confidence interval. This means that there is a close to 68 per cent chance that this interval contains the real parameter.

The statistical error also can be presented as [value − 2. (stat. error), value + 2. (stat. error)], which is a 95 per cent confidence interval. This is the confidence interval we applied to most of our comparisons, and not that of 99.7 per cent, which corresponds to the range: value ± 3. (stat. error).

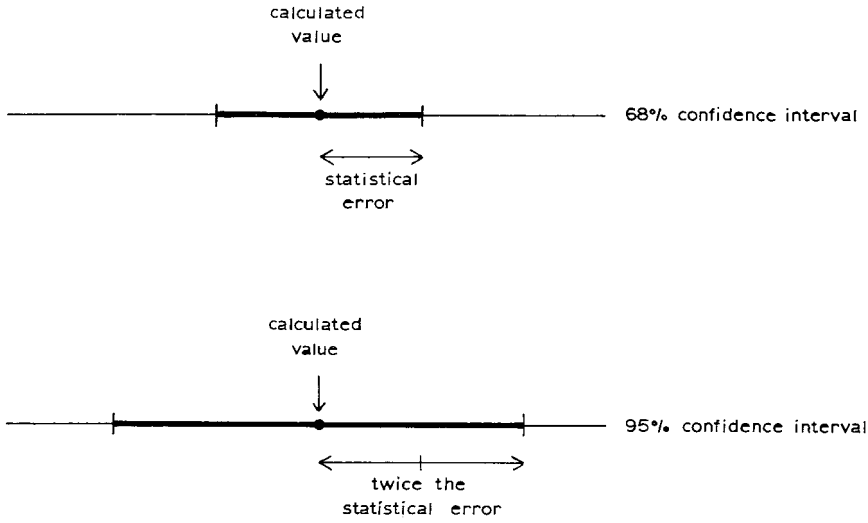

Fig. 2 Presentation of statistical errors.

1.3 Sum of statistical errors

If there is more than one cause that induces a statistical error in some value, the *resultant statistical error* is

$$E_r = \sqrt{E_1^2 + E_2^2 + \ldots\ldots + E_k^2}$$

in which E_i is the i-th statistical error and E_r the resultant statistical error. It is supposed that conditions of mutual independence of errors are met.

Figure 3 shows the graphical construction of the resultant error in the case of two statistical errors.

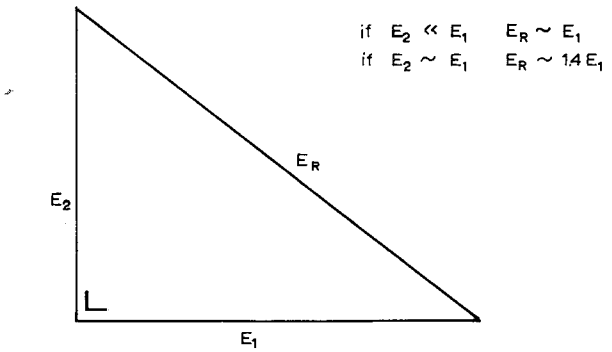

Fig. 3 Construction of a resultant statistical error.
E_1 = first statistical error
E_2 = second statistical error
E_R = resultant statistical error.

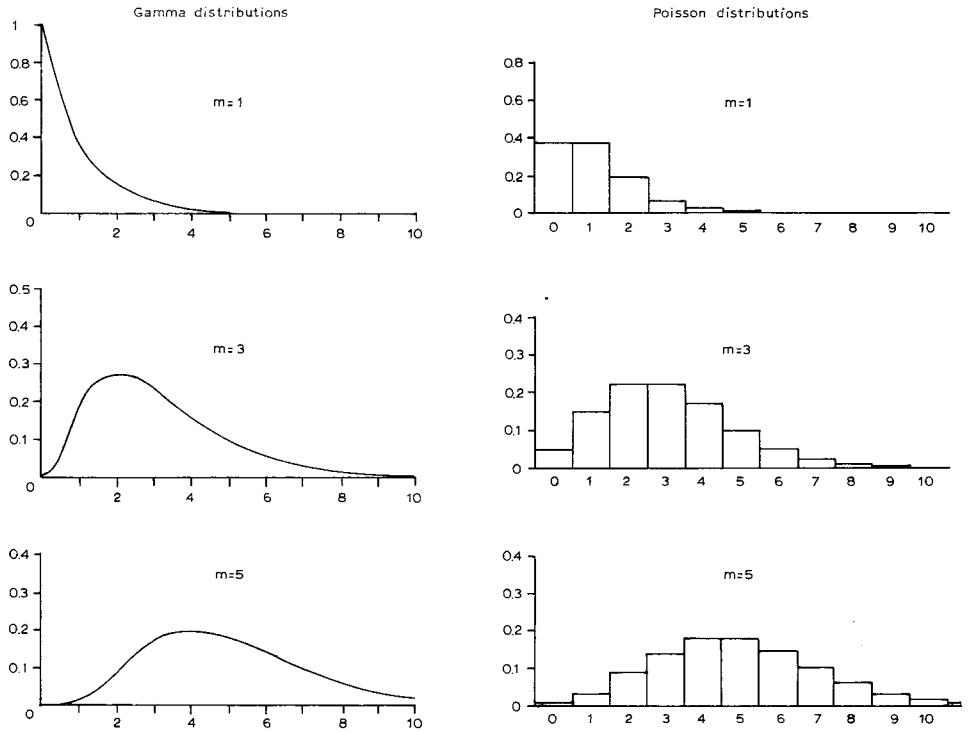

Fig. 4 Left: Gamma distributions.
The probability distributions of the time of first occurrence (upper graph), of third occurrence (middle graph), and of fifth occurrence (lower graph), if one occurrence per unit time is expected. The mean values m are 1, 3 and 5 respectively.
Right: Poisson distributions.
The probability distributions of the number of occurrences per unit time, if 1 occurrence (upper graph), if 3 occurrences (middle graph) and if 5 occurrences per unit time are expected. The mean values m are 1, 3 and 5 respectively.

1.4 Poisson intervals, gamma intervals and binomial intervals

The *Poisson probability model* describes repeated haphazard occurrences in time or space. The discontinuous probability distribution of the numbers per unit of time, length, area or volume of such occurrences is a *Poisson distribution,* characterized by the value of the theoretical mean of the numbers. If this mean value is less than five the distribution will appear to be markedly skewed (fig. 4). For larger mean values the distribution will tend to have the shape of a normal distribution, i.e., a distribution with a density function of the type

$$f(x) = \frac{e^{-((x-m)^2/(2\sigma^2))}}{\sigma \cdot \sqrt{2\pi}}$$

in which x is the value of the random variable, m the theoretical mean value and σ the theoretical standard deviation of the distribution. See figure 5.

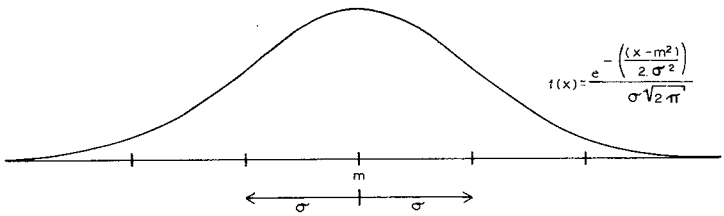

Fig. 5 The normal distribution with parameters m and σ. m is the mean value, σ is the standard deviation.

The lengths or time-spans needed to observe a fixed number of such repeated haphazard occurrences have different, continuous, probability distributions, called *gamma distributions.* Again, if this fixed number of occurrences is less than five, the distribution will be markedly skewed (fig. 4). For larger fixed numbers the gamma distribution will tend to have the shape of the normal distribution.

The *binomial probability model* describes results of random sampling from a population, each element of which has or does not have, some property. If the proportion of the elements in the population with a particular property is denoted by p, the number of elements having this property in a random sample of n elements has a *binomial distribution* with parameters n and p. The distribution will be markedly skewed if the mean number having the property in the sample, n.p (or the mean number not having the property, n.(1−p)) is less than five. For larger n.p values the shape

of the binomial distribution will again tend to be "normal". Of course n should be much larger than 10.

For all the probability distributions mentioned, it can be said that in general the lower the ratio (standard deviation/mean) is, the better the fit is to the normal distribution with corresponding mean and standard deviation. More detailed information and formulae can be found in e.g. Lindgren and McElrath (1969), and Ferguson (1967).

It is emphasized that the "Poisson intervals", "gamma intervals" and "binomial intervals" used in this volume, are *not* confidence intervals. The first three types of intervals are constructed from a set of *really observed* values (not hypothetical) so that checks can be made to see whether or not these data fit the Poisson model, or the binomial model.

The general procedure is as follows. From the set of values $x_1, x_2, \ldots\ldots, x_N$ a theoretical standard deviation SD_t is deduced (SD_P for the Poisson distribution, SD_g for the gamma distribution, SD_b for the binomial distribution). Then one can check whether about 95% of the x_i fall within the interval $[\bar{x} - 2.SD_t, \bar{x} + 2.SD_t]$, $\bar{x}$ being the mean of the x_i. If they do, one may conclude that the set of values fits the model under consideration.

The Poisson and gamma intervals are used in sections 2.3 and 2.4, the binomial intervals in section 3.2.

It should be noted that these intervals as well as confidence intervals are unreliable if the underlying probability distributions are skewed. As mentioned in the first half of this section we use the quite subjective criterion that the number must be greater than five if confidence intervals and mean numbers of Poisson, gamma and binomial intervals are to be acceptable for drawing conclusions.

TOTAL NUMBERS OF MICROFOSSILS PER UNIT WEIGHT; EVEN DISTRIBUTIONS

2.1 The estimation of the number of microfossils per unit weight of sediment from counts in a single split, spread "evenly" over the picking tray

An important topic in our exercise was the derivation of the statistical error in the calculated total number of specimens per unit weight. This could not be done without investigating the degree of uniformity of the distribution of the microfossils over the picking tray. It turned out (see 2.5) that this distribution is not equable if the densities on the tray are high, although one may get the visual impression of random scattering. This means that the Poisson model cannot be applied to establish the statistical error of the

total number per unit weight (or volume).

Zachariasse (this volume) presents the number of foraminifera per one hundred grams of sediment as

$$T = S \cdot Y \cdot (\bar{d} \pm SE_{\bar{d}})$$

in which:

S is related to the number of splits; it is the ratio of the volumes ($\simeq$ weights) of total residue to last split. In practice S is a power of two, such as $2^7 = 128$, $2^9 = 512$;

Y is the number of square fields on the picking tray;

$\bar{d}$ is the mean number of specimens per square field, $\bar{d} = \frac{\sum_{i=1}^{N} d_i}{N}$: the "density" calculated from a number of N fields (see fig. 6);

$SE_{\bar{d}}$ is the standard error of $\bar{d}$.. $SE_{\bar{d}} = SD_d/(\sqrt{N})$, in which SD_d is the standard deviation of d:

$$SD_d = \sqrt{\frac{\sum_{i=1}^{N} (d_i - \bar{d})^2}{N-1}}$$

Before discussing the question whether the distribution of the foraminifera can be regarded as even, we must point out that S itself is not free of error either. Only if the splitting procedure were perfect, might S be expected to correspond exactly to 2^z, after splitting z times. This statistical error of S in the final result of T, however, appears to be small in relation to the statistical error induced by $SE_{\bar{d}}$, according to the experiment performed by Zachariasse and the author, described in the next section 2.2.

2.2 Error in the weight of a split

The total wash-residue of 100 grams of sample CRP 30 (from one of the laminated intervals, see Brolsma and Broekman, this volume) was weighed (11.144 grams). After splitting with an Otto microsplitter one "half" was left unconsidered, the other "half" weighed and then split again. One of the new splits was put back in the bottle marked "unconsidered", the other weighed and then split again, and so on. The CRP 30 residue could be split nine times.

It appeared that the ratios of the weight values $\frac{\text{split}}{\text{preceding split}}$, had an

average of 0.500 (fifty per cent) and a standard deviation of about 0.005 (0.5 per cent). So in this case each of the successive ratios has a *relative statistical error* of about $\frac{0.005}{0.500} = 0.01$. According to section 1.3, the relative statistical error of S is the resultant error of nine statistical errors of size 0.01; therefore it is $(0.01) \cdot \sqrt{9} = 0.03$ (three per cent). The only extra assumption required for the conversion to T is that the weights of the splits are perfectly proportional to the numbers of microfossils they contain.

This procedure was repeated for the residue of 100 grams of sample CRP 21 (from a non-laminated interval). This residue had a weight of 8.254 grams and was split eight times. The standard deviation of the weight ratios appeared to be even less than 0.5 per cent.

We can conclude that in the case of our microsplitter S induces a relative statistical error in T of about three per cent, whereas the relative statistical error of the densities on T, $(100 \cdot (SE_{\bar{d}}/\bar{d})$, in percentage values, is much larger, i.e. about 20 per cent.

2.3 Density distribution over the tray

Zachariasse (this volume) reports on his attemps to make an even distribution of planktonic foraminifera over the picking tray. If these attempts are successful, the observed numbers on the square fields (d_1, d_2, d_3, ..., d_{14} in Zachariasse's investigation, fig. 6) must have a Poisson distribution,

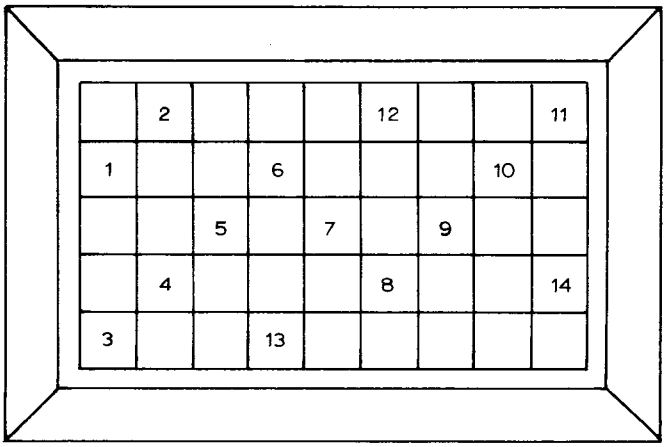

Fig. 6 The 14 fields used by Zachariasse to estimate the density of the foraminifera. The area of a field is one square centimeter. Y = 45, N = 14, see text.

i.e. the distribution of the numbers of repeated haphazard events in areas of fixed size. A similar distribution might be expected to hold for numbers of individuals of a taxon per square field.

A Poisson distribution is characterized by the equality of the mean m and the variance σ^2:

$$m = \sigma^2 \quad \text{or} \quad \sigma = \sqrt{m}$$

The mean m being estimated by $\bar{d}$, the theoretical "Poisson" standard deviation thus becomes estimated as

$$SD_P = \sqrt{\bar{d}}$$

The Poisson interval corresponding to the set of d_i-values turns out to be:

$$[\bar{d} - 2 \cdot \sqrt{\bar{d}},\ \bar{d} + 2 \cdot \sqrt{\bar{d}}]$$

If the assumption that the distribution of microfossils is even over the tray is correct, then about 95 per cent of the d_i observed are bound to fall within this interval (see 1.4).

Figure 7 gives a picture of the sets of d_i-values and their corresponding Poisson intervals concerning *planktonic foraminifera* for two of the samples

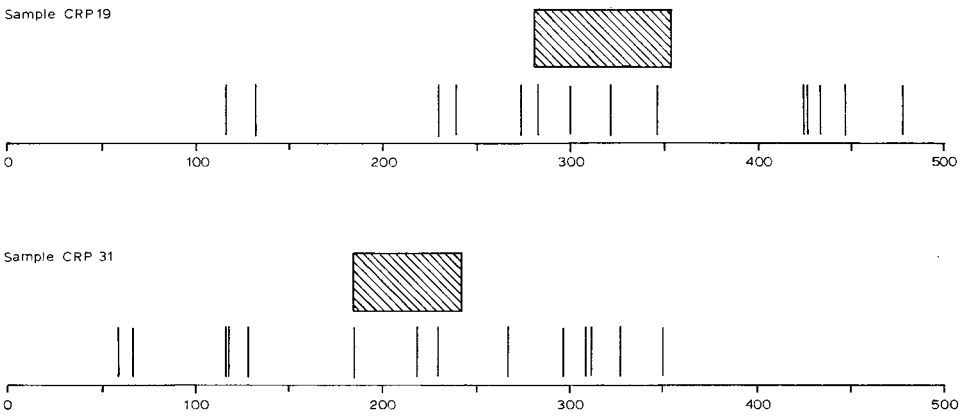

Fig. 7 Numbers of planktonic foraminifera in square fields of the picking tray, and their Poisson interval (hatched). Data of Zachariasse.

investigated by Zachariasse. From this picture it appears that the range of the d_i is much wider than expected according the Poisson model.

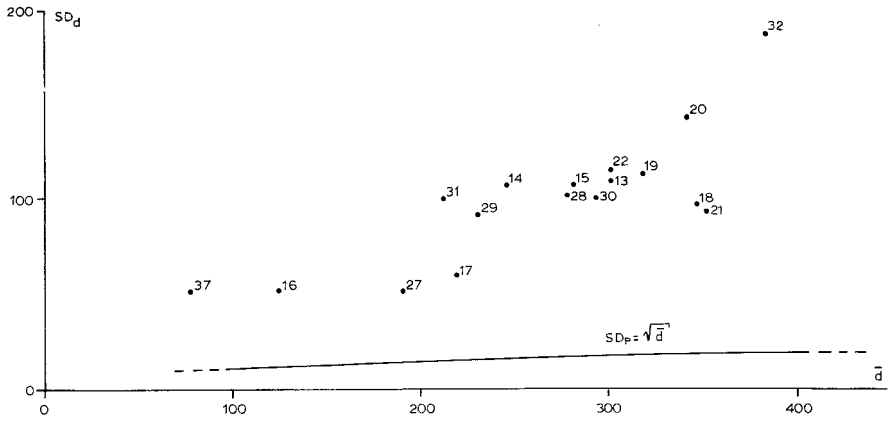

Fig. 8 SD_d versus $\bar{d}$ of planktonic foraminifera per square field for all samples studied by Zachariasse. See text. SD_d and $\bar{d}$ are based on 14 fields per sample. In the figure the sample numbers have been added, and also the graph of $SD_P = \sqrt{\bar{d}}$.

For the planktonic foraminifera a scatter diagram of SD_d versus $\bar{d}$ is presented in figure 8 for all samples studied, SD_d being the standard deviation of the d_i, i = 1,2, . ., 14 (see section 2.1). In this figure the line $SD_P = \sqrt{\bar{d}}$ versus $\bar{d}$ has also been drawn. It appears that SD_d is about five to ten times as large as SD_P, so apparently the Poisson model is not valid for these data. The attempts of Zachariasse evidently were not successful.

For the sake of completeness, the hypothesis has been tested for each sample as to whether the planktonic foraminifera have an even distribution over the tray, by means of the chi square statistic:

$$\chi^2 = \frac{(N-1)\cdot SD_d^2}{SD_P^2} = \frac{\sum_{i=1}^{N} (d_i - \bar{d})^2}{\bar{d}}$$

If the hypothesis is true, χ^2 has a chi square distribution with $(N-1)$ degrees of freedom. Table 1 shows quite clearly that for all samples the hypothesis must be rejected.

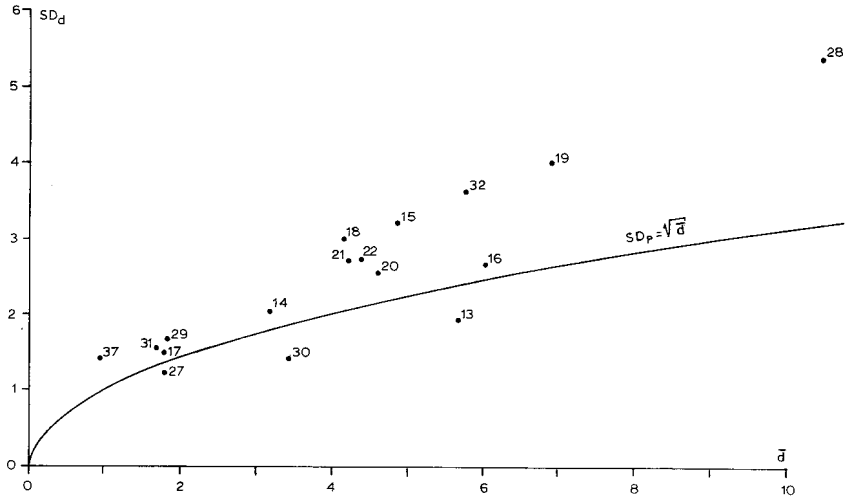

Fig. 9 SD_d versus $\bar{d}$ of benthonic foraminifera per square field for all samples studied by Zachariasse. See text. SD_d and $\bar{d}$ are based on 14 fields per sample. In the figure the sample numbers have been added, and also the graph of $SD_P = \sqrt{\bar{d}}$.

Table 1

Planktonic foraminifera Sample nr.	χ^2-value
13	530 *
14	611 *
15	542 *
16	275 *
17	212 *
18	361 *
19	537 *
20	797 *
21	334 *
22	581 *
27	189 *
28	499 *
29	475 *
30	456 *
31	618 *
32	1212 *
37	446 *

Table 2

Benthonic foraminifera Sample nr.	χ^2-value
13	8.5
14	16.1
15	25.9
16	15.0
17	17.0
18	27.9 *
19	29.1 *
20	18.3
21	22.9
22	22.3
27	11.4
28	36,0*
29	20.4
30	7.4
31	18.1
32	29.5 *
37	29.0 *

Tables 1 and 2. Chi square values for the test for uniform destribution over the tray. The chi square distribution has 13 degrees of freedom, $P_{95} = 22.4$, $P_{99} = 27.7$, $P_{99.9} = 34.5$.
All χ^2-values greater than P_{99} (the 99 th percentile) have been marked with an asterisk.

In the same way the data gathered by Zachariasse on *benthonic foraminifera* have been considered (fig. 9 and table 2). These foraminifera are much less numerous in the sample residues from the CRP samples. For this group of fossils the hypothesis had to be rejected only 5 times out of 17 (level of significance $\alpha = 0.01$). The difference in results is discussed in section 2.5.

2.4 Density distribution over the smear slide

The distribution over the smear slide has been investigated for calcareous nannofossils as well (R. R. Schmidt, this volume). However, the number of samples investigated (2) is too small to allow general conclusions to be drawn.

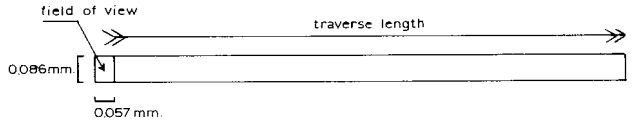

Fig. 10 The field of view tracking over the smear slide.

The procedure is as follows:
In the field of view a track is made over the smear slide (figure 10), in which a fixed number n of nannofossils (200 in this case) is counted. The traverse length x needed to reach this number is measured. This procedure is done N times (N = 10 in this case). From these N values of x, the mean value $\bar{x}$ and the standard deviation SD_x are calculated.

If the distribution of the calcareous nannofossils were even, the length of the traverse x needed to count n specimens would have a gamma distribution characterized by the following relation between mean m and variance σ^2 :

$$m^2 = n \cdot \sigma^2 \qquad \text{or} \qquad \sigma = m/\sqrt{n}$$

Estimating m from $\bar{x}$, the theoretical gamma standard deviation is estimated:

$$SD_g = \bar{x} / \sqrt{n}$$

The gamma interval corresponding to the set of x_i-values is:

$$[\bar{x} - 2 \cdot \bar{x}/\sqrt{n},\ \ \bar{x} + 2 \cdot \bar{x}/\sqrt{n}]$$

within which about 95 per cent of the x_i must fall if the assumption of evenness is correct (see section 1.4).

Figure 11 gives a picture of sets of x_i-values and their corresponding gamma intervals for the two samples. The range of the x_i of sample CRP 22 seems to fit the Poisson model, whereas this range of sample CRP 39 certainly does not.

The hypothesis that the calcareous nannofossils have an even distribution over the smear slide can be tested by the chi square statistic:

$$\chi^2 = \frac{(N-1) \cdot SD_x^2}{SD_g^2} = \frac{n \cdot \sum_{i=1}^{N} (x_i - \bar{x})^2}{\bar{x}^2}$$

which has a chi square distribution with $(N - 1)$ degrees of freedom if the hypothesis is true.

The results for the two samples are:

(N = 10, n = 200)	$\bar{x}$ in mm	SD_x in mm	χ^2	Probability level
CRP 22	8.58	0.96	22	$P \sim 0.01$
CRP 39	1.80	0.59	194	$P < 0.001$

The probability level P is the chance that the χ^2 value presented will be exceeded if the hypothesis is true.

We must conclude that for sample CRP 39 the distribution of the nannofossils cannot be regarded as even. In the case of sample CRP 22 it is doubtful whether it has an even distribution either.

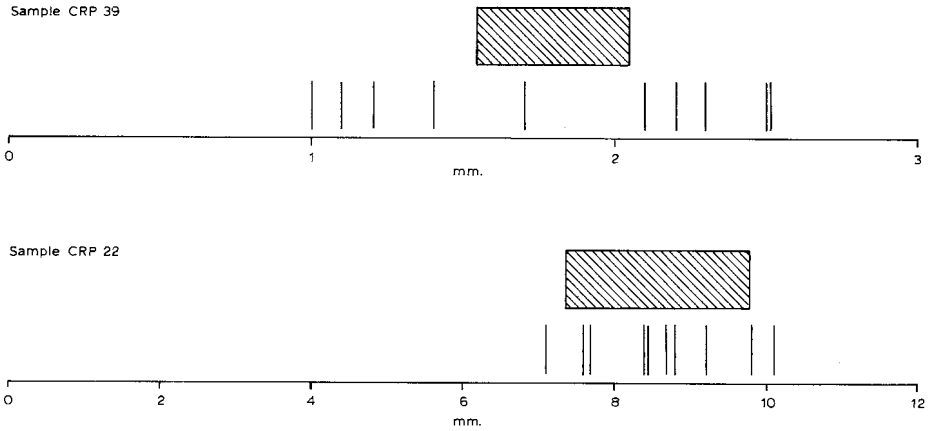

Fig. 11 Lengths of traverses for counting 200 calcareous nannofossils (Schmidt) and their gamma interval.

2.5 Discussion

One conclusion that can be drawn is that for densities of foraminifera between 100 and 400 per field (= square centimetre) on the tray it is impossible to get an even distribution over the tray. In figure 8 one gets the impression that SD_d has a more or less linear relation with $\bar{d}$:

$$SD_d / \bar{d} \sim 0.4$$

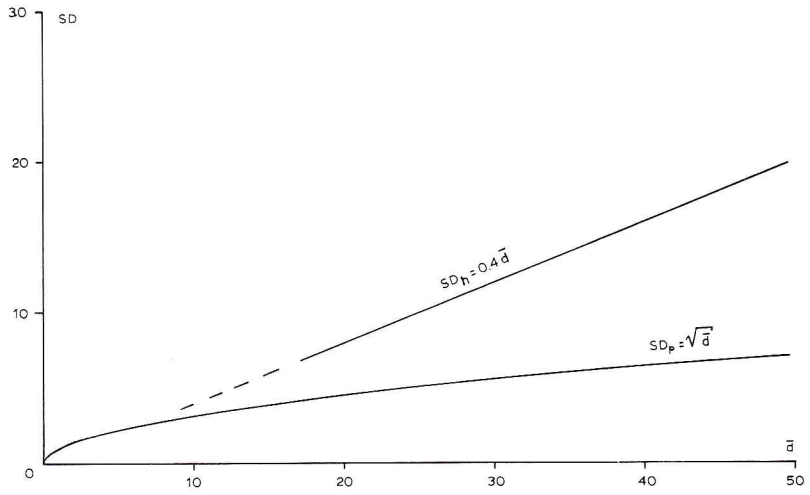

Fig. 12 Graphs of the standard deviation according to the Poisson model, SD_P, as a function of $\bar{d}$, and of the hypothetical standard deviation, SD_h, derived from the observations, as a function of $\bar{d}$.

In figure 12 this hypothetical equation $SD_h = (0.4).\ \bar{d}$ has been plotted together with the Poisson-based relation $SD_P = \sqrt{\bar{d}}$. From this figure it appears that for large $\bar{d}$-values SD_h is much greater than SD_P, but that when $\bar{d}$-values are less than 10 both lines are so close that the Poisson model gives a good approximation for the data, even although we must consider the assumption of unevenness of the distribution of the foraminifera still to be valid. The scatter diagram of SD_d versus $\bar{d}$ for the *benthonic foraminifera* (figure 9) shows this tendency. In fact for $\bar{d}$ less than 5 the distribution of the foraminifera cannot be distinguished from an even distribution in most cases in our investigation. Unfortunately, we have no data yet for cases when $\bar{d}$ is in the 10–80 range.

This difference in effect is reminiscent of what happens when one tests a

die to see whether it is faulty: A large number of throws with a false die (i.e., the six sides do not have equal chances of showing up) will lead to rejection of the hypothesis that it is a good one, with a low probability level. If the number of throws is very small, the hypothesis cannot be rejected: the false die cannot be distinguished from a good one.

COUNTING A FIXED NUMBER OF MICROFOSSILS FROM A SAMPLE

3.1 Estimating the numerical proportion of a taxon

To obtain an impression of the proportions of the individual taxa in a sample, a fixed total number of n specimens (in general 200) is identified and counted per taxon in a fixed order on the tray, thus ensuring the random character of the counts. In Utrecht this procedure of fixed numbers is followed so that comparable values of computed percentages of taxa can be presented.

The proportion of a taxon with a score of x specimens in the count is estimated simply by

$$p = x/n$$

If the observations during the count really are random, the statistical error in p may be considered to be equal to the theoretical standard deviation according to the binomial model:

$$\frac{1}{n} \cdot \sqrt{\frac{x \cdot (n - x)}{n}} = \sqrt{\frac{p \cdot (1 - p)}{n}}$$

So if we assume that the picking is random, the proportion of a taxon in the statistical population can be given as:

$$p \pm \sqrt{\frac{p \cdot (1 - p)}{n}}$$

in which $p = x/n$ is the proportion of the taxon in the count.

3.2 Testing the homogeneity of a series of counts

The Capo Rossello data have been used to check the reliability of series of counts. The questions to be answered are the following (see elsewhere in this volume):

1) Is one count of n specimens representative for the tray or smear slide? (Do several counts from the same tray or smear slide fit the model of homogeneity?)

2) Is the split on the tray or the smear slide representative for the whole sample? (Are counts from different splits or smear slides of one sample homogeneous, i.e. "similar"?)

3) Is the sample representative for the stratigraphic layer from which it comes? (Are counts from different lateral samples homogeneous?)

4) Is the layer representative for the whole stratigraphic column? (Are counts from samples along the stratigraphic column homogeneous?)

From the statistical point of view it is necessary to find out whether a series of counts can be regarded as being drawn from a single statistical population. The investigation has been carried out in several ways.

At first, the scores of a single species in a series of counts are considered. These scores, denoted here by $x_1, x_2, x_3, \ldots, x_N$ (in N counts of size n), must follow a binomial distribution if the hypothesis that the counts are from statistical populations having the same proportion of the taxon is true. A binomial distribution is characterized by the following relation between mean m and variance σ^2:

$$\sigma^2 = \frac{m \cdot (n - m)}{n} \quad \text{or} \quad \sigma = \sqrt{\frac{m \cdot (n - m)}{n}}$$

Estimating m from $\bar{x}$, the theoretical "binomial" standard deviation of the x_i is estimated:

$$SD_b = \sqrt{\frac{\bar{x} \cdot (n - \bar{x})}{n}}$$

If we express our data in proportions $p_i = x_i/n$, it follows that $\bar{p} = (\sum_{i=1}^{N} p_i)/N = \bar{x}/n$ is the mean proportion of the taxon in the series of counts. The standard deviation of the p_i according the binomial model is:

$$SD'_b = \frac{1}{n} \sqrt{\frac{\bar{x} \cdot (n - \bar{x})}{n}} = \sqrt{\frac{\bar{p} \cdot (1 - \bar{p})}{n}}$$

The binomial interval corresponding to the series of x_i-values is:

$$\left[\bar{x} - 2 \cdot \sqrt{\frac{\bar{x} \cdot (n - \bar{x})}{n}},\ \bar{x} + 2 \cdot \sqrt{\frac{\bar{x} \cdot (n - \bar{x})}{n}} \right]$$

The binomial interval corresponding to the series of p_i-values is:

$$\left[\bar{p} - 2 \cdot \sqrt{\frac{\bar{p} \cdot (1 - \bar{p})}{n}},\ \bar{p} + 2 \cdot \sqrt{\frac{\bar{p} \cdot (1 - \bar{p})}{n}} \right]$$

$\bar{x}$ or $(n.\bar{p})$ may not be less than 5 by reason of skewness of the binomial distribution (see 1.4). If this condition is fulfilled, about 95 per cent of the x_i, or p_i, must fall within these intervals if the assumption that all counts are from populations having the same proportion of the taxon is correct.

Figure 13 shows an example from the data of Brolsma (this volume). Five of the 19 samples appear to have x-values outside the interval; with respect to *Bulimina elongata,* these samples cannot have a composition with the average proportion of the 19 samples.

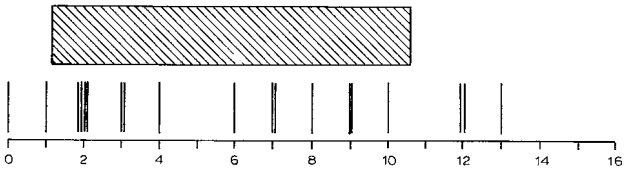

Fig. 13 Scores of *Bulimina elongata* in the counts of 100 specimens from the series of 19 non-laminated samples, and their binomial interval (Brolsma).

The hypothesis that all counts are from statistical populations (assemblages of the micropaleontologists) with the same proportion of the taxon under consideration can be tested by the chi square statistic

$$\chi^2 = \frac{(N - 1) \cdot SD_x^2}{SD_b^2} = \frac{n \cdot \sum_{i=1}^{N} (x_i - \bar{x})^2}{\bar{x} \cdot (n - \bar{x})}$$

which has a chi square distribution with $(N - 1)$ degrees of freedom if the hypothesis is true (see Brolsma or Schmidt, this volume).

By adding up the chi square values of all taxa of the assemblages, one gets a measure of the extent to which the series of counts as a whole are heterogeneous. If the counts are from statistical populations of similar composition, one might consider with some caution this sum of chi square values

as having a chi square distribution with about S · N degrees of freedom, S being the number of taxa, N being the number of counts. A measure for the degree of heterogeneity of the counts is:

$$\sqrt{(\sum_{i=1}^{S} \chi_i^2) / df} \qquad (df \sim S \cdot N)$$

This expression will give a value of about 1 if the counts are from near-identical populations, and a value greater than 1 if they are not. Actually, the expression is the ratio between the deviations in the counts, and the deviations expected if the counts were from one statistical population (see Schmidt, this volume).

Another measure for indicating the extent to which two counts are homogeneous is the Sanders coefficient of similarity used by Brolsma (this volume). If the proportions, expressed in percentages, of the i-th taxon in the first and in the second count are denoted by p_{i1} and p_{i2} respectively, the Sanders coefficient of similarity is defined as:

$$S = \sum_i \text{minimum } (p_{i1}, p_{i2})$$

which must give a value between 0 and 100. A value 0 clearly means that the counts are completely dissimilar. It is highly unlikely, however, that two counts from the same statistical population will have a similarity S = 100, because this would mean that the proportions in both counts are exactly equal for each taxon. The S value of a pair of counts from a statistical population has a probability distribution, the mean and standard deviation of which will depend on the composition of the statistical population (numbers of taxa and frequencies of individual taxa) for which no general formula can be given. The conclusion that one pair of counts is less similar than another pair because the S value of the first pair is lower than the S value of the second pair is open to some doubt. The Sanders coefficient of similarity may be useful as a measure from which no stringent conclusions can be drawn.

3.3 Comparison of pairs of assemblage counts

By means of a Q-mode computer programme (to be published elsewhere), any pair of counts of assemblages can be compared on the overall homogeneity (similarity). More precisely: for any pair a chi square statistic can be calculated to test the hypothesis that both counts are from the same

statistical population (Chi square test of homogeneity on a two by S table, S being the number of taxa).

This procedure has been used on data of Zachariasse (this volume) in order to compare counts from the same picking tray, and counts from different splits of one sample.

3.4 Counts along the stratigraphical column; variation, trends and correlations

By means of two R-mode computer programmes, one for counts with fixed n, the other for counts with variable n, a series of counts can be analyzed from a sequence of rock samples along a stratigraphical column.

As to variation, a chi square statistic is calculated for each taxon to enable one to test the hypothesis that the proportions of the taxon in the statistical populations from which the counts come are the same. For counts with fixed total numbers, the statistic has already been mentioned in section 3.2. For counts with varying total numbers, the statistic has a more complex form.

In addition an F-statistic is calculated for each taxon to test the hypothesis that there is no (overall) trend in the proportions of the taxon in the stratigraphic succession of populations, from which the counts come.

These two programmes furthermore enable us to calculate the correlation coefficients between the proportions for each pair of taxa.

Inferences drawn from such variations, trends and correlations are in many cases of doubtful value because of the well known "closed sum" effects. Actually, the proportions of all taxa in a series of populations are mutually dependent variables, because they add up to one (or 100 per cent). Mathematical techniques to eliminate as far as possible disturbances due to the closed sum are as yet inadequate.

In many cases the multinomial model (Mosimann, 1962, 1965) adequately describes a range chart consisting of a series of counts of different taxa. However, as soon as one (or more) taxon (taxa) show(s) large fluctuations in proportions in a range chart, the correlation coefficients become unreliable. In such a case, only the scores of all other taxa must be considered relevant, and the scores of the "variable" taxon have to be deleted from the counts as if this taxon had not been considered during the counting. All other taxa together form a new range chart consisting of counts with varying total numbers. In almost all cases this appears to be an acceptable procedure (to be published later).

Results from these procedures may be found elsewhere in this volume, also the practice of deleting scores of a taxon (see Zachariasse and Schmidt).

3.5 Dependence of the relative frequency of a taxon on the type of sediment

Brolsma (this volume) has investigated whether the relative frequencies of his taxa are dependent on sediment type, i.e., whether the counts are from laminated intervals or from non-laminated intervals of the Capo Rossello section. For this purpose the scores of each taxon in all counts from the samples from the laminated intervals were added together and compared with the sum of the corresponding scores in all counts on the samples from the non-laminated intervals. The sums of the total numbers of the counts from the laminated intervals and from the non-laminated intervals were taken into account.

For each taxon, a chi square statistic can be calculated to test the hypothesis that the frequencies of the taxon are independent of the types of sediment mentioned (Chi square test for independence on a two by two table). Whenever the hypothesis has to be rejected, it follows that the relative frequencies of the taxon involved in one of both sediment types are higher than in the other. If the sums of the scores of a taxon are too low however (no expected number in a two by two table may be less than 5), this chi square statistic cannot be used. In such cases Fisher's exact test of independence has been used (See Cochran, 1952).

One has to be prepared for "squeezing effects" in the closed sums, however, which are similar to those mentioned in the previous section. In fact, the sums of *Oolina hexagona* were found to cause a squeezing effect in the fraction greater than 63 μ, as well as in the fraction greater than 125 μ. The sums of *Globocassidulina subglobosa* in the fraction greater than 63 μ cause less of a squeezing effect. The tests for independence for any other taxon are reliable only if the scores of the "squeezing taxa" are deleted first. An example of the squeezing effect is given in figure 14.

LOGARITHM-TRANSFORMED ESTIMATES OF PROPORTIONS OF RARE TAXA

4.1 Estimating the numerical proportion of rare taxa

Counting some hundreds of specimens from a sample may yield only a few specimens of a rare taxon, or none at all. Especially in the case of rare taxa of stratigraphic or ecologic importance statistical conclusions are unsatisfactory if drawn from a low number of less than five. The estimate of the proportion will include too large a binomial error.

For rare taxa, the fixed number counts are inconvenient, unless one counted several thousands of specimens or even many more, which would be a waste of time and energy.

Without deletion of any score:

	all counts from laminated intervals	all counts from non-laminated intervals	all counts from the section
sums of scores of *G. subglobosa*	15	287	302
sums of scores of all other taxa	578	3103	3681
sums of the total numbers of the counts	593	3390	3983

$\chi^2 = 25$ $P_{99} = 6.6$ Hypothesis rejected

Deletion of the scores of *Oolina hexagona:*

	all counts from laminated intervals	all counts from non-laminated intervals	all counts from the section
sums of scores of *G. subglobosa*	15	287	302
sums of scores of all other taxa minus *O. hexagona*	290	3080	3370
sums of the total numbers of the counts after deletion of the scores of *O. hexagona*	305	3367	3672

$\chi^2 = 4.9$ $P_{99} = 6.6$ Hypothesis not rejected

Fig. 14 Scheme of the tests for independence between the relative frequencies of *Globocassidulina subglobosa* and both sediment types in the Capo Rossello section; fraction greater than 125 μ. Data from Brolsma, this volume.

A better procedure, practised during the last few years, can be summarized as follows. During a systematic examination of the contents of a tray or smear slide a number of at least ten individuals of the rare taxon under consideration is counted. An estimate is made of the total number of specimens in the searched area. From these two numbers a percentage value can be given for the rare taxon in the assemblage. The fact that the large number is not counted exactly introduces an extra error into the percentage estimate. As a consequence this method can be applied only for rare taxa.

This method was introduced by W. R. Riedel and applied to the Capo Rossello radiolaria (this volume). Afterwards some modifications were introduced and the statistical errors were taken into account. The modified form of this method of estimating was applied by Zachariasse and Schmidt (this volume).

In the more extensive description of the method in the following paragraphs special attention will be given to the calculation of the statistical errors.

4.2 "Logarithmic estimates" from a picking tray (foraminifera)

As shown in section 2.3, a number of N square fields are chosen from a split-residue distributed "evenly" over the tray (see figure 6). In each of these fields (planktonic) foraminifera are counted, the numbers being d_i, $i = 1, 2, \ldots, N$. From these d_i the mean $\bar{d}$ and the standard deviation SD_d are calculated.

The next step is to choose a number (M) of square fields which together are expected to cover a large enough area of the tray to contain at least ten specimens of the rare taxon under consideration. The number (K) of specimens present in the series of M fields is counted carefully.

The proportion of the taxon is evidently:

$$K/(M \cdot \bar{d}),$$

expressed in percentages:

$$p = \frac{100 \cdot K}{M \cdot \bar{d}}$$

Because low values in a wide interval between 0.01 and 5 per cent are considered, p is transformed to:

$$L = {}^{10}\log(p) = {}^{10}\log\left(\frac{100 \cdot K}{M \cdot \bar{d}}\right)$$

$(L = -2$ for $p = 0.01$, $L = -1$ for $p = 0.1$, $L = 0$ for $p = 1)$.

Now we will consider the statistical errors of L, the log-transformed proportion.

The statistical error of K is considered to be according to the binomial model:

$$\sqrt{\frac{K \cdot (M \cdot \bar{d} - K)}{M \cdot \bar{d}}}$$

See sections 1.4 and 3.1.
$M \cdot \bar{d}$, the estimate of the number of specimens present in the M fields, is so much greater than K that we may consider

$$\sqrt{K}$$

to be equally true for the statistical error.

Another error incorporated in L is induced by the estimate $M \cdot \bar{d}$. The deviation of the estimate of the density, $\bar{d}$, from its "real" value is indicated by the standard error of the mean:

$$SE_{\bar{d}} = \frac{SD_d}{\sqrt{N}}$$

The deviation of the real number of fossils in the M fields from M times the "real" density is indicated by the statistical error:

$$SD_d \cdot \sqrt{M}$$

So the deviation of $M.\bar{d}$ from the real number of fossils in the M fields is described by the resultant statistical error (1.3):

$$M \cdot SD_d \cdot \sqrt{\frac{1}{N} + \frac{1}{M}}$$

L and (±) the statistical error of L induced by K appear to be:

$$^{10}\log \left(\frac{100 \cdot (K \pm \sqrt{K})}{M \cdot \bar{d}} \right) = {}^{10}\log \left(\frac{100 \cdot K}{M \cdot \bar{d}} \cdot \frac{(K \pm \sqrt{K})}{K} \right) =$$

$$^{10}\log \left(\frac{100 \cdot K}{M \cdot \bar{d}} \right) + {}^{10}\log \left(\frac{K \pm \sqrt{K}}{K} \right) = L + {}^{10}\log \left(1 \pm \frac{1}{\sqrt{K}}\right) =$$

$$L \pm {}^{10}\log \left(1 + \frac{1}{\sqrt{K}}\right) \qquad L \pm \text{"binomial error"}$$

In a similar way it can be shown that the statistical error of L induced by $M \cdot \bar{d}$ is:

$$L \pm {}^{10}\log\left(1 + \frac{SD_d}{\bar{d}} \cdot \sqrt{\frac{1}{N} + \frac{1}{M}}\right) \qquad L \pm \text{"density error"}$$

The resultant statistical error of L is calculated according to the procedure described in section 1.3.

Example

In the investigation of the planktonic foraminifera (Zachariasse, this volume) a mean value $\bar{d} = 339$ and a standard deviation $SD_d = 144$ were calculated, based on 14 fields of a split of sample CRP 20. In a series of 9 square fields 37 specimens of *Globigerinoides obliquus* were found.

$$L = {}^{10}\log(p) = {}^{10}\log\left(\frac{100 \cdot 37}{9 \cdot 339}\right) = {}^{10}\log(1.21) = 0.084;$$

The binomial error: ${}^{10}\log\left(1 + \frac{1}{\sqrt{37}}\right) = {}^{10}\log(1.164) = 0.066$

The density error: ${}^{10}\log\left(1 + \frac{144}{339} \cdot \sqrt{\frac{1}{14} + \frac{1}{9}}\right) = {}^{10}\log(1.181) = 0.072;$

$$SE_R = \sqrt{(0.066)^2 + (0.072)^2} = 0.098;$$

so we give L with its statistical error:

$$L = 0.084 \pm 0.098$$

This means that there is a chance of close to 68 per cent that p is between the values

$10^{(0.084-0.098)} = 10^{-0.014} = 0.97$ per cent and $10^{(0.084+0.098)} = 10^{(0.182)} = 1.52$ per cent

It should be noted that ${}^{10}\log(1 + x) \sim (0.40) \cdot x$ for $|x| \ll 1$, for example ${}^{10}\log(1.164) = {}^{10}\log(1 + 0.164) \sim (0.40) \cdot (0.164) = 0.066$.

4.3 "Logarithmic estimates" from a smear slide (calcareous nannofossils)

As mentioned already in section 2.4 the lengths $x_1, x_2, \ldots, x_N$ of N tracks were recorded; from a smear slide containing calcareous nannofossils these lengths were needed to find a fixed number of n specimens. From these x_i the mean $\bar{x}$ and the standard deviation SD_x are calculated.

For any rare taxon a number K of at least ten specimens is counted and the traverse length X necessary for counting them is recorded. Since the relation $\frac{(K/X)}{(n/\bar{x})}$ may be clear, the proportion of the taxon, expressed in percentages, is:

$$p = \frac{100 \cdot K \cdot \bar{x}}{n \cdot X}$$

and log-transformed it is:

$$L = {}^{10}\log(p) = {}^{10}\log\left(\frac{100 \cdot K \cdot \bar{x}}{n \cdot X}\right)$$

If one considers the track length X fixed for a certain example, K has a statistical error, which according to the binomial model is:

$\sqrt{K}$ (see 4.2)

The formula for the statistical error of $(n.X)/\bar{x}$ (= estimate of the total number of nannofossils present on the track of length X) is given here without any further explanation (to be published elsewhere), but it shows a resemblance to that in the preceding section:

$$\frac{n \cdot X \cdot SD_x}{(\bar{x})^2} \cdot \sqrt{\frac{\bar{x}}{X} + \frac{1}{N}}$$

So the statistical error of L induced by K is:

$${}^{10}\log\left(1 + \frac{1}{\sqrt{K}}\right)$$ "binomial error"

and the one induced by $(n.X)/\bar{x}$ is:

$$^{10}\log\left(1 + \frac{SD_x}{\bar{x}} \cdot \sqrt{\frac{\bar{x}}{X} + \frac{1}{N}}\right) \quad \text{"density error"}$$

Example

Ten times 200 calcareous nannofossils were counted in a smear slide from sample CRP 39. The results gave $\bar{x} = 1.80$, $SD_x = 0.59$ (in mm). 34 specimens of *Discoaster brouweri* were found in a series of traverse lengths which if placed end on end would extend for 90 mm:

$$L = {}^{10}\log(p) = {}^{10}\log\left(\frac{100 \cdot 34 \cdot 1.80}{200 \cdot 90}\right) = {}^{10}\log(0.34) = -0.47$$

$$^{10}\log\left(1 + \frac{1}{\sqrt{34}}\right) = {}^{10}\log(1.17) = 0.068 \qquad \text{(binomial error)}$$

$$^{10}\log\left(1 + \frac{0.59}{1.80} \cdot \sqrt{\frac{1.80}{90} + \frac{1}{10}}\right) = {}^{10}\log(1.11) = 0.047 \qquad \text{(density error)}$$

$$SE_R = \sqrt{(0.068)^2 + (0.047)^2} = 0.083$$

so $L = -0.47 \pm 0.083$. There is a chance of close to 68 per cent that p is between $10^{-0.55} = 0.28$ and $10^{-0.39} = 0.41$ per cent.

4.4 Discussion

If the distribution over the tray or smear slide were "perfectly" even, the density error would be

$$^{10}\log\left(1 + \sqrt{\frac{1}{N \cdot \bar{d}} + \frac{1}{M \cdot \bar{d}}}\right)$$ for the tray, because $SD_d \sim SD_P = \sqrt{\bar{d}}$

and it would be

$$^{10}\log\left(1 + \sqrt{\frac{1}{n \cdot N} + \frac{\bar{x}}{n \cdot X}}\right)$$ for the smear slide, because

$$SD_x \sim SD_g = \frac{\bar{x}}{\sqrt{n}}$$

Note that $N \cdot \bar{d}$ and $M \cdot \bar{d}$ are the exact number in the N fields and the estimate of the number in the M fields respectively, and that $n \cdot N$ and $n \cdot X/\bar{x}$ are the

exact number in the N tracks and the estimate of the number in the track of length X respectively.

So, if the distribution of the fossils were even, the binomial error would be much larger than the density error. From the given examples it appears however, that both errors can be more or less equal, because evidently the supposition of evenness is not generally valid.

It should also be pointed out that this method of logarithmic estimates is most efficient if, as far as field counts on a tray are concerned, the number of fields M is greater than the number of fields N. If fewer fields are needed to determine the proportion of a taxon, it is more efficient to use part of the N fields from which the density has been estimated to count the number of specimens of the taxon because for these fields the total numbers are known exactly, so that on the log-transformed proportion L only a binomial error need be imposed.

It might even be advisable to start with exact counting per taxon on the N fields, and if this does not yield the required 10 specimens of a rare taxon, then one should look through (M - N) more fields. The density error will be smaller:

$$L \pm {}^{10}\log\left(1 + \frac{SD_d}{\bar{d}} \cdot \sqrt{\frac{1}{N} - \frac{1}{M}}\right)$$

Similar remarks can be made about microfossils on smear slides.

DIVERSITY INDICES

For the benthonic foraminifera Brolsma uses the Fisher α index to indicate the diversity of an assemblage of microfossils. This index is calculated from the total number of specimens (n) of a count from an assemblage, and from the number of taxa (S) recorded during the count (see Fisher et al., 1943, and Murray, 1973 for a graph in which the α values can be read directly). This index is used because it seems to be the most commonly used diversity index in paleontological literature. However, it should be pointed out that the assemblage may contain a high number of taxa that are so rare they will not show up in a limited count from the assemblage. In that case S is a doubtful measure, as is the Fisher α index.

The Fisher α index is based on an assumption about the proportions of the taxa in the assemblage. The proportions of the taxa must form an array of regularly decreasing values satisfying some property (the proportion of

the i-th taxon is a function of i and α). Such an assumption, however, is unreliable for many of the actual assemblages of microfossils. Diversity indices that take the "actual" proportions of the taxa from the assemblage into account seem to be preferable. None of them was applied to the Capo Rossello assemblages.

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BENTHONIC FORAMINIFERA

M. J. BROLSMA

INTRODUCTION

The objective of the study of the benthic foraminifera in the eight meter section of Capo Rossello was to check whether countings of individual taxa in the foraminiferal assemblages may be regarded as representative on the counting tray, for the entire sample, for the sediment layer and for the eight meter column.

First of all the supposed homogeneity of the distribution of the faunal elements in the size-fraction larger than 63 μ across the counting tray was checked. Secondly, for one of the samples the representativity of individual sample splits was analyzed. And thirdly, it was investigated whether the assemblage composition was consistent in a single layer.

Furthermore, the vertical frequency distribution of all species was analyzed, again in the fraction > 63 μ. Each assemblage was compared with the next higher one on the basis of a similarity coefficient, a diversity index and the benthos/plankton ratio. The possible association of the faunal assemblages with the two major types of lithology (laminated and non-laminated) was tested next. In addition, the numerical data in each sample for some of the frequent species were compared to the corresponding mean values in order to investigate the degree of homogeneity in vertical distribution throughout the eight meters as well as in smaller sediment intervals.

For paleoecological and biostratigraphical purposes the evaluation of the eventual results in terms of species names is often impossible by the taxonomic confusion in the literature. Therefore, the subjective character of the taxonomic determinations of four micropaleontologists – who volunteered for the comparison – was investigated on the basis of one and the same set of picked individuals.

Standing operating procedures in Utrecht consist of estimates of the numerical relations between individual taxa of the benthic fauna in the sieve-fraction larger than 125 μ, and are based on 200 counted individuals per sample. Since it is believed that excluding individuals of the 63 to 125 μ fraction implies the suppression of an important part of the information on the assemblage, additional estimates were made for all samples on the sieve-fractions larger than 63 μ, based on 100 individuals per sample. The

results of these two procedures were compared by means of the similarity coefficient for an equal number of representative samples of the two types of lithology.

Finally, it was checked whether different paleobathymetrical estimates would result from the countings of the different size-fractions.

The author is indebted to C. W. Drooger and M. M. Drooger for their continuous and stimulating help and criticism. The helpful interest of R. R. Schmidt, J. E. Meulenkamp and W. J. Zachariasse is gratefully acknowledged.

Most species dealt with in the following chapters have been illustrated by the author in another publication (Brolsma, 1978).

COUNTING ON THE TRAY

All samples were reduced with an Otto microsplitter, in order to obtain roughly the same total number of individuals per tray.

Several counting routines were critically examined, to test suspected differences in the distribution of the faunal elements on the counting tray. Foraminiferal tests may tend to cluster according to size and shape, causing an uneven distribution of species on the tray. Especially when the small 63 to 125 μ sieve-fraction is included, this problem of unequal distribution seems enlarged, as the fine material is seen to drop in clots on the tray.

Three counting techniques were applied to check the clustering effects and to obtain a relative evaluation of the "traverse-counting", which is the method we decided to maintain through the following parts of the investigation. These three techniques were applied to one of the samples, CRP 35, because it contains the largest number of benthonic specimens per 200 counted planktonic individuals (cf. fig. 17). Since already a small area of the counting slide was sufficient to reach the desired 200 specimens, the impact of clustering was expected to be largest. As most samples have low B/P ratios, clustering effects are probably smaller, since the entire counting slide or the major part thereof had to be examined before the desired total was attained.

The first count A was performed along two 1.5 mm-wide, engraved traverses forming an off-centre cross (fig. 1). On the same split the second count B was made, using the individuals in the three fixed squares of the slide, marked by crosses in fig. 1. The third count C followed about 80% of the perimeter strip of the slide. In all three counts 200 benthonic specimens were involved.

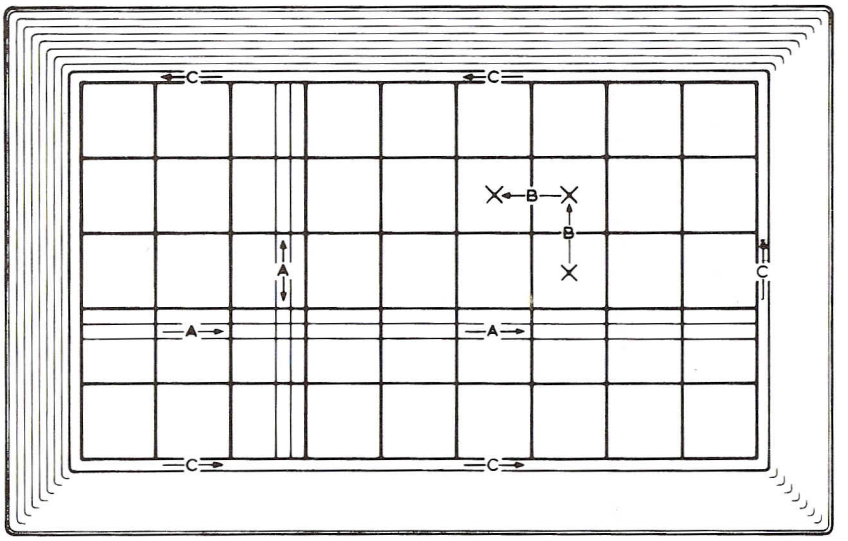


Fig. 1 Schematic drawing of the tray, showing the three ways of counting A, B and C.

A	B	C	species
2	–	–	*Anomalinoides ornata*
3	5	3	*Astrononion italicum*
2	1	2	*Bolivina advena*
2	1	–	*– antiqua*
23	33	18	*Bulimina elongata*
10	5	10	*Cibicides bradyi*
1	2	5	*– italicus*
3	2	1	*– lobatulus*
8	2	3	*Eggerella bradyi*
2	1	2	*Ehrenbergina trigona*
27	23	22	*Epistominella exigua*
7	7	1	*Florilus grateloupi*
1	–	2	*Fursenkoina schreibersiana*
15	15	19	*Globocassidulina subglobosa*
1	–	3	*Gyroidina orbicularis*
1	1	5	*– umbonata*
9	5	7	*Hanzawaia boueana*
1	3	1	*Lagena* spp/*Fissurina* spp.
5	–	–	*Melonis barleeanus*
1	1	–	*– soldanii*
1	–	–	*Nodosaria vertebralis* var. *albatrossi*
28	40	34	*Nuttallides rugosus* var. *convexus*
1	–	–	*Oolina hexagona*
5	3	2	*Oridorsalis stellatus*
2	5	5	*– umbonatus*
6	3	5	*Planulina ariminensis*
1	–	–	*– bradyi*
4	2	7	*Pleurostomella alternans*
1	–	1	*– rapa* var. *recens*
3	3	4	*Pullenia bulloides*
1	2	1	*– quadriloba*
1	–	1	*Rosalina globularis*
1	–	–	*Sigmoilina tenuis*
2	2	4	*Sigmoilopsis celata*
1	7	8	*Siphonina bradyana*
7	10	10	*Stilostomella adolphina*
1	1	1	*Valvulineria complanata*
–	1	–	*Ammonia beccarii*
–	1	–	*Bigenerina nodosaria*
–	1	–	*Dentalina communis*
–	1	2	*– filiformis*
–	1	–	*Dimorphina tuberosa*
–	2	–	*Gyroidina parva*
–	1	–	*Siphonina plano-convexa*
–	1	1	*Textularia* sp. cf. *T. candeina*
–	1	1	*Uvigerina proboscidea*
–	–	2	*Bolivina dilatata*
10	5	6	Indeterminable
37	37	34	Total number of species
200	200	200	Total number of specimens

Fig. 2 Distribution chart of the benthonic foraminifera in the counts A, B and C of sample CRP 35.

The results of the counts are shown in fig. 2. 37 species were identified in both counts A and B, and 34 in count C; this corresponds to Fisher α-values (Fisher et al., 1943; and Murray, 1973) of 12–14 and 12 respectively. The differences may be regarded as insignificant.

The similarity coefficient of Sanders (1960) between the three counts is relatively high (72.5–75.5%, fig. 3). This coefficient is the sum of the percentage values, based on the lower number of specimens for each taxon present in the two samples of the comparison.

Counts	Sanders	Jaccard
A-B	72.5	57.4
A-C	73.5	69.0
B-C	75.5	65.1

Fig. 3 Table showing the degree of similarity between the three counts A, B and C of sample CRP 35 by means of the Sanders coefficient (in %) and Jaccard coefficient (x 100).

The Jaccard coefficient of similarity only takes into account the number of species in common and not their frequencies. The values we multiplied with 100. The Jaccard coefficient may be summarized as $\frac{C}{N_1 + N_2 - C} \times 100$, in which C represents the number of species in common, N_1 and N_2 the numbers of species in counts 1 and 2, respectively (Jaccard, 1908; for a discussion see: Cheetham and Hazel, 1969). In our case similarity values were found between 57.4 and 69.0 (fig. 3). The low value of 57.4 for the comparison of counts A and B is not reflected in a correspondingly low Sanders coefficient, which is to be attributed to the numerical dominance of the species in common. In our example, the Sanders coefficients are much the same, the fairly great differences in Jaccard coefficients seem to be meaningless. The similarity index of Sanders (1960) was preferred during the later part of the investigation, because it takes into account the frequencies of the species.

To test the numerical differences for individual taxa between the three counts, the four most frequent species were used: *Nuttallides rugosus* var. *convexus, Bulimina elongata, Epistominella exigua* and *Globocassidulina subglobosa.* The hypothesis that the actual scores of the species fit the binomial model was tested by a chi-square statistic. The relevant data are shown in fig. 4 (for explanation of the standard deviation (SD) and the binomial standard deviation (SD_b), see M. M. Drooger, this volume).

The resulting chi-square values did not appear to be significant (level of

	Σx	$\bar{x}$	SD_b	SD	observed range x	χ^2
B. elongata	74	25	4.6	7.6	18–33	5.41
E. exigua	72	24	4.6	2.6	22–27	0.66
G. subglobosa	49	16	3.9	2.3	15–19	0.71
N. rugosus convexus	102	34	5.3	6.0	28–40	2.55

Fig. 4 Table showing the sums, means, standard deviations, observed ranges and χ^2 values of the four most frequent taxa in counts A, B and C of sample CRP 35.

significance $\alpha = 0.05$) and thus the hypothesis cannot be rejected. In other words, the distribution of the four most common taxa across the counting tray was sufficiently random to obtain comparable results from the three different counting procedures.

Summarizing, it may provisionally be concluded from our comparisons that clustering effects and sorting to size and shape cannot be shown to cause significantly different results between the three counting techniques. Too much reliance should not be placed, however, on the results of this single test.

In the following parts of our investigation the traverse-counting method A was applied, wherever possible. In poor samples, most of the contents of the entiry tray had to be counted.

DIFFERENT SPLITS FROM ONE SAMPLE

In order to investigate whether the counts of a sample split may be considered as representative for the entire sample, five splits of sample CRP 35 were processed with the same traverse-counting method. The five splits are labelled A, D, E, F and G. The numerical results of the counts are shown in figure 5. The number of species per 200 counted individuals for the five splits varies between 35 and 41. The Fisher α-index varies accordingly from 12 to 16. Comparison of all splits (fig. 6) shows the similarity coefficient values (Sanders, 1960) to be relatively high, varying between 70 and 81%.

Numerical differences between the five counts are best exemplified with the same four frequent species: *B. elongata, E. exigua, G. subglobosa* and *N. rugosus* var. *convexus*. Again the chi-square statistic does not lead to rejection of the hypothesis that the data fit the binomial model (fig. 7). The five splits seem to contain at least the four most common taxa in comparable

A	D	E	F	G	
2	–	–	–	–	*Anomalinoides ornata*
3	1	2	1	–	*Astrononion italicum*
2	1	4	–	1	*Bolivina advena*
2	4	1	2	3	*– antiqua*
23	14	23	27	24	*Bulimina elongata*
10	3	9	9	10	*Cibicides bradyi*
1	3	3	2	1	*– italicus*
3	2	1	3	–	*– lobatulus*
8	9	3	2	1	*Eggerella bradyi*
2	–	2	2	2	*Ehrenbergina trigona*
27	26	15	18	26	*Epistominella exigua*
7	4	–	1	–	*Florilus grateloupi*
1	–	1	1	–	*Fursenkoina schreibersiana*
15	15	20	22	18	*Globocassidulina subglobosa*
1	3	2	1	3	*Gyroidina orbicularis*
1	13	8	5	9	*– umbonata*
9	4	5	9	4	*Hanzawaia boueana*
1	5	3	3	3	*Lagena* spp/*Fissurina* spp
5	7	3	9	4	*Melonis barleeanus*
1	–	–	–	–	*– soldanii*
1	2	1	2	1	*Nodosaria vertebralis* var. *albatrossi*
28	36	45	37	39	*Nuttallides rugosus* var. *convexus*
1	–	–	–	–	*Oolina hexagona*
5	2	2	2	7	*Oridorsalis stellatus*
2	7	5	2	5	*– umbonatus*
6	6	5	10	6	*Planulina ariminensis*
1	–	–	–	–	*– bradyi*
4	3	4	1	5	*Pleurostomella alternans*
1	–	1	1	–	*– rapa* var. *recens*
3	1	2	1	4	*Pullenia bulloides*
1	–	1	–	–	*– quadriloba*
1	–	–	–	–	*Rosalina globularis*
1	–	1	–	–	*Sigmoilina tenuis*
2	1	–	1	–	*Sigmoilopsis celata*
1	5	3	–	2	*Siphonina bradyana*
7	8	6	10	6	*Stilostomella adolphina*
1	–	–	–	–	*Valvulineria complanata*
–	4	2	2	1	*Bolivina dilatata/spathulata*
–	1	–	–	1	*Cibicides refulgens*
–	1	–	–	–	*Dentalina communis*
–	1	1	–	1	*–* sp. cf. *D. emaciata*
–	1	–	–	–	*Discorbis* sp.
–	1	1	1	1	*Pullenia salisburyi*
–	3	–	–	1	*Vulvulina pennatula*
–	–	1	–	–	*Bolivina plicatella* var. *mera*
–	–	3	–	1	*Cassidulina crassa*
–	–	1	1	–	*Gyroidina parva*
–	–	1	–	–	*Lenticulina* sp.
–	–	1	1	4	*Pullenia quinqueloba*

A	D	E	F	G	
–	–	1	–	–	*Sphaeroidina bulloides*
–	–	–	1	–	*Bulimina costata*
–	–	–	1	2	*Dentalina filiformis*
–	–	–	2	–	*Dimorphina tuberosa*
–	–	–	–	1	*Anomalina helicina*
–	–	–	–	1	*Trifarina angulosa*
10	3	7	7	2	Indeterminable
37	36	41	35	35	Total number of species
200	200	200	200	200	Total number of counted specimens
13	13	16	12	12	Fisher α
A	D	E	F	G	species

Fig. 5 Distribution chart of the benthonic foraminifera in five splits of sample CRP 35.

	A	D	E	F	G
A	X	70	70	72.5	74
D		X	72	71	77
E			X	77.5	81
F				X	76
G					X

Fig. 6 Table showing the Sanders coefficients of similarity calculated for the five splits of CRP 35.

	Σx	$\bar{x}$	SD_b	SD	observed range x	χ^2
B. elongata	111	22	4.4	4.9	14–27	4.80
E. exigua	112	22	4.5	5.5	15–27	6.09
G. subglobosa	90	18	4.0	3.1	15–22	2.31
N. rugosus convexus	185	37	5.5	6.1	28–45	4.97

Fig. 7 Table showing the sums, means, standard deviations, observed ranges and χ^2 values for the four frequent taxa in the five splits of CRP 35.

proportions. However, the numbers of some less frequent taxa (*Eggerella bradyi* and *Gyroidina umbonata*) may contradict the equal distribution hypothesis for the five splits.

ASSEMBLAGES IN LATERAL SAMPLES

In order to gain an insight in the reproducibility of a faunal composition, e.g. in topotype samples, five samples were taken from the same layer of 5 cm thickness. These samples (CRP 22–26) were collected from the basal part of the third laminated unit at lateral distances of 1 to 1.5 m going in SSE direction from the sampled 8 meter column. Owing to the lateral discontinuity of laminae and to the fold structures at the base of this unit (see Brolsma and Broekman, this volume) the sediment sampled at each of the five spots may not cover the same group of laminae. Although this is a disadvantage inherent to the choice of this particular interval, the layer had the advantage of distinct lateral continuity and good accessibility.

From each sample one hundred benthonic specimens were counted in the fraction larger than 63 μ, instead of 200, because the assemblages proved to be not as rich as that of CRP 35. The numerical results are shown in fig. 8. Twelve to twenty-one species per 100 specimens were found, which numbers correspond to Fisher α-indices of 3.5 to 8 (fig. 9). These values are much smaller than those in the previous tests, which difference is thought to be related to the laminated nature of this sediment (see Brolsma, 1978). The variation in number of species in a lateral sense is rather small, except for sample 26 with only 12 species. In the table of fig. 10 it may be seen that the similarity coefficients between adjoining samples tend to be higher (probability level is 0.01) than between samples farther apart. The lower values suggest similarities below the range of coefficients (70–81) found in both earlier tests that were based on one sample.

The seven most common species are *Bolivina antiqua, Bulimina elongata, Epistominella exigua, Globocassidulina subglobosa, Nuttallides rugosus* var. *convexus, Oolina hexagona* and *Stilostomella adolphina.* The numerical variation of individual species in these five lateral samples seems to be rather large. For instance, for *B. antiqua* a minimum value of 5 was counted in sample 23 and a maximum of 17 in sample 25. For this reason, the standard deviation values were calculated and compared (fig. 11).

For all seven species the chi-square values did not lead to rejection of the hypothesis that these data fit the binomial model. For *G. subglobosa*, however, the probability level was rather low ($P \simeq 0.05$), and *B. antiqua* and *S. adolphina* are not that much better. The composition of the faunas, as

22	23	24	25	26	
1	4	8	4	2	*Bolivina advena*
16	5	15	17	13	– *antiqua*
12	23	20	26	21	*Bulimina elongata*
2	1	–	1	–	*Cibicides lobatulus*
3	4	2	–	–	*Eggerella bradyi*
7	8	3	5	2	*Epistominella exigua*
2	–	–	–	–	*Eponides repandus*
2	–	–	–	–	*Fursenkoina schreibersiana*
8	5	7	15	15	*Globocassidulina subglobosa*
1	–	–	–	–	*Gyroidina parva*
1	–	–	1	–	– *umbonata*
1	–	–	2	–	*Lagena* spp/*Fissurina* spp
3	–	–	–	–	*Martinottiella communis*
1	2	2	–	–	*Nodosaria vertebralis* var. *albatrossi*
10	7	4	4	3	*Nuttallides rugosus* var. *convexus*
11	17	18	13	23	*Oolina hexagona*
1	1	–	–	–	*Oridorsalis stellatus*
1	2	1	2	1	*Pleurostomella alternans*
4	3	2	–	–	– *rapa* var. *recens*
9	7	7	3	14	*Stilostomella adolphina*
1	–	–	–	–	*Valvulineria glabra*
	1	1	1	–	*Bolivina reticulata*
	1	–	–	–	*Glandulina laevigata*
	1	–	–	–	*Melonis barleeanus*
	1	–	–	–	*Planulina ariminensis*
	1	–	–	–	*Pullenia* spp
	3	–	–	–	*Vulvulina pennatula*
		2	–	–	*Astrononion italicum*
		3	–	1	*Cibicides bradyi*
		2	–	–	– *refulgens*
		1	–	–	– *robertsonianus*
			2	–	*Cibicides* sp. cf. *C. kullenbergi*
			1	1	*Gyroidina orbicularis*
			1	–	*Trifarina angulosa*
				2	*Cassidulina crassa*
3	3	2	2	2	Indeterminable
100	100	100	100	100	Number of counted specimens
21	20	17	17	12	Number of species

Fig. 8 Distribution chart of the benthonic foraminifera in the five samples from the basal few centimeters of the third laminated unit taken at lateral distances of 1.0–1.5 m (CRP 22–26).

well as the relative frequencies of single taxa, is fairly consistent in the five assemblages.

If one considers the small maximum lateral distance between the samples, five meters only, and the tendencies of difference in figures 10 and 11, no real positive answer can be given about the reliability of topotype samples. With greater distances in the same layer, patchiness in distribution and in density of the faunal elements on the sea bottom may be another cause for notable differences in faunal composition.

	S	α
22	21	8
23	20	7.5
24	17	6
25	17	6
26	12	3.5

Fig. 9 Table showing the numbers of species per 100 counted specimens and the resulting Fisher α-values, samples CRP 22–26.

	22	23	24	25	26
22	X	65	66	64	60
23		X	73	66	63
24			X	71	74
25				X	74
26					X

Fig. 10 Table showing Sanders coefficients of similarity between the five lateral samples CRP 22–26.

	Σx	$\bar{x}$	SD_b	SD	observed range x	χ^2
B. antiqua	66	13	3.4	4.8	5–17	8.10
B. elongata	102	20	12.0	5.2	12–26	0.76
E. exigua	25	5	2.2	2.5	2– 8	5.47
G. subglobosa	50	10	3.0	4.7	5–15	9.77
N. rugosus convexus	28	6	2.3	2.9	3–10	6.27
O. hexagona	82	16	3.7	4.7	11–23	6.36
S. adolphina	40	8	2.7	4.0	3–14	8.69

Fig. 11 Table showing the sums, means, standard deviations, observed ranges and χ^2 values of seven of the most prominent taxa in the five lateral samples CRP 22–26.

Another aspect of our investigation concerns the subjectivity of the taxonomic determinations of individual (micro)paleontologists. Available information in the literature, expressed in species names, is thought to be useless in many cases owing to suspected differences in taxonomic appreciation. In order to gain an insight in the differences between specialists in taxonomic determinations, a set of 200 specimens from sample CRP 35D, specifically determined and counted by the present author, was subsequently sent to R. Wright (Tallahassee), G. F. Lutze (Kiel) and finally to A. A. H. Wonders (Utrecht), who made their own determinations and countings. The randomly arranged 200 specimens in the Chapman slide were independently studied and interpreted. It should be noted that the number of specimens in the slide decreased from 200 to 157 during the various counting procedures and transport, which may explain some of the differences, but certainly not all. All three mentioned colleagues volunteered to participate in this test on subjectivity, and, agreeing on the importance of the results, authorized the present author to publish the results.

Nearly all picked specimens were about 100 μ in diameter and, thus, well below the size of specimens generally figured to illustrate species in standard taxonomic literature. Moreover, most figures of smaller species are inadequate for precise identification.

The degree of experience of the four paleontologists with Neogene, Mediterranean foraminifera was considerably different. Lutze had most experience in quantitative work on Neogene foraminifera from the deep-sea outside the Mediterranean and in the fraction larger than 250 μ. Because of his work on larger specimens Lutze was practically unacquainted with most of the small species from the Trubi material. Wonders was not acquainted with Trubi foraminifera but he was familiar with Lower Pliocene faunas elsewhere in the Mediterranean, though in size-fractions larger than 125 μ. Wright and Brolsma had more similar experience. Both extensively studied Trubi foraminifera, including those from the smaller fractions. Wright concentrated on D.S.D.P. material from legs 13 and 42A, whereas Brolsma's experience was based on land-sections in Sicily.

It is therefore not surprising that the results differ considerably (figs. 12–14). A less pessimistic impression of the subjective character of species labelling by individual micropaleontologists may be obtained if the determinations of equally experienced specialists are compared who have studied the same type of material over a longer period of time.

On the species level (fig. 12) Wright identified 51 different taxa, Lutze

M. J. Brolsma %	R. C. Wright %	G. F. Lutze %	A. A. H. Wonders %	Sample CRP 35D
–	1	–	–	*Amphicoryna scalaris*
–	1.5	–	–	*Anomalina cicatricosus*
–	1.5	–	–	– sp.
–	0.5	–	–	*Anomalinoides badensis*
–	0.5	–	–	– *flinti?*
–	1	–	–	*Bolivina albatrossi*
–	1	–	–	– *catanensis*
–	0.5	–	–	– *compacta*
–	0.5	–	–	– *reticulata*
2	0.5	–	0.6	– *spathulata*
–	7	–	–	*Bulimina affecta*
7.5	6	6	7.0	*Cassidulina subglobosa*
–	2	–	–	*Cibicides westi*
–	1.5	–	–	– sp.
1.5	0.5	–	–	*Cibicidoides bradyi*
–	0.5	–	–	– sp. cf. *C. kullenbergi*
0.5	0.5	–	0.6	*Dentalina communis*
0.5	0.5	–	–	*Discorbis* sp.
4.5	2.5	–	–	*Eggerella bradyi*
13	8	–	5.1	*Epistominella exigua*
–	0.5	–	–	– sp.
–	0.5	–	–	*Eponides? pusillus*
–	1.5	–	–	*Eponides schreibersii*
–	1	–	–	– sp.
–	0.5	–	–	*Gaudryina* sp.
–	1.5	–	–	*Gyroidina altiformis*
1.5	8	–	–	– *orbicularis*
–	0.5	–	8.3	– *soldanii*
–	1.5	–	–	– sp.
2	0.5	–	1.9	*Hanzawaia boueana*
–	0.5	–	–	*Hyalinea balthica*
–	0.5	–	–	*Nonionella* sp.
18	16	–	18.5	*Nuttalides rugosus (convexus)*
–	1	–	–	*Oolina acuticosta*
–	0.5	–	–	– *clavata*
–	0.5	1	–	– *laevis*
3.5	4	4	4.5	*Oridorsalis umbonatus*
–	0.5	–	–	*Orthomorphina* sp.
3	1	–	3.8	*Planulina ariminensis*
–	1	–	–	*Pleurostomella acuminata*
1.5	0.5	–	–	– *alternans*
–	0.5	–	–	*Pullenia osloensis*
0.5	0.5	–	0.6	– *salisburyi*
–	0.5	–	–	– sp.
–	0.5	–	–	*Sigmoilopsis schlumbergeri*
–	1	–	–	*Siphonina reticulata*
–	1	–	1.3	*Sphaeroidina bulloides*
–	0.5	–	–	*Stilostomella annulidera*

M. J. Brolsma %	R. C. Wright %	G. F. Lutze %	A. A. H. Wonders %	Sample CRP 35D
–	3	–	–	– *antillea*
–	1	6	–	– *lepidula*
1.5	0.5	–	0.6	*Vulvulina pennatula*
0.5	–	–	–	*Astrononion italicum*
0.5	–	–	–	*Bolivina advena*
2	–	–	1.3	– *antiqua*
7	–	–	6.4	*Bulimina elongata*
1.5	–	–	–	*Cibicides italicus*
1.5	–	–	1.3	– *lobatulus/refulgens*
0.5	–	–	–	*Dentalina* sp. cf. *D. emaciata*
0.5	–	–	–	*Dimorphina tuberosa*
2	–	–	–	*Florilus grateloupi*
6.5	–	13	3.9	*Gyroidina umbonata*
2.5	–	–	–	*Lagena* spp./*Fissurina* spp.
3.5	–	–	–	*Melonis barleeanus*
1	–	–	–	*Nodosaria vertebralis* var. *albatrossi*
1	–	–	–	*Oridorsalis stellatus*
0.5	–	0.5	–	*Pullenia bulloides*
0.5	–	–	–	*Sigmoilopsis celata*
2.5	–	–	–	*Siphonina bradyana*
4	–	–	1.3	*Stilostomella adolphina*
		2	–	*Bolivina* ex. gr. *dilatata* s.l.
		2	–	*Bolivina* spp.
		6	–	*Buliminella* sp. ex. gr. *tenuata*
		2	–	*Cibicides/Hanzawaia* spp.
		0.5	–	*Dentalina* fragment
		19	–	*Epistominella* (?) sp. cf. *E. minuta*
		16	–	*Epistominella* ex. gr. *exigua*, cf. *tamana*
		1.5	–	*Fursenkoina?* sp.
		0.5	–	*Nodosaria* fragment
		1	–	*Oolina* (?) *sulcata* (?)
		0.5	0.6	*Pullenia* sp. cf. *P. quinqueloba*
			3.2	*Alabamina* sp.
			1.3	*Amphicoryna ? proxima*
			0.6	*Anomalina helicina*
			2.5	*Bolivina appenninica*
			0.6	*Cibicides ungerianus*-group
			4.5	*Eponides haidingeri*
			0.6	*Nodosaria* sp.
			5.1	*Nonion soldanii*
			1.3	*Pleurostomella* sp.
			3.2	*Stilostomella* sp.
			1.2	*Textularia* spp.
1	7.5	19	8.2	Indeterminable
36	51	17	32	Total number of species
200	191	176	157	Total number of counted specimens
12–14	20–25	4–5	12–14	Fisher α-index

Fig. 12 Distribution chart of the benthonic foraminiferal species in four counts of the same material, carried out by Brolsma (Utrecht), Wright (Tallahassee), Lutze (Kiel) and Wonders (Utrecht). The results are expressed as percentages of the total number of specimens available to the examiners.

M. J. Brolsma %	R. C. Wright %	G. F. Lutze %	A. A. H. Wonders %	Sample 35 D
–	1	–	1.3	*Amphicoryna*
–	3	–	0.6	*Anomalina*
–	1	–	–	*Anomalinoides*
4.5	3.5	4	4.4	*Bolivina*
7	7	6	6.4	*Bulimina/Buliminella*
7.5	6	6	7	*Cassidulina*
3	3.5	2	1.9	*Cibicides*
1.5	1	–	–	*Cibicidoides*
1	0.5	0.5	0.6	*Dentalina*
0.5	0.5	–	–	*Discorbis*
4.5	2.5	–	–	*Eggerella*
13	8	35	5.1	*Epistominella*
–	3	–	4.5	*Eponides*
–	0.5	–	–	*Gaudryina*
8	12	13	8.3	*Gyroidina*
2	0.5	–	1.9	*Hanzawaia*
–	0.5	–	–	*Hyalinea*
–	0.5	–	–	*Nonionella*
18	16	–	18.5	*Nuttallides*
–	2	1	–	*Oolina*
4.5	4	4	4.5	*Oridorsalis*
–	0.5	–	–	*Orthomorphina*
3	1	–	3.8	*Planulina*
1.5	1.5	–	1.3	*Pleurostomella*
1	1.5	1	1.2	*Pullenia*
0.5	0.5	–	–	*Sigmoilopsis*
2.5	1	–	–	*Siphonina*
–	0.5	–	1.3	*Sphaeroidina*
4	4.5	6	4.5	*Stilostomella*
1.5	0.5	–	0.6	*Vulvulina*
0.5	–	–	–	*Astrononion*
0.5	–	–	–	*Dimorphina*
2	–	–	–	*Florilus*
2.5	–	1	3.9	*Lagena/Fissurina*
3.5	–	–	5.1	*Melonis*
1	–	0.5	0.6	*Nodosaria*
		1.5	–	*Fursenkoina ?*
			3.2	*Alabamina*
			1.2	*Textularia*
1	7.5	19	8.2	Indeterminable
36	51	17	32	Total number of species
200	191	176	157	Total number of counted specimens
12–14	20–25	4–5	12–14	Fisher α-index

Fig. 13 Distribution chart of the genera of benthonic foraminifera in four counts of the same material, carried out by Brolsma (Utrecht), Wright (Tallahassee), Lutze (Kiel) and Wonders (Utrecht). Data expressed in percentage values.

only 17. Wonders and Brolsma recognized 32 and 36 species respectively, numbers intermediate between those of the other two. Lutze and Wright gave the same names to 4 species; Wonders and Brolsma to 15 species. Wright, Lutze and Brolsma had only 2 species names in common, Wright, Wonders and Brolsma 10. Only two species names (*(Globo)cassidulina subglobosa* and *Oridorsalis umbonatus*) were used by all four specialists. In fig. 14 these relations have been depicted in a pyramid projection.

At the generic level (fig. 13) there is better agreement. Wright recognized 30 genera, Wonders and Brolsma 25 and Lutze 14. The most frequent groups of species were recognized by all four cooperators although in many instances under different names. Wright and Brolsma had 20 generic names in common. Ten genera were shared by all four (fig. 14b).

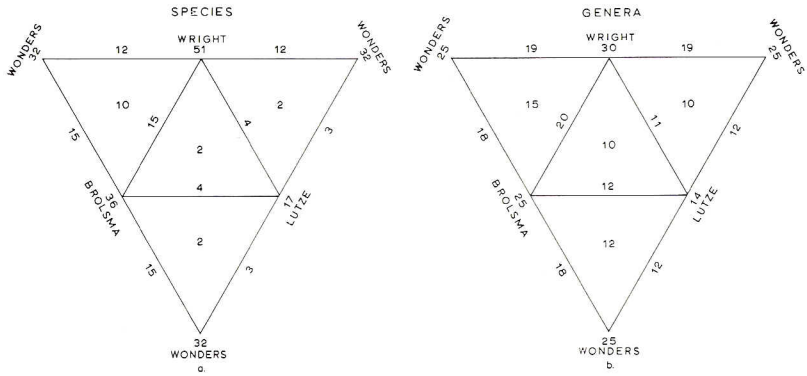


Fig. 14a Pyramid projection showing the numbers of names of benthonic species the four collaborators had in common.

Fig. 14b Pyramid projection showing the numbers of generic names the four collaborators had in common.

Using the percentage values of the species in the test-assemblage the degree of similarity between the determinations of the four was calculated by means of the Sanders coefficient. The similarity values, shown in fig. 15,

	Wright	Brolsma	Lutze	Wonders
Wright	X	60	53	55
Brolsma		X	59	64
Lutze			X	53
Wonders				X

Fig. 15 Table showing the Sanders coefficients of similarity based on the numbers of specimens which received the same species name from the four examiners in the subjectivity test.

appear to be low, but they are more satisfactory than those of the comparisons through the Jaccard method, i.e., based on taxonomic units of equal weight. The results of the two Utrecht collaborators are closest, which may suggest that school relationship is more important than experience with the same faunas.

These differences in lists of species names in the order of up to 75%, and in determination of specimens of 35–45%, must be considered as extreme. One may wonder, however, whether the errors caused by combining lists of species names by different specialists or from the literature permit conclusions of sufficient reliability in paleoecological or biostratigraphic correlations.

The four paleobathymetrical estimates for the CRP 35 D assemblage, given independently by the four collaborators, are in good harmony for the two most experienced Trubi investigators (Wright and Brolsma) and rather deviating for the other two. Wright's depth estimate of 500–800 m overlaps that of Brolsma (cf. Brolsma, 1978) of 500–1000 m. Wonders estimated the depth to have exceeded 200–300 m. Lutze compared his data with a zonation off West Africa (Lutze, 1977 MS) and concluded to a depth of more than 1500 m.

FREQUENCY FLUCTUATIONS ALONG THE COLUMN

For all samples the frequency distributions of most taxa in the fraction larger than 63 μ, are shown in fig. 16. The similarity coefficient values calculated for each pair of the vertically successive samples are shown in fig. 17; they vary from 32% to 85%, most are between 40% and 70%. Minimum values are found for pairs straddling laminated/non-laminated boundaries, maximum values for pairs of adjoining samples within either laminated or non-laminated intervals. The lowermost laminated interval is exceptional in the high similarity coefficient values of 84% and 85% between samples 9 and 10, and 11 and 12, respectively.

If one considers the similarity coefficient values for different counts in one sample (> 70) and from one layer (> 60), the values found for most of the pairs suggest that the assemblages are actually different from one sample to the next higher one. Apart from the obvious differences in benthic faunal composition between laminated and non-laminated sediments, incongruities in composition exist within the sediments of similar lithology as well.

The Fisher α-values seem to be arranged in a gradual, fluctuating pattern

with minimum values in the laminated and maximum values in the non-laminated sediments.

The number of benthonic specimens per 200 counted planktonic individuals is low in both types of sediment (B/P ratios in fig. 17). In clayey intercalations (samples 34 and 35) the benthonics are most numerous. Minimum values are reached in the laminated intervals. It should be noted, however, that these results are based on the coarser fraction, since the abundance of juvenile plankton in the fraction between 63 and 125 μ did not allow reliable countings to estimate the B/P ratios in total fractions.

FAUNAL CHARACTERISTICS IN THE LAMINATED AND NON-LAMINATED INTERVALS

The numerical proportion of each species in the fractions larger than 63 μ was tested for its association with either the laminated or the non-laminated character of the sediments. Therefore, the sums of the respresentatives of each species in each of the two sediment groups were calculated; these have been entered in the bottom rows of fig. 16. The chi-square test for independence was applied to test the hypothesis that the numerical population proportions of the species are the same for both sediment groups. The species with χ^2 values exceeding 6.63, which corresponds to the 99th percentile of the chi-square distribution with one degree of freedom, are regarded to be associated with either one or the other of the two sediment-types. From both left hand columns in fig. 18 it may be concluded that only three species seem to have a higher level of tolerance for the conditions that prevailed during deposition of the laminated sediments: *Oolina hexagona, Globocassidulina subglobosa* and *Martinottiella communis.* A much greater number, 19 species or groups of species, appear to be associated with the non-laminated sediments.

In the same way a chi-square test for independence was made for the counts in the fraction larger than 125 μ for the species also present in the previous 63 μ counts. In fig. 18 (third and fourth columns) only the chi-square values larger than 6 have been entered. From this picture it appears that from the 19 species which are associated with the non-laminated sediments in the smaller size fraction, four are absent, two had been assigned to different taxonomic categories, and seven show no affinity whatsoever to either sediment group in the larger fraction. Six species remain to show affinities for the non-laminated sediment group in this set of counts.

O. hexagona is found to be predominant in the laminated deposits, in both size-fractions. *M. communis,* which in the smaller fraction is clearly associated with the laminated deposits, shows no association in the larger

Laminated intervals	Samples	Arenaceous forms	Bolivina advena	B. antiqua	B. inflata	B. spp.	Bulimina elongata	Cibicides bradyi	C. spp.	Epistominella exigua	Globocassidulina subglobosa	Gyroidina orbicularis/soldanii	G. umbonata	Lagena spp./Fissurina spp.	Martinottiella communis	Neoconorbina williamsoni	Melonis barleeanus	Nuttalides rugosus var. convexus	Oolina hexagona	Oridorsalis stellatus	O. umbonatus	Planulina arimiensis	Sigmoilina tenuis	Uvigerina proboscidea	Valvulineria glabra	Astrononion italicum	Bolivina dilatata
	45		11	5			2	5	1	16	8		1	1			1	5	7		1		2			2	
6	44	1	14				6	1		12	3				6	1			41								
	43	1	12	2					1	10	7	2				4	3	16	3						1	6	2
	42			3	3		13	1	2	8	14		4	2			1	8		1	2		1			1	
	41		3	7		1	12	1	1	9	7		3			2	1	15		3	3	1	2		1		2
	40	2	5	7		1	9	6	1	11	9	1	2	3		2		7	2	1	2	2					
	39		1	8	6		7		2	12	21		1	2		1	1	9				3				4	
	38	1	6	6		1	7	2	1	18	11		1	1			6	4	3				2		2		2
5	37	1	22	1			12	1		6	4				5			4	36			1		1	1		
	36	1	11				13	1		26	1		1	2	5		3	2	5			1				1	4
	35	3		1			12	2	1	11	6	1	1				3	23	2	3	2	3		1	1	1	
	34	2	1	2			9	6	1	4	19	3	1	1			1	16		7	3	3	1			1	
	33	1	7	1		1	2	5	1	13	7		5	1			2	16	9	3		3	2		1	1	
	32		1	1			3	9	2	21	3		2				2	18	4		3	2			2	4	
	31		4	10		1	1	3	1	9	7			1				9	13		1		8		2	1	
4	30	2	4	5		2	5	2		4	8				3			4	38	1			1				
	29a			5			5			10	5				1				51			1				1	
	29	1	3	3		1	10	1		7	6		1	1	1			2	43	1	1	1	2	1	1		
	28			5	1	1	4	2		10	6		3	5			3	17	4	5		2	1			2	
3	27		10	4	3		12			2	14				4			3	28	1	2	1				1	
	22			16	1		12			7	8		1	1	3			10	11	1					1		
	21	2	3	6		1	10			2	14		5	3			1	24		12		3	2				
	20	1	3	2	1	2	3	1	1	11	18	1	4	1	1	1	1	10	12	2					4	1	
2	19	1	1	1			2			4	22		1					2	61				1	1			
	18		4	3		1	3			11	22		1	1	1		1	3	26	1					1		
	17	1	2	4		2	2	3	2	8	23		3			1		8	1	2	2		4		1	2	
	16	2	2	5		1	6	3	2	8	11		1	1		1	3	13		7	3	3	2	1			
	15	3	1	3	1		8	4		14	12		3	2				10	1	5	2	4					
1	14		5		6		9			6	25				2			3	30			1					2
	13	2	3		1	1	2		2		13			2	1			1	69			1					
	12	1	2	5	3		8			2	27				3			2	45								
	11		1	1	2		5			6	34				4			2	41								
	10		2		1		6			8	17				7			1	55								
	9		4	2			6	1		6	22				2		1	1	49	1							
	8a		1		1		4	1		17	23							4	31	1						1	4
	8	2	8	3	1	1	2	2	1	10	15	1	3	1	1	1	5	8	22	2	2	1	5	1	1		
Non laminated $\bar{x}$		1.10	3.68	4.26	0.68	0.68	5.89	2.89	1.10	10.78	11.47	0.47	2.26	1.31	0.10	0.68	1.78	12.42	4.36	2.78	1.36	1.57	1.68	0.15	0.84	1.36	0.31
Laminated $\bar{x}$		0.58	5.11	2.7	1.05	0.29	7.05	0.47	0.12	7.88	14.94		0.29	0.41	2.82	0.05	0.29	2.58	38.82	0.41	0.17	0.41	0.23	0.17	0.23	0.23	0.58
Non laminated		21	70	81	13	13	112	55	21	205	218	9	43	25	2	13	34	236	83	53	26	30	32	3	16	26	6
Laminated		10	87	46	18	5	120	8	2	134	254		5	7	48	1	5	44	660	7	3	7	4	3	4	4	10

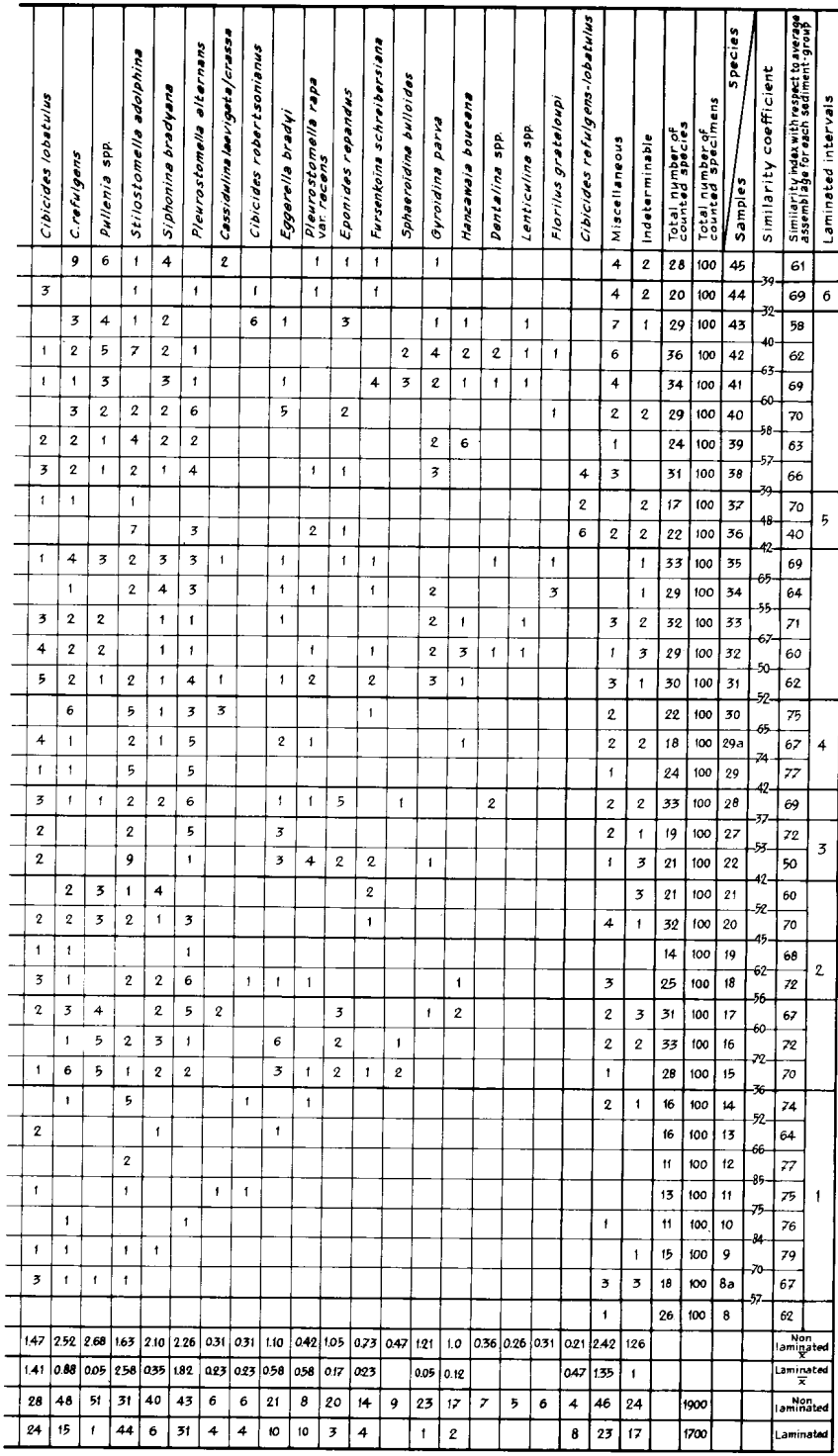


Fig. 16 Distribution chart of the benthonic foraminifera in the size fraction larger than 63 μ for the eight meter section of the Trubi at Capo Rossello. At the bottom four rows show the sums and mean values of representatives of each species per sediment group.

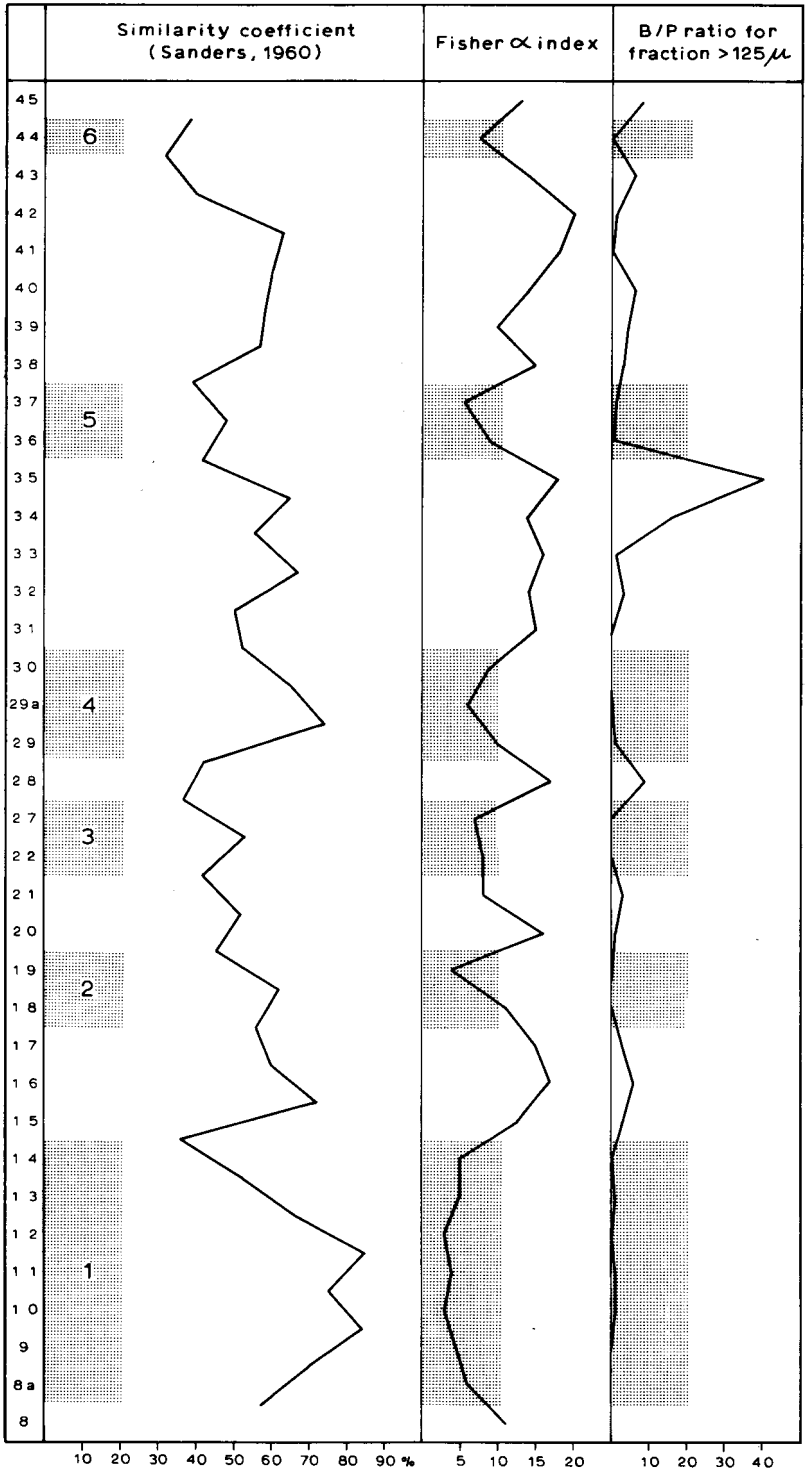


Fig. 17 The similarity coefficient values between the pairs of vertically successive samples, the Fisher α-indices and the B/P ratios for the entire length of the 8 meter section. The B/P ratio was estimated for the size fraction larger than 125 μ. The laminated intervals are indicated by dotted bands.

	First test				Second test			
	Fraction > 63 μ		Fraction > 125 μ		Fraction > 63 μ		Fraction > 125 μ	
	non-lam.	lam.	non-lam.	lam.	non-lam.	lam.	non-lam.	lam.
Astrononion italicum	13.94							
Cibicides bradyi	30.67		22		12.1			
Cibicides refulgens	14.1							•
Cibicides spp.	13.78		absent		6.2		absent	
Epistominella exigua	8.89					7.6		
Eponides repandus	10.85		absent				absent	
Globocassidulina subglobosa		9.45	25			73.6**		
Gyroidina parva	17.97		absent		9.3		absent	
Gyroidina umbonata	26.44				11.1			
Hanzawaia boueana	10.32							
Lagena spp./*Fissurina* spp.	8.32							
Martinottiella communis		48.39				91.7		
Melonis barleeanus	18.72		no data		7.3		no data	
Neoconorbina williamsoni	9.05		absent				absent	
Nuttallides rugosus var. *convexus*	120.95		absent		42.8		absent	
Oolina hexagona		649.86		1608		650.4*		1608*
Oridorsalis stellatus	30.95		35		12.7		9.8	
Oridorsalis umbonatus	15.95		6		6.8			
Planulina ariminensis	12.01		19					
Pullenia spp.	43.44		27		23.3			
Sigmoilina tenuis	19.02				7.9			
Siphonina bradyana	21.84		61		8.6		12.6	
Uvigerina proboscidea				45				119.1
Bolivina advena						38.1		
Bolivina inflata						8.8		
Bulimina elongata						40.8		
Stilostomella adolphina						23.1		•
Bolivina plicatella var. *mera*								•
Elphidium spp.								•
Nodosaria vertebralis var. *albatrossi*								•
Pleurostomella alternans								7.5
Vulvulina pennatula								71.2

Fig. 18 χ^2 values for 32 benthonic species or groups of species, indicating the association with one of both sediment types. Values are entered for two different size fractions. In the second test the total number of counted specimens per sediment group is corrected for squeezing effects, caused by the two predominant species *O. hexagona* and *G. subglobosa*.
** indicates scores of *O. hexagona* deleted only; * no deletion of scores; • significant association of a fairly rare taxon.

fraction with either of the two sediment groups. Most peculiar is the reversed association of *G. subglobosa,* in the smaller fraction with the laminated, in the larger fraction with the non-laminated sediments. *Uvigerina proboscidea* is clearly associated with the laminated sediments in the larger fraction, whereas no correlation of this taxon with either sediment group was observed in the smaller fraction.

Close inspection of the actual numbers per taxon in fig. 16 raised the question whether some of these taxa are not too abundant to justify the conclusions given above.

For the > 63 μ fraction, the total number of counted specimens from all laminated samples is 1703, *Oolina hexagona* scores 660, *Globocassidulina subglobosa* 254. In all non-laminated samples together, these numbers are 1903, 83 and 218, respectively. For the > 125 μ fraction, the total number of counted specimens from all laminated samples is 593, *Oolina hexagona* scores 288. For all non-laminated samples in the > 125 μ fraction, these numbers are 3390 and 23, respectively.

Realizing that the numbers of *O. hexagona* and *G. subglobosa* in the > 63 μ fraction, and the numbers of *O. hexagona* in the > 125 μ fraction may cause a squeezing effect (see M. M. Drooger, this volume), the calculations were repeated on the basis of the comparisons of the sum of each taxon with the corrected totals 1703 – 660 – 254 = 789 and 1903 – 83 – 218 = 1602 of the laminated and non-laminated groups of sediments respectively (fraction > 63 μ). A similar procedure was carried out for the larger fraction for both sediment groups, using the totals of 593 – 288 = 305 for the laminated, and of 3390 – 23 = 3367 for the non-laminated intervals. The test for *G. subglobosa* was performed by comparison with the total number of specimens per sediment group minus the *O. hexagona* scores. The results have been entered in the four left hand columns of fig. 18.

For some of the less frequent species, the scores were tested with Fisher's exact test (see M. M. Drooger, this volume) and significant results have been entered as black dots in fig. 18. A probability level of 0.01 was applied.

For the > 63 μ fraction eight species, five of which new, now appear to have a higher level of tolerance for the conditions that prevailed during deposition of the laminated sediments: *Oolina hexagona, Globocassidulina subglobosa, Martinottiella communis, Epistominella exigua, Stilostomella adolphina, Bolivina advena, Bolivina inflata* and *Bulimina elongata. E. exigua* even shifts from the non-laminated to the laminated column. Ten species or groups of species remain to show an association with the non-laminated sediments, amongst which two *Gyroidina* and two *Oridorsalis*

species, the *Pullenia* group, *Siphonina bradyana* and *Nuttallides rugosus* var. *convexus*. If one considers the ecologic preference of the species involved, the new results seem to make more sense (Brolsma, 1978) than those from the first test.

For the fraction $> 125\ \mu$, it appears that of the 10 species associated with the non-laminated sediments in the smaller size fraction, two are absent and five show no affinity whatsoever with either sediment group. Only two species remain to show affinities to the non-laminated sediment group in this set of counts (*S. bradyana* and *O. stellatus*).

Six species, which in the smaller fraction were clearly associated with the laminated deposits, show no association in the larger fraction with either one or the other of the sediment groups. The entire *Bolivina/Bulimina* group has disappeared. Only two species (*O. hexagona* and *S. adolphina*) remain associated with the laminated deposits in this larger fraction. However, seven additional species appear to show links with the laminated sediments in this larger fraction, amongst which another *Bolivina* species, and other presumably mud-dwelling forms such as *Uvigerina proboscidea, Vulvulina pennatula, Nodosaria vertebralis* var. *albatrossi* and *Pleurostomella alternans*. Aberrant forms in the association from the ecological point of view are the *Elphidium* group and *Cibicides refulgens*. The latter species is a well-known epiphytic form, and the main habitat of the former group is in shallower water.

Brolsma (1978) suggests oxygen depletion to have been responsible for the deterioration of the bottom environment during accumulation of the laminated sediments. The preference of the *Bolvina-Bulimina* group for these laminated deposits might indicate a higher degree of tolerance for the adverse bottom conditions. Apparently *O. hexagona* tolerated this unfavourable environment best. The dwarfing effects as a result of the extreme conditions can be distinctly observed in this taxon as well as in the *Bolivina-Bulimina* group. Similar effects may be concluded for *G. subglobosa, M. communis* and *E. exigua*. No such influence seems to have acted upon *U. proboscidea* and the other six species, which turned up in significantly higher numbers in the larger fraction. A preference of arenaceous forms for the oxygen-depleted environment is not evident. Arenaceous forms are associated with both sediment groups. The epiphytic *C. refulgens* may be an allochthonous element, which only shows an association with the laminated deposits due to the relative scarcity of the original population at the bottom. The association of the *Elphidium* group with the laminated deposits cannot be explained.

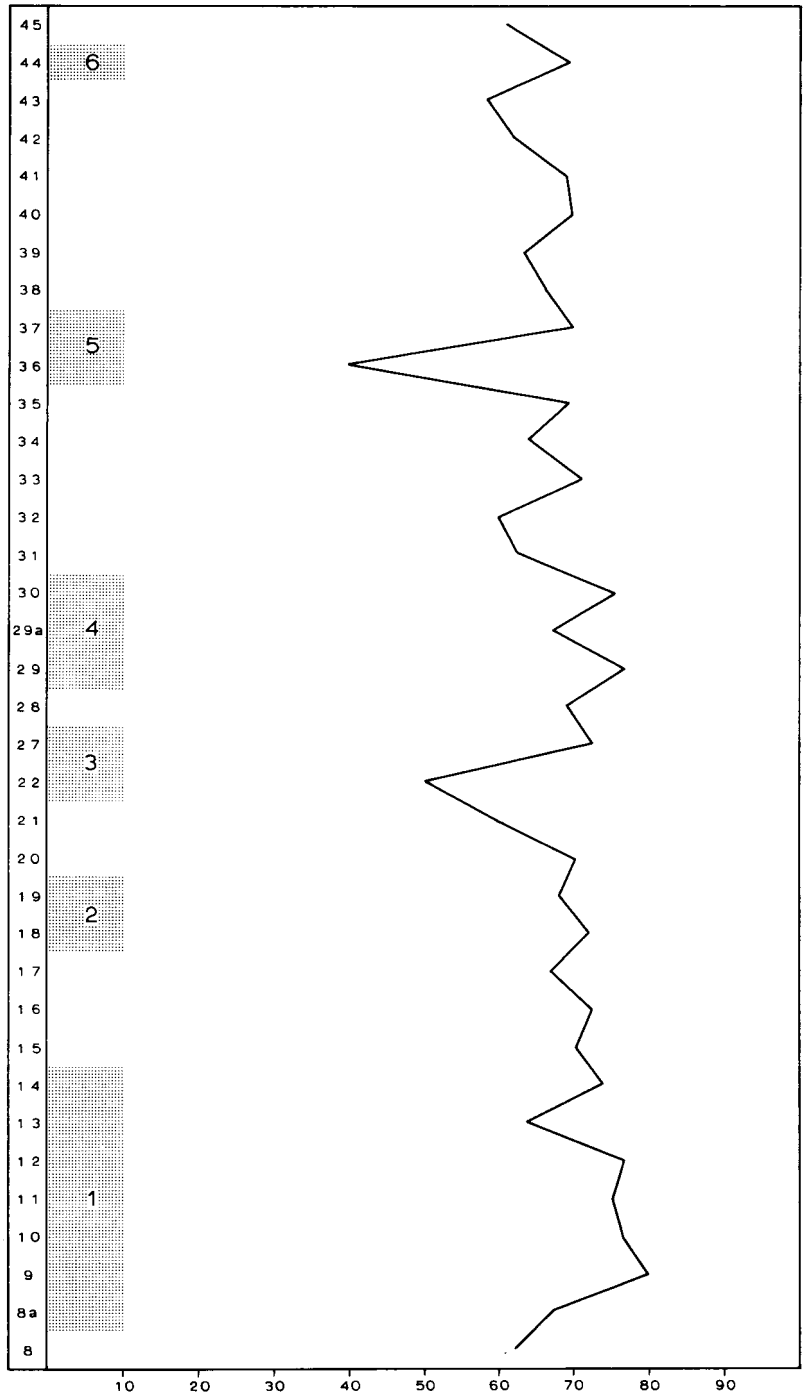


Fig. 19 Similarity coefficient values between the idealized, average assemblage of each of both sediment groups and the actual assemblage of each sample.

AVERAGE FAUNAL COMPOSITION

The mean number of representatives of each species per laminated or non-laminated sample is indicated in the left hand columns in figure 16. On the basis of these data, idealized average assemblages have been calculated for the two sediment groups. These average assemblages were compared with each of the laminated or non-laminated assemblages for the degree of similarity. The resulting similarity coefficient values are graphically shown in figure 19.

The third and fifth laminated intervals show minimum values of 50 and 40, respectively, apparently as a consequence of the minimum value of *Oolina hexagona* and the peaks of *B. antiqua* (in sample 22) and *E. exigua* (in sample 36).

All other assemblages are fairly similar (60 to 80%) to the average of their group. The mean similarity coefficient value of the assemblages in the non-laminated sediments with respect to the average assemblage is 65.5 (± 1.0), whereas the slightly higher value of 69 is found for the laminated group. For the latter group this value would be 72 if the extreme values in the third and fifth interval are excluded.

If one compares this suite of similarity coefficient values with that between adjoining samples in figure 17, the former shows a more regular curve which is on the average at higher values, even if the effects at the laminated/non-laminated boundaries are excluded. One is inclined to conclude that fairly rapid minor environmental changes occurred throughout around a fairly constant average for each of both sediment types.

The mean number of representatives of a certain species in the samples of either the laminated or non-laminated sediments must be equal to or larger than 5 to use the binomial standard deviation for calculating a reliable, symmetrical binomial interval for the scores, at a 95% probability level. Only 7 species appear to be so frequent to produce a SD_b value for either one or both groups of samples (fig. 20). These binomial intervals were compared with the actual observations. In the table of figure 21 scores have been entered for observations below, within or above the binomial interval. It thus appears that in non-laminated sediments about 25% of the numerical data fall outside the corresponding binomial interval. In the laminated group 35% of the numerical observations are outside. *Bolivina antiqua* and *Bulimina elongata* answer the expected values best for the non-laminated and laminated units, respectively.

The fairly high numbers of deviations per sediment group again indicate

	Σx		$\bar{x}$		SD_b	
	laminated	non laminated	laminated	non laminated	laminated	non laminated
Bolivina advena	87	70	5.11	3.68	2.20	–
Bolivina antiqua	46	81	2.7	4.26	–	2.02
Bulimina elongata	120	112	7.05	5.89	2.56	2.35
Epistominella exigua	134	205	7.88	10.78	2.69	3.10
Globocassidulina subglobosa	254	218	14.94	11.47	3.56	3.18
Nuttallides rugosus var. *convexus*	44	236	2.58	12.42	–	3.30
Oolina hexagona	660	83	38.82	4.36	4.87	2.04

Fig. 20 Table showing the sums, means and binomial standard deviations per sediment group for the seven most frequent species.

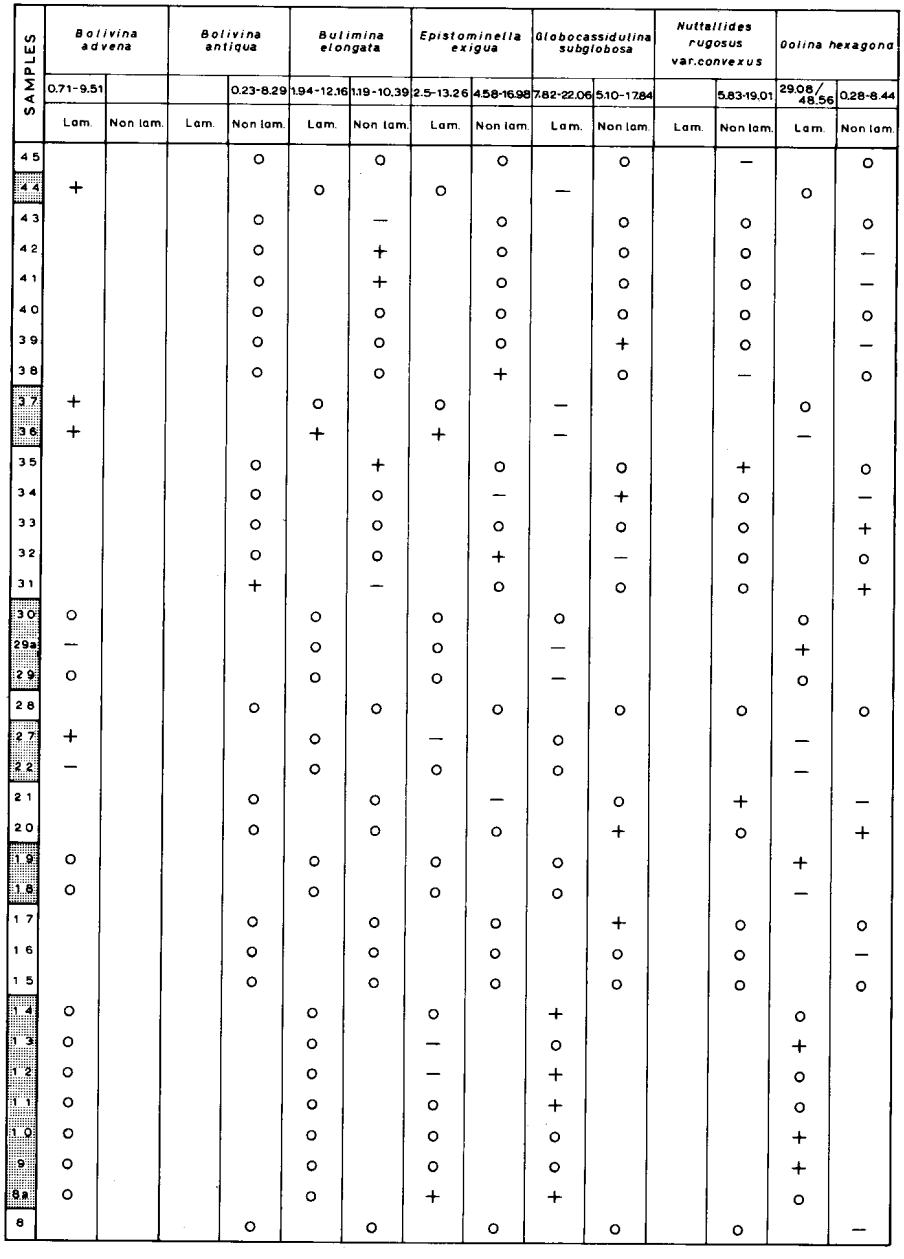
that the composition of the assemblages was not constant throughout the investigated eight meter section. The + and – character of the scores vaguely suggests that in the laminated sediments *B. advena* shows a relative increase and *O. hexagona* and *G. subglobosa* a relative decrease in upward direction. No trend analyses were carried out to substantiate these suggestions.

COMPARISON OF DIFFERENT SIZE FRACTIONS

For many species the individuals that can be recognized have definite size-limits, i.e. below a certain size limit their juveniles cannot be distinguished from those of other species. Counts on fractions larger than 125 μ contain high numbers of the species with the larger sized specimens. In many paleoecological studies the 60 to 125 μ fraction has been left unconsidered because of the determination problems for the juveniles. In such studies a significant part of the assemblages may have been neglected (cf. S. and G. Stefanini, 1976), possibly causing unwarranted paleoecological interpretations.

In order to check the influence of size differences on environmental conclusions, two series of counts have been made for the benthic foraminifera in the entire series of samples from Capo Rossello. In one series the fraction larger than 125 μ was considered, in the other the total fraction larger than 63 μ.

The scarcity of benthonic forms in the fraction larger than 125 μ prevented the counting of 200 individuals in a considerable number of the samples (fig. 22). The number of specimens counted per sample varies from 2 to



SAMPLES	*Bolivina advena*		*Bolivina antiqua*		*Bulimina elongata*		*Epistominella exigua*		*Globocassidulina subglobosa*		*Nuttallides rugosus var.convexus*		*Oolina hexagona*	
	0.71-9.51			0.23-8.29	1.94-12.16	1.19-10.39	2.5-13.26	4.58-16.98	7.82-22.06	5.10-17.84		5.83-19.01	29.08/48.56	0.28-8.44
	Lam.	Non lam.	Lam.	Non lam.	Lam.	Non lam.	Lam.	Non lam.	Lam.	Non lam.	Lam.	Non lam.	Lam.	Non lam.
45				o		o		o		o		–		o
44	+				o		o		–				o	
43				o		–		o		o		o		o
42				o		+		o		o		o		–
41				o		+		o		o		o		–
40				o		o		o		o		o		o
39				o		o		o		+		o		–
38				o		o		+		o		–		o
37	+				o		o		–				o	
36	+				+		+		–				–	
35				o		+		o		o		+		o
34				o		o		–		+		o		–
33				o		o		o		o		o		+
32				o		o		+		–		o		o
31				+		–		o		o		o		+
30	o				o		o		o				o	
29a	–				o		o		–				+	
29	o				o		o		–				o	
28				o		o		o		o		o		o
27	+				o		–		o				–	
22	–				o		o		o				–	
21				o		o		–		o		+		–
20				o		o		o		+		o		+
19	o				o		o		o				+	
18	o				o		o		o				–	
17				o		o		o		+		o		o
16				o		o		o		o		o		–
15				o		o		o		o		o		o
14	o				o		o		+				o	
13	o				o		–		o				+	
12	o				o		–		+				o	
11	o				o		o		+				o	
10	o				o		o		o				+	
9	o				o		o		o				+	
6a	o				o		+		+				o	
8				o		o		o		o		o		–

Fig. 21 Table showing the binomial intervals of the seven most frequent benthonic species, in relation to the actual observations. Symbols –, 0 and + indicate the actual numbers to fall below, within or above these binomial intervals, respectively.

Laminated intervals	Samples / Species	*Anomalina helicina*	*Astrononion italicum*	*Cibicides refulgens*	*Eggerella bradyi*	*Cibicides bradyi*	*Globocassidulina subglobosa*	*Lagena* spp./*Fissurina* spp.	*Lenticulina* spp.	*Melonis barleeanus/soldanii*	*Oolina hexagona*	*Oridorsalis stellatus*	*O. umbonatus*	*Planulina ariminensis*	*Pleurostomella alternans*	*Pullenia* spp.	*Sigmoilopsis celata*	*Siphonina bradyana*	*Uvigerina* spp.	*Dentalina Filiformis*	*Epistominella exigua*	*Nodosaria vertebralis* var. *albatrossi*	*Vulvulina pennatula*	*Cibicides lobatulus*
	45	10	1			13	4	2	4	3	6	31	3	10	1	9	1	54	1	1	1			
6	44	2	1			2						1		1		2		5	1		1		4	2
	43	6	7		3	16	1	4		1		12	7	9	4	17		52	2	2	1		3	1
	42	2	3		5	12	23	2	5	4		5	2	12	3	19	2	30	15		1		2	3
	41		2		9	13	21	5	5			23	2	9	5	14	2	31		1	1			5
	40	3	2		6	26	15	3	7			12	7	10	7	17	5	24		4				3
	39	4	5		5	16	29	6	5	5		12	1	8	2	14	9	29	7		2		1	5
	38	4			3	17	20	2	3	1		19		7	6	17		47	2	2	2		2	4
5	37				1	1	1				17	1		1	1			1	1				4	
	36			2	1	2	3	1			1	2		4	4	4	1	6				1	10	1
	35				4	24	12	6	1	4		20	4	31	5	23	4	17		1		2	9	
	34		1			14	28	2		1		17	2	29	3	13	4	38					3	
	33	7	6		3	6	17	5	1	4	2	11	2	25		18	2	43	2				4	
	32	4	6		2	10	8	5	4	6		18	2	28	3	19	1	49				1		
	31	5	7		4	8	8	6	2	8	12	13	2	18	2	15		38		5		1	7	
4	30		1	1	2	2	2	1		1	11	3		5		3		3				1	2	
	29a					1	3				33			1	2							1		
	29		1				1	1		1	18	1		3	3			6				3	1	
	28				3	3	13	5	1	1	1	24	8	20	3	15	1	40	2			7	2	
3	27						3		1		2	1						1		1		1		
	22				1		1				4	2			2									
	21	1	2	1	2	12	26	1	3	1		32	2	23	5	9	3	40	1	2		1	4	
	20					3	3	2	1	2	1	3	2	1		6		5	5					
2	19										8			1										
	18					1					2	1						2						
	17					3	2		5	1		10		1		5	1	10	1			1	2	1
	16		1		8	18	33	5	1			15		24	1	17	5	18		3			2	
	15	1	1		4	16	21	6	1			28	1	13	6	26	3	33	5			5		
1	14					1	1				39					3	1	1						
	13										44		1	1		1								
	12				1			1			39												1	
	11						1				1													
	10								1		38			1				2	1				1	1
	9				1	1		1		2	31			1				4	2	1	1	1	1	
	8	1	1	1	1	5	3	1	1	2	1	6	1	3	1	3	1	13	2					
Non laminated		48	45	2	62	235	287	68	50	44	23	311	48	281	57	276	44	611	45	21	8	18	41	22
Laminated		2	3	3	7	11	15	5	2	4	288	12	1	19	12	13	2	31	5	2	2	8	24	4

Bolivina plicatella var. mera	Hanzawaia boueana	Bulimina costata	Pleurostomella rapa var. cocoa	Bigenarina nodosaria	Cibicides italicus	Gyroidina orbicularis	Gumbonata	Karreriella bradyi	Quinqueloculina spp.	Sphaeroidina bulloides	Cibicides pseudoungerianus	Nodosaria soluta	Florilus grateloupi	Uvigerina proboscidea	Anomalinoides ornata	Martinottiella communis	Cassidulinoides bradyi	Ehrenbergina trigona	Miscellaneous	Indeterminable	Total number of benthonics/200 planktonics	Total number of counted species	Total number of counted specimens	Species / Samples	Laminated intervals
		1		3	12	3	9				5			6	4	3			2	1	8	30	204	45	
				1	2		1				1			21					1	1		17	50	44	6
		1	1	3	15	7	9	1			7			2	5				2	3	6	35	204	43	
		1	2	12	4	3	4	4		2	4					3		2	6	3	1	42	200	42	
		2	1	3	6	5	1	4	3	7	5		2			5		4	4	2		41	202	41	
	1		1	10	4	1	6	5	2	3				3		3		1	7	7	6	39	205	40	
		1		4			2	2		3	1		1	17	3		1			2	4	39	202	39	
		1	3	2		2	2	3		6	4		1	12	1		1		2	2	3	38	200	38	
		2	1		1		1				1			7	1		1		4	2	1	22	50	37	5
1						2								1				1	2			22	50	36	
				1	10	7	5	1	3		1			1	3	2			1	7	40	33	209	35	
				1	5	8	2	3	2		1	8				10	1		1	3	16	26	200	34	
					3	10	1	6			1	13			3	1			3	2	1	31	200	33	
	5				3	3	3	4	2		2	4		1	2	1			4	1	3	39	201	32	
						8	2	3	2		1	2			5	3		4	8	2		39	201	31	
						1		1	1		1	2			3	1			2			25	50	30	
			1	2	1				3										2		1	12	50	29a	4
	1		1						2				1		1	1			2	2	1	19	50	29	
					9	1	4	5	2		1	8	5		1		2		6	8	9	37	201	28	
																						7	10	27	
		1																	2	1		8	14	22	3
	1	2	1	3	9		3				5			1	1	1			3	2	3	37	203	21	
			1		1	1	1				4		1	1					5	1	1	28	50	20	
														1								3	10	19	2
											1											5	7	18	
						2		1	1		1		3						1		3	23	52	17	
		1	1	15	4	3		8			1	2							3	12	6	27	202	16	
				6	12	1	1	5	1	1									1	6	3	31	204	15	
			1																1	2		8	50	14	
		1																	1	1	1	6	50	13	
3	2																		2	1		8	50	12	1
																					1	2	2	11	
																			2	3	1	9	50	10	
																			2	1		15	50	9	
																			2	1		21	50	8	
0	7	10	13	91	106	43	61	44	6	29	72	7	9	49	25	31	7	7	1				3390	Non Laminated	
4	3	4	4	3	5	2	3	6	0	1	5	1	0	34	3	0	1	1	0				593	Laminated	

Fig. 22 Distribution chart of the benthonic foraminifera in the size fraction larger than 125 μ for the eight meter section of the Trubi at Capo Rosello. At the bottom two rows show the summation of each species per sediment group.

more than 200. The number of species is low (2–25) in the laminated and relatively high (21–39) in the non-laminated sediments.

Because in the counting procedure on the fraction larger than 63 μ a great proportion of the benthonic individuals is of small size, larger number of individuals per sample could be counted, even in those samples which appeared to be very poor in the other series of counts. The numerical data on 100 specimens counted per sample are shown in figure 16. Sample 8A was taken after the > 125 μ count was completed and is therefore entered only in figure 16.

Again the number of species in the laminated sediments is smaller (11–25) than in the non-laminated (21–36), probably as a consequence of the numerical dominance of *Oolina hexagona* in the laminated sediments.

For three samples of each of the two sediment groups, the degree of similarity between the two size fractions was analyzed.

In figure 23 the results of the six similarity tests have been entered. The values for the assemblages from the laminated sediments are considerably influenced by the predominance of *Oolina hexagona,* which raises these values to 54 and 62 for two of the samples. The extremely low value of 6 for sample 44 must be caused by the absence of *O. hexagona* in the coarser fraction and the presence of numerous *Uvigerina proboscidea,* which species is absent in the finer fraction.

Similarity coefficient values between the two size-fractions are more uniform, though low, in the non-laminated sediments, varying between 30 and 40. These results indicate that the two size-fractions contain strongly different assemblages.

	lam	non-lam
44	6	
42		32
33		30
29A	62	
16		40
9	54	

Fig. 23 Table showing the similarity coefficient values for the pairs of countings based on the > 63 μ and > 125 μ fractions, for three samples from each sediment group.

PALEOBATHYMETRY ESTIMATES

Comparison of the paleobathymetric estimates based on both sets of countings is rather disappointing. This is primarily due to the applied method (Brolsma, 1978). Although rare species are neglected and for each sample only the taxa are considered that constitute 10% or more of the assemblage, these taxa are given equal weight. As a consequence, the differences in paleobathymetric evaluation of both sets of counts depend on the 10% taxa present in one of the sets and not in the other, but the differences in actual percentages are left unconsidered. The upper depth limit of an assemblage is defined by the deepest upper depth limit found amongst its species. The shallowest lower depth limit amongst the species delimits the lower boundary of the assemblage.

For the $> 125\ \mu$ fractions (fig. 24) the upper depth limit of most samples is somewhat less than 100 m, and is primarily based on *Siphonina bradyana, Planulina ariminensis, Oridorsalis stellatus* and *Cibicides bradyi.* A lower depth limit at 924 m for 20 samples is based on the lower depth boundary of *S. bradyana.* Based on these data, it seems justified to assume a depth of deposition between 100 and 1000 m for the entire eight meter section. The anomalous indications from the laminated intervals cannot have been caused by a sudden increase in depth of deposition, but rather by the predominance of the depth-tolerant species *Oolina hexagona.*

The paleobathymetric reconstruction based on the size fraction larger than $63\ \mu$ (fig. 25) is handicapped by the lack of data on *Bulimina elongata* and *Bolivina advena,* two of the species of much greater importance because of the introduction of the smaller specimens. *Epistominella exigua* and *Nuttallides rugosus* var. *convexus* are two additional species not dealt with by Brolsma (1978). According to the literature the depth limits of the former species are 0 and 5000 m, of the latter 541 and 1016 m. Peak abundances of *E. exigua* were recorded for deeper water (2500 to 4500 m, Pujos-Lamy, 1973) as well as for shallower water (50 to 100 m, Roettger, 1970). *N. rugosus* var. *convexus* was described from 541 to 1016 m in the Eastern Mediterranean; between 600 and 700 m it represents up to 13% of the assemblages (Parker, 1958). This, however, is the only available reference.

N. rugosus var. *convexus* thus may define the upper and lower depth boundaries at 541 and 1016 m for 12 assemblages (heavy bars in fig. 25). The most plausible depth of deposition for most parts of the sequence is between 550 and 1000 m. This depth estimate corresponds surprisingly well with the bathymetric ranges obtained from the $> 125\ \mu$ counts, in which most assemblages do not extend beyond a depth of a thousand meters.

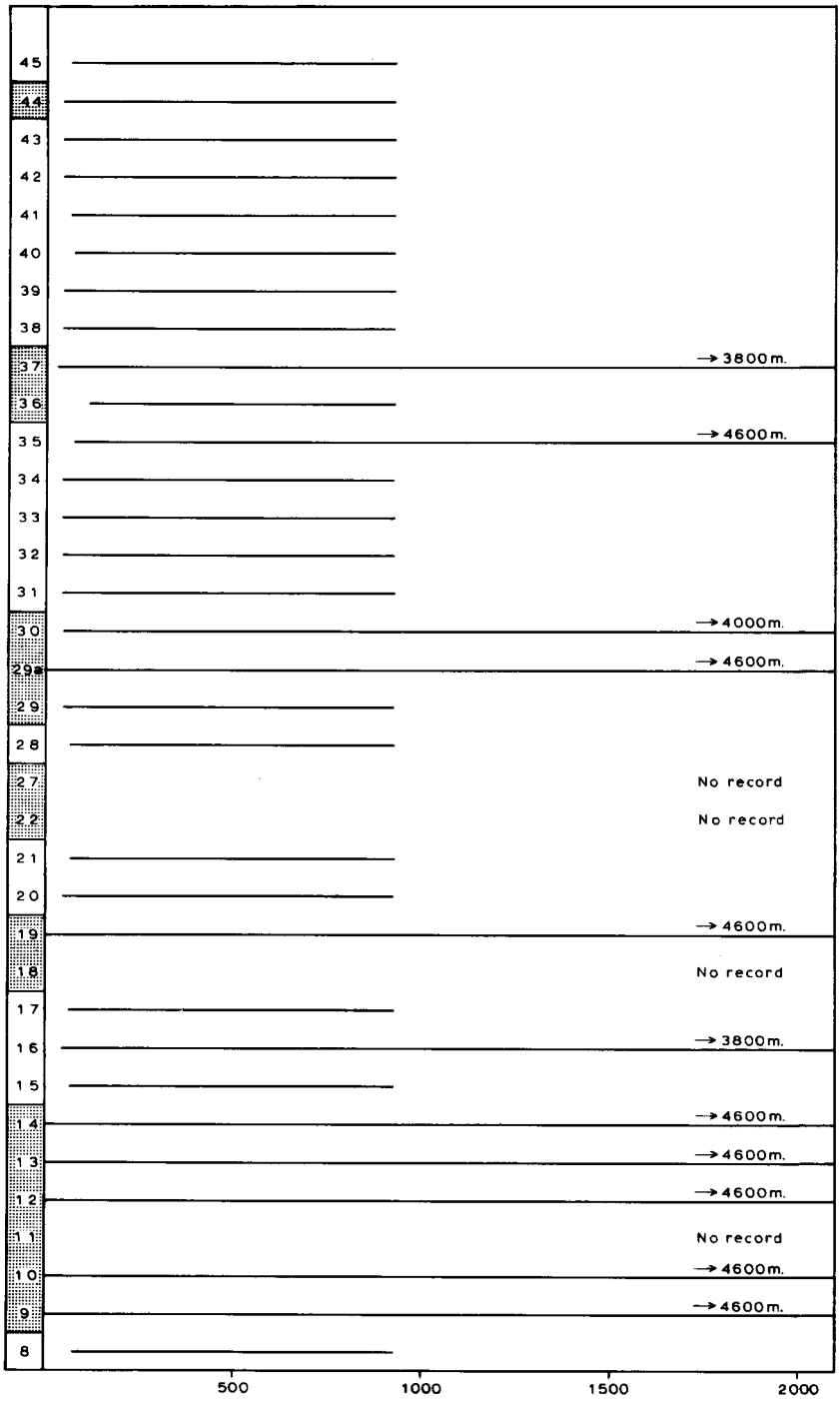


Fig. 24 Chart showing the paleobathymetric range for each assemblage in the size fraction larger than 125 μ, in the eight meter section in the Trubi at Capo Rossello. Several samples were too poor to allow a depth estimate.

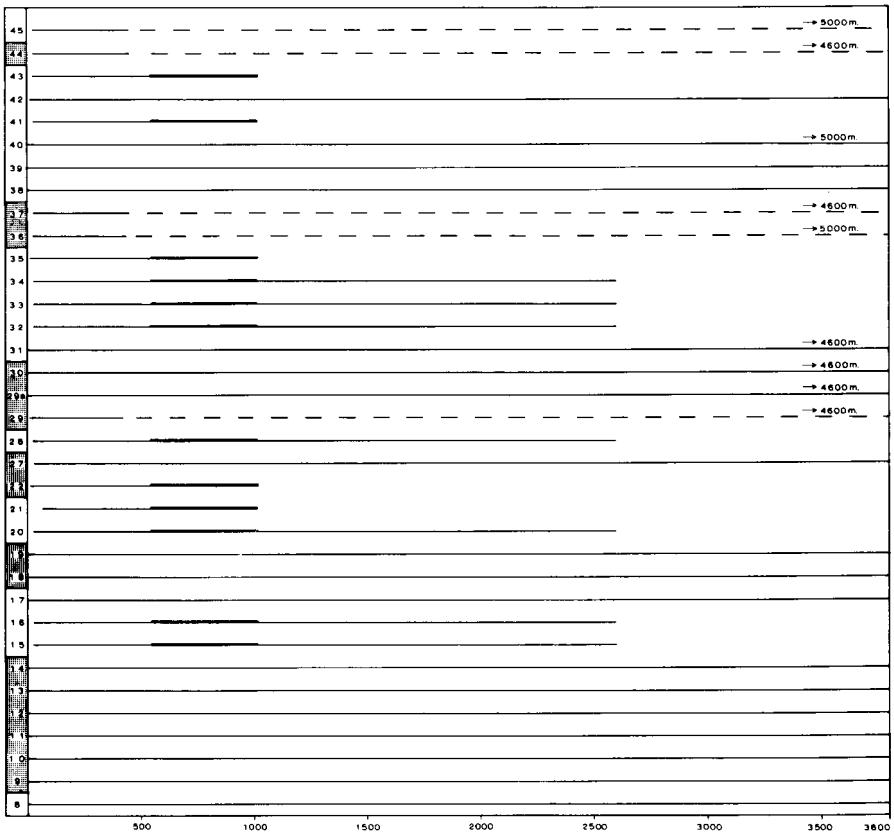


Fig. 25 Chart showing the paleobathymetric range for each assemblage in the size fraction larger than 63 μ, in the eight meter section of the Trubi at Capo Rossello. Heavy bars refer to the depth range of *Nuttallides rugosus* var. *convexus*. Dashed lines are drawn for samples poor in dominant species.

Some additional remarks must be made. The depth data for the smaller faunal elements introduced in the evaluation of the second count, are based on bathymetric studies of Recent material, with dimensions of the specimens usually larger than 100 μ. It is possible that the known bathymetrical distribution of certain species may become substantially extended if the smaller than 100 μ specimens were included in studies of Recent material. As an example, not much reliance should be placed on the depth range of 541 to 1016 m, based on one species, *N. rugosus* var. *convexus,* which was recorded from one particular place (Eastern Mediterranean) with dimensions larger than 149 μ (cf. Parker, 1958) which is larger than our specimens.

Summarizing, the congruity of both paleobathymetric estimates may well be due to lack of information on the depth-distribution of species with small-sized specimens. Although we gathered enough evidence to demonstrate that assemblages of $> 63\ \mu$ and $> 125\ \mu$ have quite different numerical compositions, we failed to prove or disprove a difference in depth estimates. The subjective approach of different micropaleontologists seems to be much more important as an obstacle in attaining reliable results.

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RADIOLARIA

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MATERIAL AND METHODS

Radiolarian investigations were based on two sets of samples from the Rossello section – an MJ series collected in 1973 (Brolsma, 1978) and the CRP series collected in 1975 (Brolsma and Broekman, this volume). Of the MJ series, samples nos. 78, 79, 86, 87, 89, 94 and 95 contained sufficient radiolarians for the present investigation, while samples nos. 75, 76, 77, 82, 83 and 100 contained too few or none. Of the CRP series, samples nos. 14, 22–31, 36 and 37 contained sufficient radiolarians, samples nos. 9, 13, 15 and 21 contained very rare corroded specimens, and the other samples from nos. 8 through 45 contained no radiolarians. Correspondences between the samples in the two series are as follows –

MJ 78 is equivalent to CRP 14, or between CRP 14 and CRP 15.

MJ 79, 86, 87, 89, 94 and 95 are equivalent to CRP 15, 22, 27, 29, 36 and 37, respectively.

Samples from both series were prepared for radiolarian study in the usual way. After disaggregating the sediment by boiling in a dilute solution of tetrasodium pyrophosphate and hydrogen peroxide, wet-sieving through a mesh of 63 μ, and eliminating the calcareous fraction by treatment with hydrochloric acid, the coarse fraction with radiolarians was pipetted as uniformly as possible onto glass slides and mounted in Canada balsam. Thus the counts are based on the total radiolarian assemblage coarser than 63 μ. In the case of the MJ series, the samples before treatment were dried for 24 hours at 60°C and then weighed, so that the total numbers of radiolarians per unit weight of sediment could be determined, but this was not done for the CRP series.

The samples of the MJ series were used to establish the taxonomy of the radiolarians (building upon that used by Riedel, Sanfilippo and Cita, 1974), and the assemblages were counted by one of us (A.S.) – this phase was completed in March 1975. Counts on the CRP series of samples were made in March-April 1976 (by W.R.).

Table 1 shows the percentage abundances of selected radiolarian taxa, in the MJ samples. In order to determine the abundance of each taxon in rela-

tion to the total assemblage, 200 specimens were counted in each of two slides from a sample, in addition to the representatives of the five commonest taxa (*Stichocorys delmontensis, S. peregrina,* unidentified spongodiscids, Spongodiscid sp. A of Riedel, Sanfilippo and Cita, 1974, and pyloniids). Counts were made of specimens as they appeared in traverses through the central parts of the slides. Because some segregation of radiolarian taxa probably occurs as residues are pipetted from a beaker onto successive slides, the first and sixth slides made from each sample were counted – in Table 1, the percentages resulting from the two counts on each sample are given separately, those from the first slide being given above those from the sixth slide, for each pair. Sparse taxa not encountered during counting, but during more thorough searching of one slide of normal density, are tabulated as "+". For purposes of comparison, the bottom row of the table shows results from the sample ROS-22 which formed the basis of the paper by Riedel, Sanfilippo and Cita (1974). The stratigraphic position of this sample relative to that of the MJ samples is shown by Brolsma (1978, fig. 29).

The total number of radiolarians larger than 63 μ from each weighed sample of the MJ series was calculated from counts of the number of speci-

Samples / Radiolarian taxa		Total number of radiolarians counted	Collosphaerids	Actinommids indet.	*Druppatractus irregularis*	*Haeckeliella inconstans*	*Hexacontium hooti*	*Hexalonche heracliti*	*Hexalonche philosophica*	*Thecosphaera greeci*	*Stylosphaera angelina*	Pyloniids	Lithelids	*Prunopyle/Larcopyle*	Artiscins indet.	*Ommatartus avitus*	*Q.didymus*	*Q.tetrathalamus*	Phacodiscids indet.	*Heliodiscus asteriscus*	*H.echiniscus*	*Euchitonia* spp.	Spongodiscids indet.	*Spongaster pentas*	*Spongodiscid sp.A*
MJ-78	Sl. 1	1070	1.12	1.21	-	0.37	1.31	0.09	0.09	1.31	0.56	18.04	0.93	+	0.56	-	0.09	0.19	-	-	0.47	2.90	28.97	0.09	4.67
	Sl. 6	935	1.18	2.78		0.54	1.39	-	0.43	0.96	0.86	20.13	0.32	0.32	1.07		0.32	0.32	0.75	0.11	0.54	3.75	28.16	0.11	2.36
MJ-79	Sl. 1	818	4.28	4.27	-	0.24	1.22	0.24	0.49	1.71	0.61	18.95	0.98	0.73	0.61	-	-	0.37	0.12	-	0.37	2.93	26.28	0.24	4.40
	Sl. 6	658	5.33	5.02	-	-	1.37	-	0.46	3.35	1.07	15.98	1.22	0.91	1.52		0.46	0.30	0.15	-	-	2.13	26.48	0.30	1.98
MJ-86	Sl. 1	669	-	1.64	2.54	0.30	0.90	+	-	1.20	1.35	11.21	0.75	+	2.39	-	0.45	1.05	0.15	0.15	0.15	3.29	24.96	-	4.48
	Sl. 6	521	-	2.69	2.50	0.38	1.15	-	0.58	0.19	1.73	12.86	0.96	0.96	0.58		0.19	0.77	-	-	0.58	2.50	22.07	-	3.26
MJ-87	Sl. 1	479	-	1.89	1.89	0.21	2.10	0.21	0.21	1.89	0.63	9.64	2.94	1.05	2.10	-	0.21	1.05	-	0.21	1.05	3.14	22.22	-	3.35
	Sl. 6	549	0.18	1.09	2.19	-	1.46	-	0.55	0.55	0.18	12.39	3.46	0.73	1.28		1.28	1.82	0.36	-	0.18	2.91	20.95	-	4.74
MJ-89	Sl. 1	563	0.18	1.78	3.73	1.07	1.95	0.36	0.53	0.71	0.53	14.92	1.78	0.71	0.53	-	0.36	0.18	-	-	0.18	4.26	30.01	-	4.80
	Sl. 6	476	-	3.15	2.31	.21	2.31	-	0.63	0.63	-	10.71	1.47	1.47	1.68		-	0.21	-	-	0.21	2.31	26.26	-	3.78
MJ-94	Sl. 1	697	-	2.30	0.14	0.43	0.72	0.14	1.58	2.15	1.29	15.78	1.22	0.86	2.73	0.14	0.43	0.43	0.43	0.29	0.57	4.59	25.54	0.14	8.18
	Sl. 6	635	-	4.23	0.15	0.15	1.02	-	1.90	1.61	1.61	17.08	1.90	0.86	1.31		1.02	0.15	0.29	-	0.29	4.38	22.04	-	7.59
MJ-95	Sl. 1	606	0.29	3.94	+	0.87	3.35	0.58	0.73	3.06	-	13.99	1.02	0.29	1.25	-	0.44	-	0.44	-	1.90	3.79	31.49	-	9.04
	Sl. 6	613	0.33	2.28		0.16	6.20	-	0.82	1.79	0.16	14.85	1.63	0.98	2.61		0.16	-	0.33	0.33	0.98	5.06	28.87	-	6.69
ROS-22 C.10.473		717	-	1.39	6.42	0.14	1.81	0.28	0.14	3.49	0.84	11.99	1.67	0.28	1.26		0.28	0.56	-	0.14	0.28	4.04	44.07	-	5.02

Table 1. Percentage abundances of selected radiolarian taxa, in relation to the total assemblage coarser than 63 μ, in the MJ samples (counts by A.S.). Numbers in the body of the table are given to two decimal places, not because the percentages can be accepted as having that degree of precision, but to make possible recalculation of the number of specimens of each taxon observed, from the total numbers given in the left-hand column.

mens in 8 (or sometimes up to 16) square fields, each 900 μ on a side, spaced on two diagonals across each slide. Arithmetic means and standard deviations for the sets of eight to sixteen counts from each slide of each sample are given in Table 2, as an indication of the degree of reliability of these estimates. These numbers are converted to numbers of radiolarians per gram, given on the far right of Table 1. Specimens were not counted unless they were at least half entire, and at least half within the boundary of the field.

Four kinds of countings were performed (by W.R.) on the samples of the CRP series –

1) On oblique traverses of the radiolarian slides, the taxa making up the first 200 specimens encountered (in two sets of 100 each) were counted, in addition to the representatives of the five taxa judged to be commonest in the MJ samples (*Stichocorys delmontensis, S. peregrina,* unidentified spongodiscids, Spongodiscid sp. A, and pyloniids). The results are given in Table 3, with percentages in parentheses that may be compared to the counts based on the MJ samples (Table 1).

Spongodiscid sp.B	Spyrids	*Lophophaena* spp.	*Pseudodictyophimus gracilipes*	Theoperids indet.	*Carnutella profunda*	*Eucyrtophalus elisabethae*	*Eucyrtidium cienkowski* group	*E.punctatum* group	*Lampromitra erosa*	*Lithomelissa campanulaeformis*	*Pterocanium* sp.	*Stichocorys delmontensis*	*S.peregrina*	*Carpocanistrum* sp.(p).	*Carpocanarium* spp.	*Pterocorythids* indet.	*Anthocyrtidium ehrenbergi*	*Pterocorys* cf.*hertwigii*	*Lamprocyclas maritalis*	*Artistrobium auritum*	*Lithomitra* sp.	*Siphocampe corbula*	*Spirocyrtis* sp.	*Botryopyle dictyocephalus* grp.	*Pseudocubus vema*	Hundreds of radiolarians (>63μ) per gram of sediment
0.09	0.47	0.19	-	+	0.09	0.19	1.40	0.75	0.28	-	0.65	9.06	20.65	1.03	-	+	0.75	0.28	0.47	0.37	-	-	+	0.28	-	275
-	0.11	0.64		0.21	0.11	0.11	1.39	0.64	0.21		0.11	4.71	23.23	0.43			0.21	0.32	0.21	0.32			0.43	0.11	0.21	
0.24	0.73	-	-	-	-	-	1.22	0.37	-	-	0.37	5.85	19.07	0.49	-	0.37	0.12	0.73	0.24	0.12	-	-	+	-	-	46
-	0.30	0.15			-	-	2.89	0.61	-		0.30	7.61	17.50	0.91			0.30	1.37	0.15	-				-		
0.15	0.90	0.90	-	0.75	0.15	-	2.24	0.75	0.30	0.30	1.20	9.87	19.43	1.79	-	0.60	0.30	1.49	0.63	0.60	-	-	0.30	0.45	+	185
-	1.54	1.73		0.77	0.19	0.38	2.50	1.92	0.96		1.73	4.71	11.31	2.30		0.96	-	5.37	0.19	0.19		0.19	0.77	0.77		
-	0.63	1.68	-	1.26	0.21	0.63	3.35	0.42	0.42	0.21	0.84	11.11	11.74	2.31	+	2.94	0.63	3.79	0.42	0.21	0.42	+	0.63	0.21	+	258
-	0.18	2.00		1.46	0.18	0.18	2.91	0.73	0.73		0.55	10.20	13.84	3.10		1.09	0.55	5.28	0.18	0.18				0.36		
-	0.18	1.60	-	1.24	0.18	0.18	2.66	1.60	0.53	-	0.71	5.15	9.59	1.78	+	0.36	1.95	1.07	0.53	2.13	+	+	+	-	+	165
0.21	1.05	3.15	0.42	0.42	0.84	-	3.99	1.89	0.84		0.84	5.46	11.76	2.52	0.42		2.94	2.73	0.42	2.10			0.21	0.42		
0.14	0.29	0.14	-	+	0.14	-	1.97	0.29	-	-	0.86	12.63	9.04	1.87	+	0.29	0.14	0.43	0.43	-	-	-	+	-	0.86	135
-	0.44	-		0.29	-	0.15	2.04	0.73	-		0.58	11.24	12.99	1.75			0.29	0.88	0.15	0.15				-	1.31	
-	-	0.44	-	0.29	-	-	2.04	0.44	-	+	1.17	2.19	13.85	0.58	-	+	0.29	0.73	0.53	0.15	-	-	+	-	0.29	65
-	0.16	0.16		0.65	-	-	2.28	0.98	0.16		0.65	4.89	11.91	1.47			0.98	0.33	0.82	-				-	0.33	
-	-	0.14			-	-	1.67	0.42	0.14		0.28	1.16	9.34	1.26			0.28	-	0.42	-				-	0.28	Not available

Sample No.	Slide No.	First 8 fields		Second 8 fields	
		M	S	M	S
MJ 78	1	30.13	6.79	31.75	6.39
	2	19.38	10.97	24.25	9.82
	3	41.13	6.45		
	4	32.63	11.39	40.25	11.20
	5	35.88	9.98		
	6	31.13	12.18		
	7	39.88	3.98	38.50	15.24
	8	23.38	5.78	27.13	10.96
	9	30.38	13.98	30.50	9.32
MJ 79	1	48.25	16.17	40.38	11.67
	2	52.00	12.42	44.88	6.27
	3	39.75	12.67	51.00	10.38
	4	60.13	15.29	56.75	19.11
	5	55.25	11.99	53.75	16.37
	6	45.38	18.05	44.00	15.55
MJ 86	1	28.38	4.63	30.88	4.22
	2	20.50	5.10	19.50	4.63
	3	18.50	4.28	17.50	3.78
	4	21.25	6.45	20.50	6.16
	5	22.38	4.57	19.38	6.74
	6	16.88	5.79	15.25	4.65
	7	20.75	3.92	19.63	3.46
	8	19.75	3.41	23.00	4.07
	9	13.50	5.10	17.13	4.91
	10	19.63	3.78	22.25	7.32
MJ 87	1	16.75	3.65	19.13	5.57
	2	14.88	4.73	14.00	3.66
	3	21.75	3.73	19.63	7.33
	4	22.75	5.87		
	5	18.75	3.99		
	6	18.25	5.75		
	7	17.88	3.94		
	8	17.13	2.75		
	9	17.38	4.69		
	10	17.00	6.93		

Sample No.	Slide No.	First 8 fields	
		M	S
MJ 89	1	26.38	4.50
	2	30.25	8.28
	3	13.50	3.42
	4	16.88	5.54
	5	14.50	4.04
	6	19.13	4.70
MJ 94	1	16.63	5.63
	2	16.50	4.84
	3	23.75	5.92
	4	15.63	6.14
	5	16.25	4.03
	6	15.50	2.45
	7	19.25	3.06
MJ 95	1	26.75	8.29
	2	21.50	7.07
	3	28.38	9.30
	4	27.25	7.42
	5	40.88	9.34
	6	31.38	5.90
	7	28.25	7.89
	8	37.00	5.37
	9	46.25	12.50

Table 2. Arithmetic means (M) and standard deviations (S) of the numbers of radiolarians in from eight to sixteen microscope fields per slide, for the MJ samples.

2) "Constant-numerator" percentage estimates of the abundances of radiolarian families and some subfamilies were made, in a manner consistent with investigations we are carrying out at Scripps Institution of Oceanography on other Neogene localities (Mediterranean and Pacific). The procedure begins with an estimation of the density of radiolarians on each slide, by counting ten square fields (framed in the microscope eyepiece) on each of two diagonals on the slide. Means and standard deviations of each ten counts are given on the left of Table 4. This density is then used to estimate the number of radiolarians in the counted number of fields that must be

searched through to find ten specimens of a taxon, and the resultant proportion is converted to an estimated percentage. The number of radiolarians that need to be scanned to encounter ten specimens ranges from a few tens for the most abundant taxa, to some tens of thousands for the rarest taxa. If one allows for statistical errors (M. M. Drooger, this volume), the method ensures that recorded abundances of 2% and 7%, for instance, are really different, and that recorded abundances of 0.2% and 0.7% differ in a similar way. Estimated percentage abundances of families and some subfamilies are given in Table 4, with the original raw estimates in the upper part of each row, and modified estimates corrected to totaal 100% in the lower part.

3) Similar constant-numerator percentage estimates were made of the abundances of some species and genera which appeared to vary widely in the 200-specimen counts, but which occurred so sparsely that those initial counts were insufficient to describe reliably the fluctuations in abundance. The percentage estimates of the selected genera and species are given in Table 5.

4) The fourth category of counts are the replicates. The three above types of counts were repeated on the same general part of slide no. 1 from sample CRP 37 about two weeks after the original counts, and Riedel made a 200-specimen count on slide no. 2 of sample MJ 95 for comparison with Sanfilippo's count made on slides nos. 1 and 6 about a year earlier. The replicates are shown in the bottom rows of Tables 3–5.

RESULTS

Several kinds of general comparisons can be made here between the various bodies of data tabulated – more detailed analysis of certain aspects of the methods will be found in the section on mathematical treatment by M. M. Drooger (this volume).

In the first place, the constant-numerator percentage estimates, based on examination of thousands of specimens and recorded in Tables 4 and 5, inspire more confidence than the counts in Table 3 based on only a few hundred specimens, especially in the case of species occurring rarely – compare, for example, the records of *Eucecryphalus elisabethae* and of *Pseudocubus vema,* in Tables 3 and 5. Order-of-magnitude variations in abundance from sample to sample occur in these rare forms rather than in the common taxa.

Variability between two different workers can be evaluated by comparing the counts made by Sanfilippo with those made by Riedel on similar

Sample number	Collosphaerids	Actinommids indet.	*Druppatractus irregularis*	*Haeckeliella inconstans*	*Hexacontium hostsi*	*Hexalonche heraclitii*	*H. philosophica*	*Thecosphaera grecoi*	*Stylosphaera angelina*	Pyloniids	*Prunopyle/Larcopyle*	Artiscins indet.	*Ommatartus avitus*	*O. didymus*	*Otetrathalamus*	Phacodiscids indet.	*Heliodiscus asteriscus*	*H. echiniscus*	*Euchitonia* spp.	Spongodiscids indet.	*Spongaster pentas*	Spongodiscid sp. A	S. sp. B	Spyrids indet.	*Thalaspyris rhombus*	*Zygocircus productus*
CRP 14	4 2 (0.9)	7 11 (2.6)	-	1 - (0.1)	3 3 (0.9)	-	0 2 (0.3)	9 12 (3.1)	1 - (0.1)	26 33 (8.6)	-	8 2 (1.5)	-	-	- 3 (0.4)	-	-	3 1 (0.6)	10 11 (3.1)	141 189 (48.3)	-	6 9 (2.2)	- 1 (0.1)	2 2 (0.6)	-	-
CRP 22	- -	2 4 (1.3)	6 8 (2.9)	- -	3 1 (0.8)	- -	- 1 (0.2)	- 2 (0.4)	3 6 (1.9)	10 17 (5.7)	- -	2 2 (0.8)	3 - (0.6)	1 - (.2)	- 1 (0.2)	- 3 (0.6)	- 1 (0.2)	- - -	11 7 (3.8)	72 94 (34.9)	- -	6 6 (2.5)	- -	1 2 (0.6)	-	-
CRP 23	- -	2 1 (0.8)	4 5 (2.3)	- -	1 1 (0.5)	- -	1 - (0.3)	- 1 (0.3)	3 3 (1.5)	7 9 (4.1)	- -	1 2 (0.8)	1 5 (1.5)	- -	1 - (0.3)	- -	- -	1 - (0.3)	5 5 (2.5)	65 53 (29.9)	- -	1 1 (0.5)	- -	4 2 (1.5)	-	-
CRP 24	- -	1 4 (1.4)	9 8 (4.5)	- -	3 1 (1.1)	- -	- -	- 2 (0.6)	3 3 (1.7)	4 14 (5.0)	- -	- -	3 1 (1.1)	2 - (1.6)	- -	- -	- -	- -	5 2 (2.0)	32 43 (20.9)	- -	3 5 (2.2)	- 1 (0.3)	4 4 (2.2)	- -	1 - (0.3)
CRP 25	- -	3 2 (1.2)	4 4 (2.0)	- -	2 3 (1.2)	- -	- 2 (0.5)	2 - (0.5)	3 2 (1.2)	12 11 (5.7)	- -	2 3 (1.2)	4 5 (2.2)	1 - (0.3)	2 1 (0.7)	1 - (0.3)	- -	1 - (0.3)	6 3 (2.2)	39 51 (22.2)	- -	4 2 (6.0)	- -	3 2 (1.2)	- -	- -
CRP 26	- -	- 1 (0.2)	5 3 (2.0)	- 1 (0.2)	- 2 (0.5)	- -	- -	1 2 (0.7)	3 1 (1.0)	14 7 (5.2)	- -	2 1 (0.7)	3 3 (1.5)	- -	1 - (0.2)	- -	- -	- -	4 2 (1.5)	52 41 (22.9)	- -	1 1 (0.5)	- -	1 2 (0.7)	- -	- -
CRP 27	- -	3 1 (1.1)	5 6 (3.0)	- -	2 2 (1.1)	- -	- -	- -	2 3 (1.4)	5 14 (5.2)	- -	5 1 (1.6)	1 4 (1.4)	- -	1 3 (1.1)	- 1 (0.3)	- -	- -	3 4 (1.9)	26 39 (17.8)	- -	3 1 (1.1)	- -	2 2 (1.1)	- 1 (0.3)	1 1 (0.5)
CRP 28	2 1 (0.8)	7 7 (3.8)	6 8 (3.8)	1 - (0.3)	1 1 (0.5)	- - (0.3)	- 2 (0.5)	3 2 (1.4)	1 1 (0.5)	20 24 (11.9)	- -	- 2 (0.5)	- - -	- 1 (0.3)	- - -	- - -	2 3 (1.4)	- - -	6 4 (2.7)	42 35 (20.9)	- -	- 3 (0.8)	- -	2 5 (1.9)	- -	- -
CRP 29	- -	5 5 (3.1)	5 4 (2.8)	- 1 (0.3)	3 1 (1.2)	- -	- -	- 2 (0.6)	- -	8 9 (5.2)	1 (0.3)	3 2 (1.5)	- -	- -	- -	- -	- -	- -	5 2 (2.2)	39 41 (24.6)	- -	- 1 (0.3)	- -	4 2 (1.8)	- -	1 - (0.3)
CRP 30	- -	6 5 (2.6)	11 9 (4.8)	- 1 (0.2)	4 3 (1.7)	- -	- -	7 8 (3.6)	- -	15 16 (7.4)	- -	4 7 (2.6)	- -	- -	2 3 (1.2)	1 - (0.2)	- 1 (0.2)	1 - (0.2)	8 5 (3.1)	76 81 (37.5)	- -	- 4 (1.0)	- -	1 1 (0.5)	- -	- -
CRP 31	- -	16 11 (7.5)	4 1 (1.4)	2 - (0.6)	2 15 (4.7)	1 1 (0.6)	1 2 (0.8)	8 13 (7.2)	- -	27 26 (14.7)	- -	11 7 (5.0)	- 1 (0.3)	- -	- 2 (0.6)	- 1 (0.3)	- -	2 1 (0.8)	1 4 (1.4)	37 27 (17.7)	- -	- 1 (0.3)	- -	1 - (0.3)	- -	- -
CRP 36	- -	8 5 (2.5)	2 - (0.4)	- -	- -	- -	- 1 (0.2)	3 6 (1.3)	3 4 (1.4)	13 13 (5.1)	1 - (0.2)	2 5 (1.4)	1 - (0.2)	- -	- 2 (0.4)	- -	- -	- -	4 4 (1.6)	89 85 (34.0)	- -	5 - (1.9)	- -	2 2 (0.8)	- -	- -
CRP 37	- -	7 1 (1.5)	2 1 (0.6)	2 1 (0.6)	4 5 (1.7)	- -	1 5 (1.1)	3 5 (1.5)	1 2 (0.6)	18 19 (6.9)	- -	6 2 (1.5)	- -	- -	- 1 (0.2)	- -	- -	3 4 (1.3)	13 11 (4.5)	112 121 (43.6)	- -	7 12 (3.6)	- -	3 - (0.6)	- -	- -
CRP 37	- -	6 4 (2.0)	3 1 (0.0)	- 2 (0.4)	10 5 (3.0)	- -	- 3 (0.6)	4 5 (1.8)	1 1 (0.4)	10 21 (6.1)	- -	6 4 (2.0)	- -	- -	- -	- -	- -	4 4 (1.6)	8 9 (3.3)	90 130 (43.0)	- -	5 11 (3.1)	- -	4 2 (1.2)	- -	- -
MJ 95	- 1 (0.2)	5 5 (1.9)	1 1 (0.4)	3 3 (1.1)	20 11 (5.5)	1 - (0.2)	2 3 (0.9)	9 10 (3.4)	-	28 11 (6.9)	-	5 5 (1.8)	-	1 (0.2)	1 1 (0.4)	2 - (0.4)	-	5 4 (1.6)	8 11 (3.4)	103 122 (40.9)	-	2 5 (1.2)	- 1 (0.2)	-	-	-

Table 3. Results of counting the first 200 radiolarians encountered in CRP samples, in addition to *Stichocorys delmontensis, S. peregrina,* unidentified spongodiscids, Spongodiscid sp. A, and pyloniids. The penultimate row contains the results of a replicate count on sample CRP 37, and the bottom row shows Riedel's count of sample MJ 95. At the top of each row is given the number of specimens in the first hundred radiolarians, below that is the number in the second hundred, and in parentheses the resulting percentage of the total assemblage.

but not identical material, i.e., material from the same layer, but from different samples. Unsatisfactorily delimited or poorly understood taxa tend to be counted differently by the two workers (e.g. pyloniids and litheliids in Tables 1 and 4, and in the bottom row of Table 3), while the results are strikingly concurrent in the case of some distinctive taxa (e.g., *Druppatractus irregularis,* Fig. 5). The counts by Sanfilippo, based usually on 1000–2000 specimens per sample, are thought to be intermediate in reliability between Riedel's counts based on a few hundred specimens and his estimates based

Lophophaena sp.	*Pseudodictyophimus gracilipes*	Lithelilids	Theoperids indet.	*Cornutella profunda*	*Eucecryphalus elisabethae*	*Eucyrtidium cienkowskii* group	*E. punctatum* group	*Lampromitra erosa*	*Lithomelissa campanulaeformis*	*Lychnodictyum audax*	*Ptercanium* sp.	*Stichocorys delmontensis*	*S. peregrina*	*Carpocanistrum* spp.	*Carpocanarium* sp.	Pterocorythids indet.	*Anthocyrtidium ehrenbergi*	*Pterocorys* cf. *hertwigii*	*Lamprocyclas maritalis*	*Artostrobium auritum* group	*Lithomitra* sp. cf. *lineata*	*Siphocampe corbula*	*Spirocyrtis* sp.	*Botryopyle dictyocephalus* grp.	*Pseudocubus vema*	Total number of radiolarians counted
5 6 (1.6)	- -	13 18 (4.5)	10 7 (2.5)	7 1 (1.2)	- -	3 5 (1.2)	1 3 (0.6)	- -	- -	- -	- -	5 4 (1.3)	29 41 (10.2)	7 6 (1.9)	1 - (0.1)	- -	- -	- -	- -	2 4 (0.9)	- -	- -	- -	3 - (0.4)	- -	683
15 20 (7.4)	- -	10 11 (4.4)	11 1 (2.5)	3 2 (1.1)	1 - (0.2)	6 6 (2.5)	2 2 (0.8)	- -	- -	- -	2 - (0.4)	16 22 (8.0)	16 17 (6.9)	1 4 (1.1)	1 - (0.2)	4 8 (2.5)	- -	1 3 (0.8)	2 1 (0.6)	5 2 (1.5)	- 2 (0.4)	- -	- -	4 - (0.4)	- -	476
11 14 (6.3)	1 - (0.3)	15 12 (6.9)	7 5 (3.0)	2 4 (1.5)	2 1 (0.8)	8 7 (3.8)	2 5 (1.8)	- -	- -	- -	- 1 (0.3)	9 13 (5.6)	15 11 (6.6)	7 7 (3.6)	1 - (0.3)	7 5 (3.0)	- 1 (0.3)	3 5 (2.0)	- 1 (0.3)	3 1 (1.0)	2 1 (0.8)	- -	1 - (0.3)	3 4 (1.8)	2 - (0.5)	394
14 18 (8.9)	- 1 (0.3)	12 13 (7.0)	2 6 (2.2)	3 4 (2.0)	4 2 (1.7)	4 4 (2.2)	1 1 (0.6)	1 - (0.3)	- -	- -	2 3 (1.4)	10 20 (8.4)	10 17 (7.5)	- 2 (0.6)	2 - (0.6)	1 2 (0.8)	1 1 (0.6)	4 8 (3.4)	2 1 (0.8)	3 2 (1.4)	2 2 (1.1)	1 - (0.3)	1 - (0.3)	3 2 (1.4)	7 2 (2.5)	358
14 11 (6.2)	- -	14 16 (7.4)	3 4 (1.7)	2 2 (1.0)	1 - (0.2)	3 4 (1.7)	1 1 (0.5)	2 1 (0.7)	- -	- -	3 - (0.7)	23 22 (11.1)	16 26 (10.3)	3 5 (2.0)	4 1 (1.2)	1 4 (1.2)	- 1 (0.2)	3 6 (2.2)	2 1 (0.7)	3 6 (2.2)	1 4 (1.2)	- -	- 2 (0.5)	5 2 (1.7)	1 2 (0.7)	406
18 15 (8.1)	- -	17 13 (7.4)	5 5 (2.5)	5 2 (1.7)	- 1 (0.2)	2 5 (1.7)	4 2 (1.5)	- 1 (0.2)	- -	- -	- 4 (1.0)	28 27 (13.5)	20 16 (8.8)	9 3 (4.2)	2 1 (0.7)	2 7 (2.2)	- 1 (0.2)	1 3 (1.0)	1 - (0.2)	3 3 (1.5)	3 3 (1.5)	- 1 (0.2)	- -	5 5 (2.5)	3 2 (1.2)	407
13 22 (9.6)	- -	18 9 (7.4)	3 2 (1.4)	- 7 (1.9)	- -	2 2 (1.1)	1 2 (0.8)	- -	- -	- -	2 2 (1.1)	24 23 (12.8)	17 14 (8.5)	6 5 (3.0)	2 1 (0.3)	3 4 (1.9)	- -	6 - (1.6)	1 1 (0.5)	4 5 (2.5)	6 1 (1.9)	1 1 (0.5)	1 1 (0.5)	6 4 (2.7)	- 2 (0.5)	366
12 13 (6.8)	- 1 (0.3)	22 12 (9.2)	2 1 (0.8)	- 4 (1.1)	- -	2 1 (0.8)	2 4 (1.6)	2 2 (1.1)	- 1 (0.3)	- -	1 - (0.3)	18 11 (7.9)	6 10 (4.3)	13 7 (5.4)	- 3 (0.8)	1 2 (0.8)	1 - (0.3)	- 1 (0.3)	1 1 (0.5)	3 3 (1.6)	- -	1 - (0.3)	- -	4 3 (1.9)	2 1 (0.8)	369
17 21 (11.7)	3 1 (1.2)	5 6 (3.4)	10 16 (8.0)	1 2 (0.9)	1 1 (0.6)	9 2 (3.4)	3 1 (1.5)	1 1 (0.6)	- -	- -	- 1 (0.3)	10 9 (5.8)	2 6 (2.5)	6 6 (3.7)	1 1 (0.6)	3 1 (1.2)	1 2 (0.9)	1 2 (0.9)	- -	10 11 (6.5)	- -	- 1 (0.3)	2 1 (0.9)	- 2 (0.6)	- -	325
8 5 (3.1)	- -	18 25 (10.3)	4 7 (2.6)	2 1 (0.7)	- -	8 4 (2.9)	3 3 (1.4)	1 - (0.2)	- -	- -	1 3 (1.0)	4 2 (1.4)	14 7 (5.0)	3 1 (1.0)	- -	1 - (0.2)	- - (0.5)	- 2 -	- -	5 4 (2.1)	- 1 (0.2)	- -	- -	1 1 (0.5)	- -	419
1 2 (0.8)	- -	24 18 (11.6)	4 3 (1.9)	1 - (0.3)	- -	2 1 (0.8)	3 1 (1.1)	- -	- 1 (0.3)	- -	- -	5 6 (3.0)	22 10 (8.9)	8 5 (3.6)	2 1 (0.8)	1 - (0.3)	1 - (0.3)	1 - (0.3)	- -	3 3 (1.7)	- 1 (0.3)	- -	- -	- -	- -	361
5 9 (2.7)	- -	16 18 (6.6)	6 3 (1.8)	3 5 (1.6)	- -	10 2 (2.3)	6 4 (2.0)	- -	- -	- -	3 1 (0.8)	47 35 (16.0)	18 7 (4.9)	6 13 (3.7)	3 - (1.2)	5 2 (1.4)	- -	1 - (0.2)	1 - (0.2)	7 8 (2.9)	- -	- -	- -	2 3 (1.0)	- -	512
4 2 (1.1)	- -	21 23 (8.2)	4 5 (1.7)	3 4 (1.3)	- -	4 7 (2.1)	5 3 (1.5)	- -	- -	- -	- 1 (0.2)	9 10 (3.6)	17 19 (6.7)	1 4 (0.9)	5 4 (1.7)	- 1 (0.2)	- -	- -	2 3 (1.3)	3 4 (1.3)	2 1 (0.6)	- -	- -	1 - (0.2)	- -	534
6 - (1.2)	- -	22 26 (9.4)	2 5 (1.4)	3 3 (1.2)	- -	6 6 (2.4)	4 4 (1.6)	- -	- -	- -	- -	10 8 (3.5)	15 9 (4.7)	- 3 (0.6)	6 4 (2.0)	- 1 (0.2)	- 1 (0.2)	- -	2 3 (1.0)	2 3 (1.0)	1 1 (0.4)	- -	- -	- -	- -	509
- -	- -	22 21 (7.6)	- -	- -	- -	10 9 (3.4)	- 2 (0.4)	- -	- -	- -	- 2 (0.4)	11 20 (5.5)	26 35 (10.8)	5 1 (1.1)	- -	- 1 (0.2)	- 2 (0.4)	1 1 (0.4)	- 4 (0.7)	- -	- -	- -	- -	- -	- -	563

on several thousands. No further calculations on subjectivity differences were carried out. The results are far better than those presented for the benthonic foraminifera (Brolsma, this volume), but substantial differences in taxon-appreciation between both authors do exist.

Reproducibility of results by the same worker seems quite satisfactory (see bottom rows of Tables 3 and 4), at least when investigations are separated by only a few weeks.

No trends that could be evolutionary and thus capable of stratigraphic

CRP Sample no. (slide 1)	Radiolarians per field: First 10 fields Mean	First 10 fields St. dev.	Second 10 fields Mean	Second 10 fields St. dev.	Collosphaerids	Actinommids (excl. artiscins)	Artiscins	Phacodiscids	Spongodiscids	Pylonlids	Tholoniids	Lithelilds	Spyrids	Plagoniids	Theoperids	Carpocaniids	Pterocorythids	Artostrobiids	Cannobotrythids	Drosphaerids	Saturnalins	Incert. Sed.
14	7.5	4.0	8.4	3.5	0.4 0.4	12 13	1 1	0.2 0.2	48 50	5 5	0.01 0.01	12 13	0.5 0.5	2 2	12 13	2 2	0.05 0.05	0.2 0.2	0.1 0.1	- -	- -	0.1 0.1
22	3.7	3.1	4.4	1.8	- -	7 6	3 3	0.4 0.4	30 26	4 4	- -	12 11	2 2	11 10	30 26	1.5 2	3 3	4 4	2 2	- -	- -	1 1
23	3.7	2.0	4.6	2.8	- -	11 7	2 1	0.2 0.1	35 24	2 1	0.02 0.01	12 8	1 1	16 11	47 31	2 1	9 6	10 7	2 1	- -	- -	1 1
24	1.1	1.4	1.0	1.3	- -	6 6	2 2	0.4 0.4	30 32	2 2	- -	13 13	2 2	10 10	19 20	1 1	5 5	4 4	2 2	- -	- -	1 1
25	4.7	2.5	5.0	2.6	0.05 0.05	10 10	11 11	0.3 0.3	26 28	1 1	- -	10 10	1 1	4 4	26 27	1 1	3 3	2 2	1 1	- -	- -	1 1
26	3.7	2.1	3.8	2.5	0.02 0.02	6 5	2 2	0.2 0.2	24 19	3 3	- -	6 5	2 2	15 13	34 28	11 9	2 2	11 9	2 2	- -	- -	1 1
27	3.6	2.5	2.8	1.6	0.01 0.01	6 7	2 2	0.2 0.2	20 24	1 1	- -	5 6	2 2	8 10	20 24	10 12	3 4	4 5	2 2	- -	- -	1 1
28	3.5	1.2	4.7	1.9	0.01 0.01	20 11	10 6	1 1	53 30	7 4	- -	12 7	2 1	16 9	36 20	11 6	2 1	3 2	2 1	- -	- -	1 1
29	4.5	2.1	8.3	3.9	0.05 0.06	7 8	2 2	0.5 0.6	15 17	3 3	- -	9 10	2 2	9 10	30 35	2 2	2 2	5 6	2 2	- -	- -	0.5 0.6
30	10.8	3.5	8.7	3.5	0.01 0.01	17 15	3 3	0.3 0.3	44 39	2 2	- -	18 16	1 1	2 2	18 16	1 1	1 1	3 3	0.2 0.2	- -	- -	0.2 0.2
36	2.2	1.5	2.1	1.7	- -	5 5	2 2	0.2 0.2	38 39	3 3	0.01 0.01	16 16	1 1	3 3	22 23	3 3	1 1	2 2	1 1	- -	- -	1 1
37	8.5	1.6	8.0	2.3	0.05 0.05	6 6	1 1	0.3 0.3	48 45	7 7	- -	13 13	0.2 0.2	3 3	20 19	2 2	0.7 0.7	2 2	0.08 0.08	- -	- -	1 1
37					0.02 0.02	5 5	2 2	0.3 0.3	50 55	3 3	- -	11 12	0.3 0.3	0.8 0.9	15 16	1 1.5	0.5 0.6	1 1	0.1 0.1	- -	- -	0.6 0.7

Table 4. "Constant-numerator" percentage estimates of radiolarian families and some subfamilies, in the CRP samples. The upper number for each taxon in a sample is the originally estimated percentage, and the lower number is the percentage corrected to total 100% for each sample. The bottom row contains the results of a replicate estimation on sample CRP 37.

subdivision of this short (8-meter) sedimentary sequence were detectable among the radiolarians. However, there are marked fluctuations in abundance of some of the taxa (see Figs. 1–12). These fluctuations, together with the fact that siliceous microfossils occur in some samples and not in others, invite interpretation in paleoenvironmental terms.

CRP Sample no. (Slide 1)	*Druppatractus irregularis*	*Haeckeliella inconstans*	*Hexacontium hootsi*	*Hexalonche philosophica*	*Thecosphaera grecoi*	*Stylosphaera angelina*	*Heliodiscus asteriscus*	*H. echiniscus*	*Zygocircus productus*	*Cornutella profunda*	*Eucecryphalus elisabethae*	*Carpocanarium sp.*	*Lamprocyclas maritalis*	*Pseudocubus vema*
14	0.01	0.3	2	0.05	3	0.05	-	0.2	0.02	1	-	0.1	-	-
22	2	0.1	0.5	0.2	0.7	1	0.02	0.3	0.2	0.6	1	0.4	0.05	0.3
23	2	0.05	0.3	0.1	0.3	1	-	0.2	0.03	0.4	0.4	0.07	0.07	0.7
24	3	-	1	0.2	0.3	2	0.03	0.4	0.2	0.9	1	0.2	0.2	1
25	1	0.1	1	0.2	0.1	1	0.03	0.3	0.06	0.5	0.2	0.1	0.1	0.2
26	3	0.1	0.3	0.2	0.5	1	0.01	0.1	0.2	0.8	0.3	0.3	0.2	0.8
27	2	0.01	0.3	0.05	0.3	1	-	0.1	0.07	0.7	0.2	0.1	0.1	0.3
28	2	0.2	0.4	0.4	1	1	0.4	0.2	0.1	0.4	0.05	0.5	0.2	0.2
29	4	0.1	0.6	0.1	0.4	0.3	0.03	0.1	0.1	1	0.07	0.2	-	0.1
30	3	0.2	2	0.2	3	0.03	0.01	0.3	0.02	0.4	-	0.2	0.02	0.01
36	0.2	0.1	0.2	0.4	1	1	0.01	0.3	0.02	0.6	0.05	0.3	0.1	0.2
37	0.1	0.1	2	0.2	2	0.1	-	0.3	0.02	1	-	0.6	0.4	0.01
37	0.2	0.1	1	0.2	1	0.1	-	0.3	0.02	0.6	0.01	1	0.4	-

Table 5. "Constant-numerator" percentage estimates of selected species, in the CRP samples. The bottom row contains the results of a replicate estimation on sample CRP 37.

INTERPRETATION

A marked degree of parallelism of relative frequencies from sample to sample is demonstrated by a group of forms comprising *Eucecryphalus elisabethae* (Fig. 1), *Pseudocubus vema* (Fig. 2), cannobotrythids (Fig. 3) and *Stylosphaera angelina* (Fig. 4). A somewhat similar trend is shown by the curves for *Druppatractus irregularis* (Fig. 5), pterocorythids (Fig. 6) and artostrobiids (Fig. 7). Especially the first four of these species occur

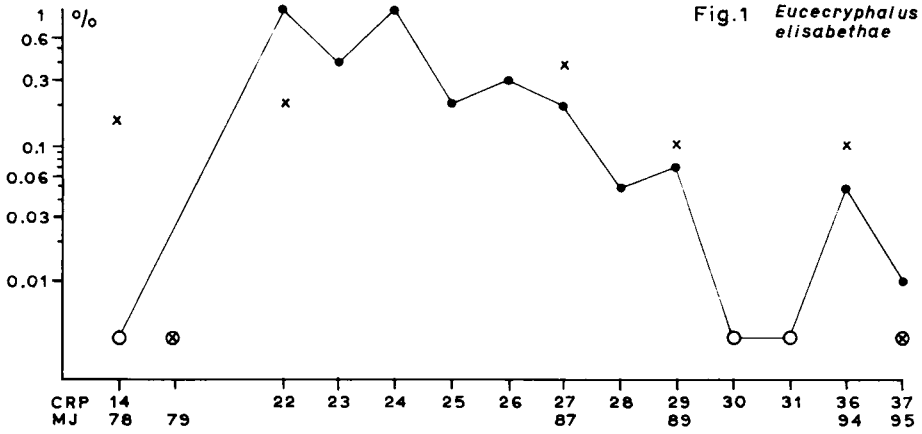


Fig.1 *Eucecryphalus elisabethae*

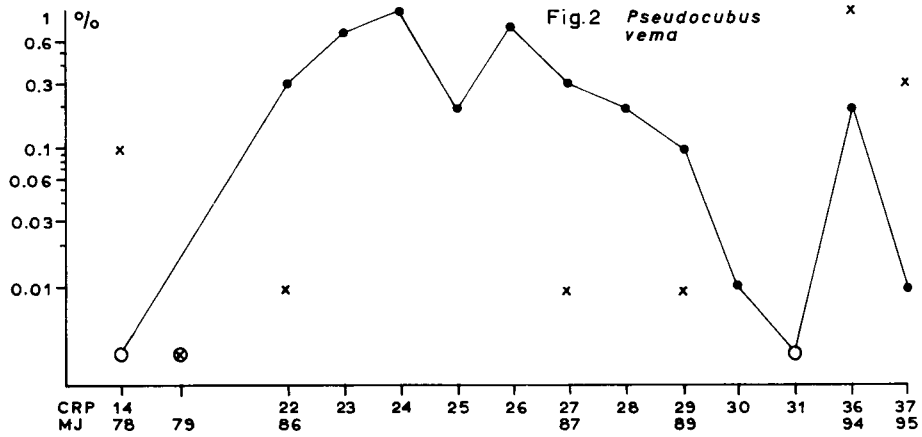


Fig.2 *Pseudocubus vema*

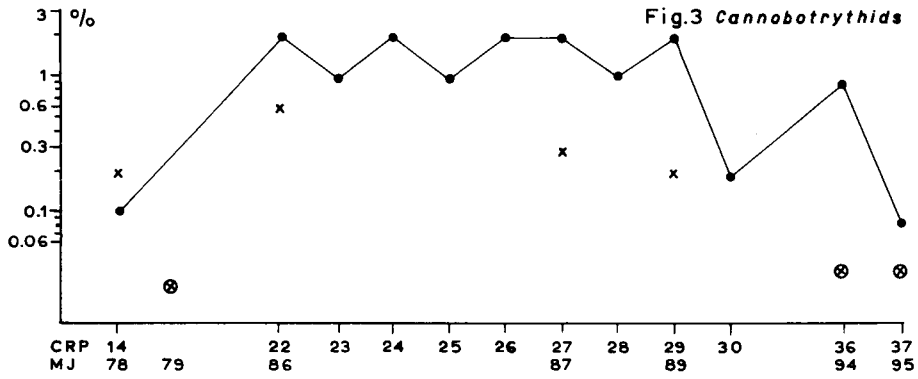
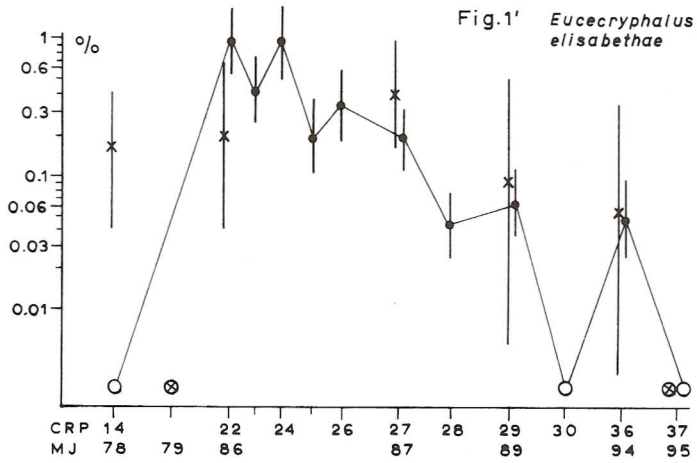
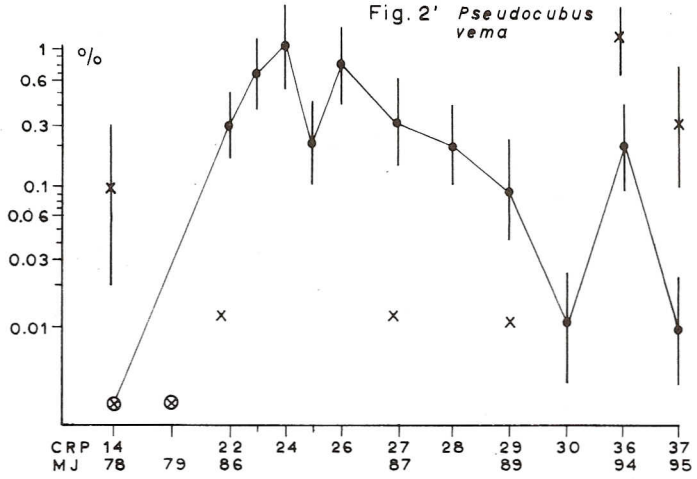


Fig.3 *Cannobotrythids*





Figs. 1'–12' The estimated percentage abundances of the selected taxa in the Rossello samples (fig. 1–12) with the 95% confidence intervals inserted.

Figs. 1–12 Estimated percentage abundances of selected taxa in the Capo Rossello samples, plotted on a logarithmic scale – a presentation chosen for its being conservative in indicating fluctuations. Estimates by Riedel on CRP samples are shown as dots connected by a solid line, while Sanfilippo's estimates on MJ samples are shown by crosses. Zeros indicate no specimens found. Note that although the samples are arranged approximately in stratigraphic order, their spacing along the horizontal axis is not to scale, and that CRP 22–26 have been all collected from the same horizon.

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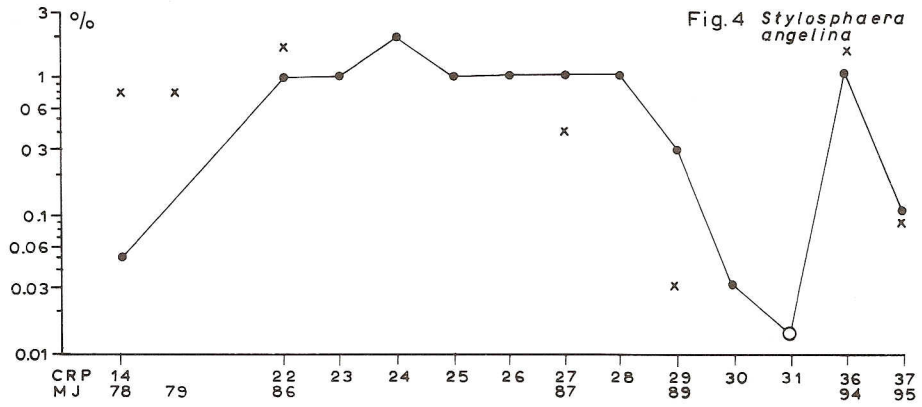


Fig. 4 *Stylosphaera angelina*

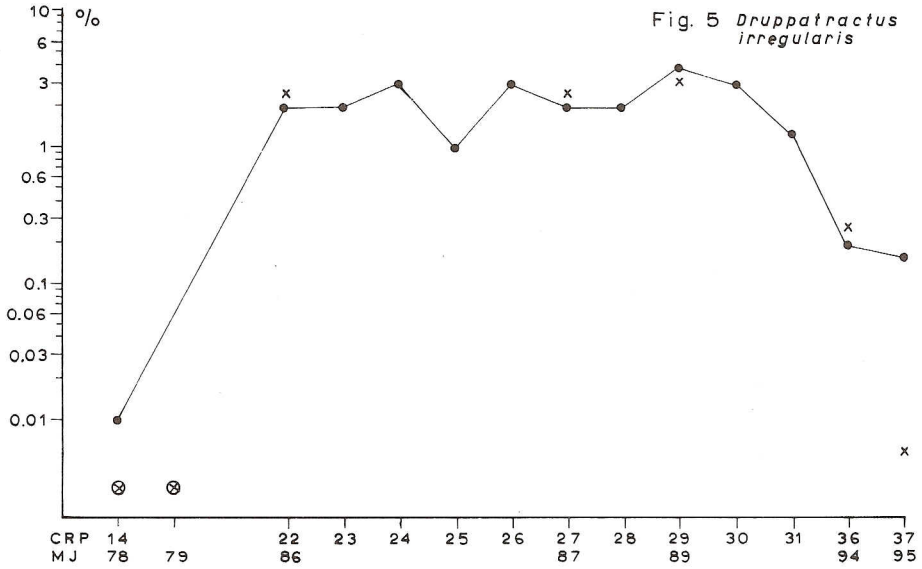


Fig. 5 *Druppatractus irregularis*

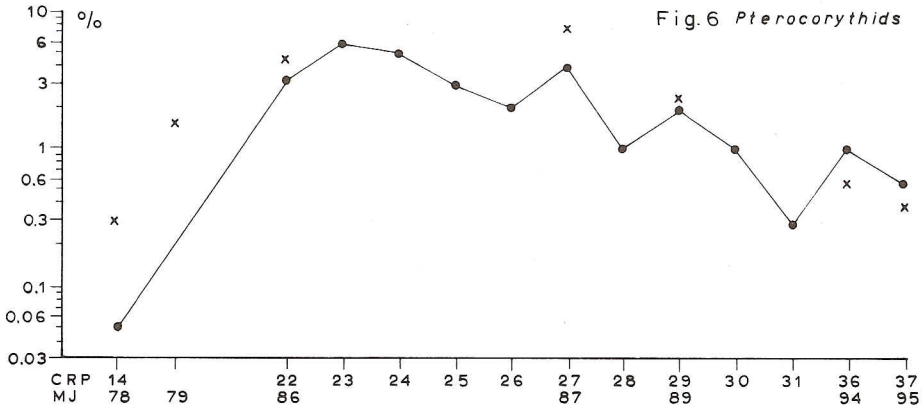


Fig. 6 *Pterocorythids*

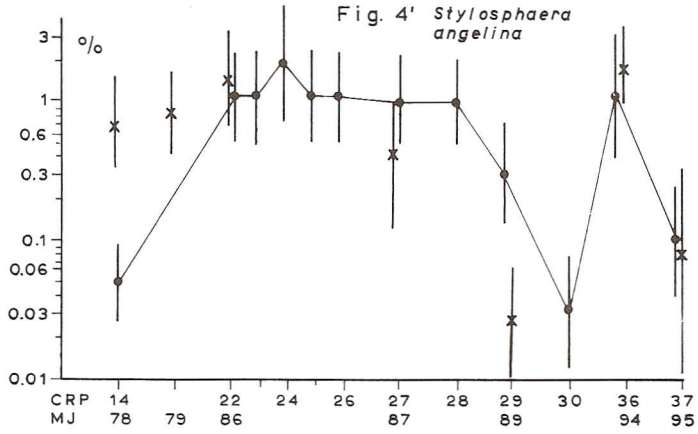


Fig. 4' Stylosphaera angelina
%
3
1
0.6
0.3
0.1
0.06
0.03
0.01
CRP 14 22 24 26 27 28 29 30 36 37
MJ 78 79 86 87 89 94 95

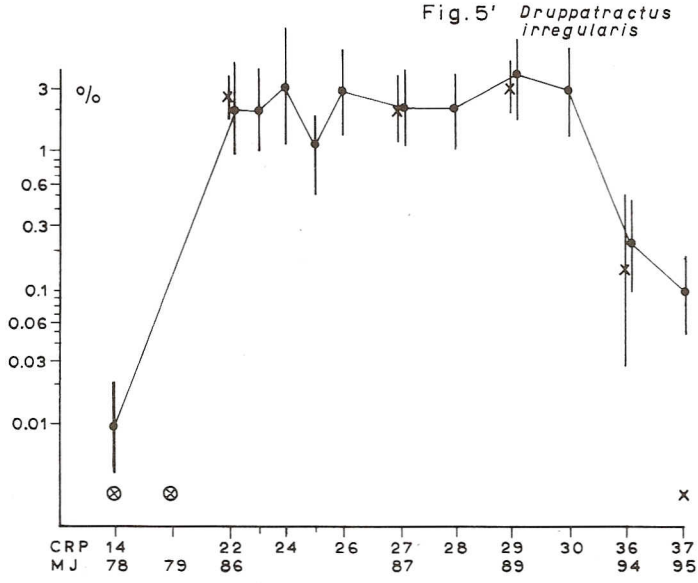


Fig. 5' Druppatractus irregularis
%
3
1
0.6
0.3
0.1
0.06
0.03
0.01
CRP 14 22 24 26 27 28 29 30 36 37
MJ 78 79 86 87 89 94 95

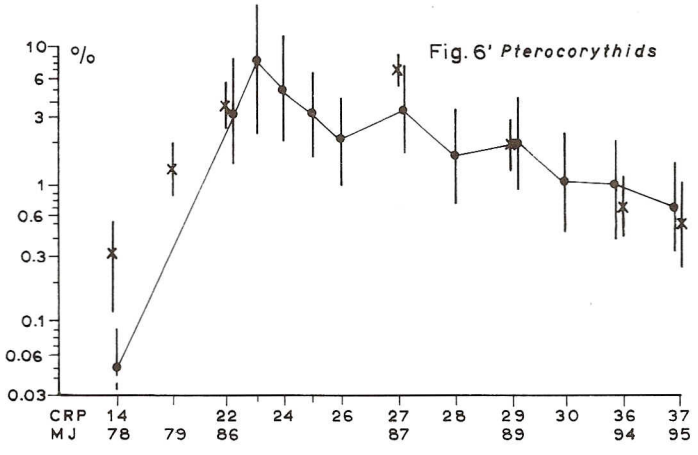


Fig. 6' Pterocorythids
%
10
6
3
1
0.6
0.3
0.1
0.06
0.03
CRP 14 22 24 26 27 28 29 30 36 37
MJ 78 79 86 87 89 94 95

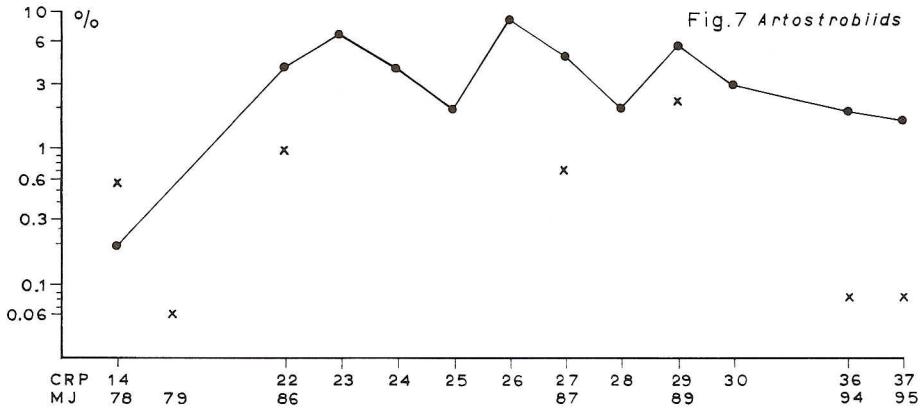


Fig. 7 *Artostrobiids*

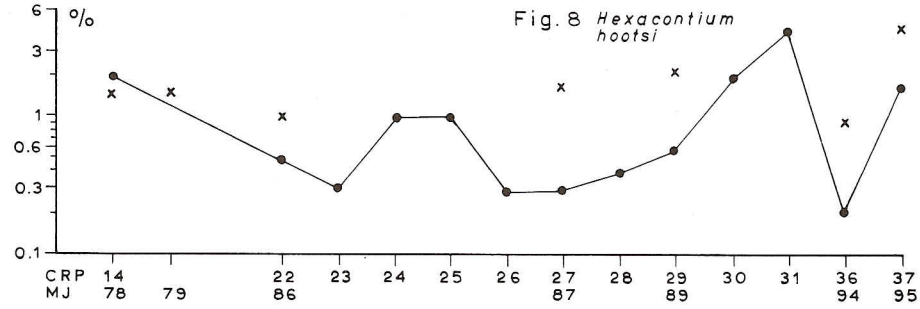


Fig. 8 *Hexacontium hootsi*

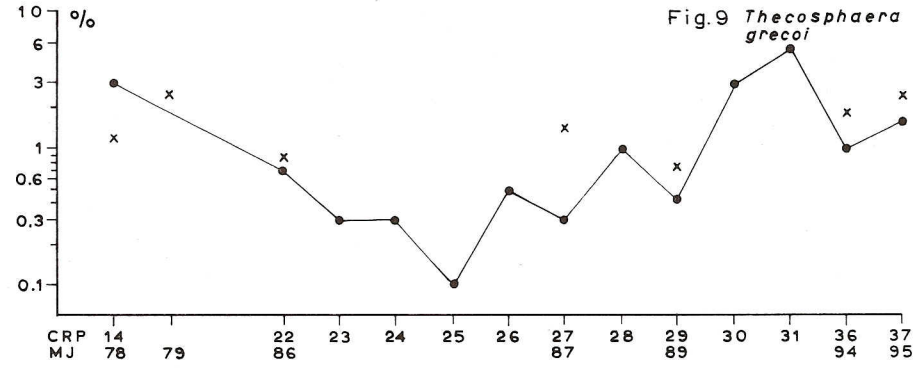


Fig. 9 *Thecosphaera grecoi*

with relatively high abundances in CRP samples 22–29 and 36, and relatively low abundances in samples 14, 30, 31 and 37.

A contrary tendency is shown by *Hexacontium hootsi* (Fig. 8) and to a lesser extent by *Thecosphaera grecoi* (Fig. 9), which occur with low abundances in CRP samples 22–29 and 36, and relatively high abundances in samples 14, 30, 31 and 37.

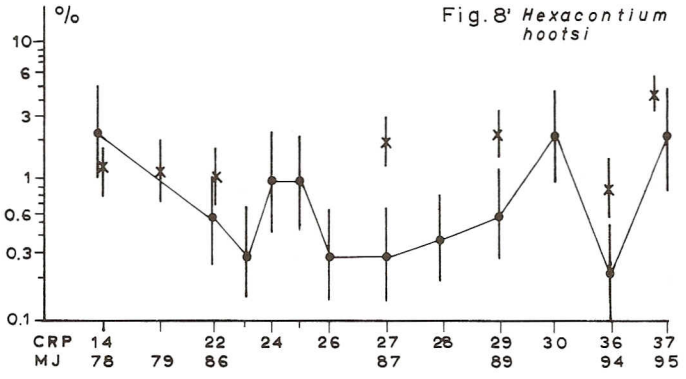


Fig. 8' *Hexacontium hootsi*

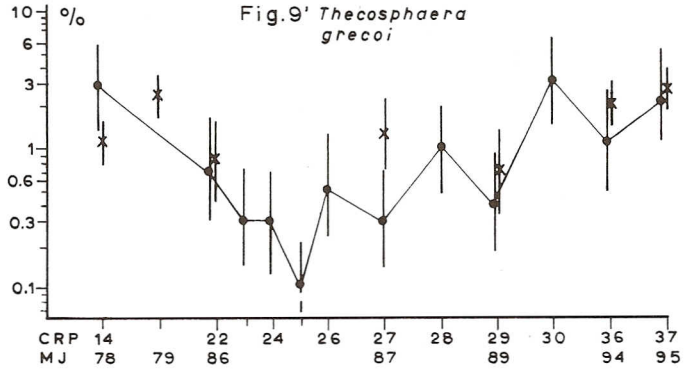


Fig. 9' *Thecosphaera grecoi*

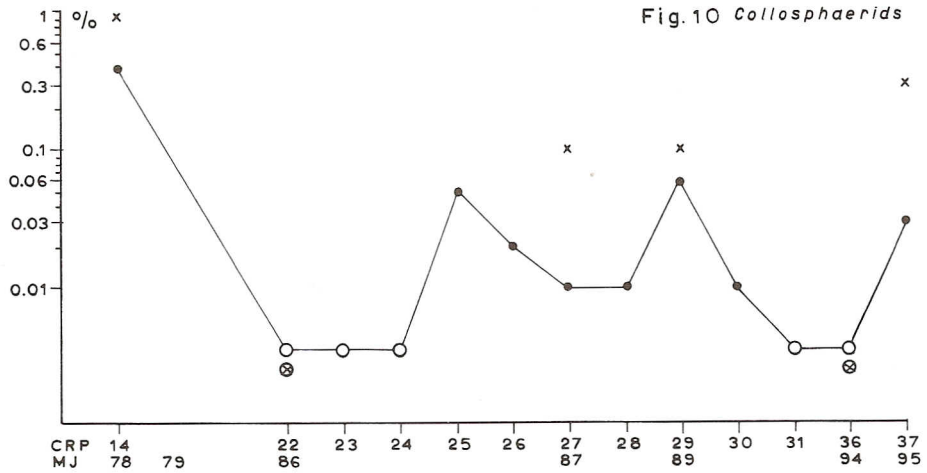


Fig. 10 *Collosphaerids*

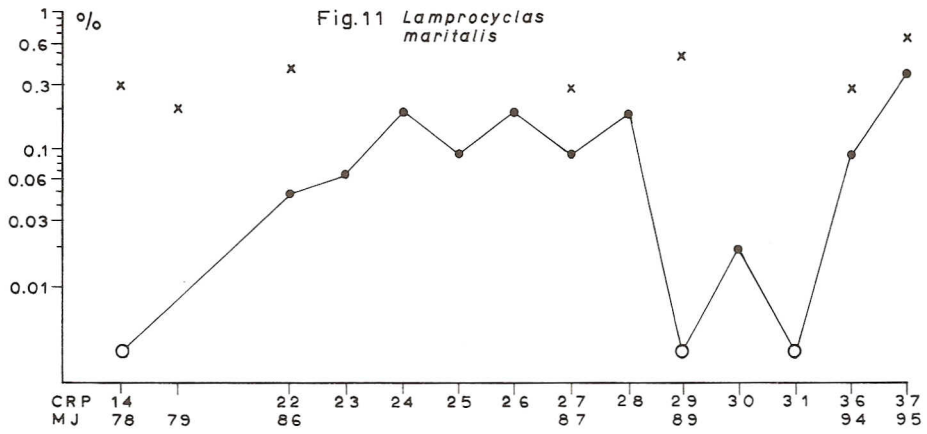


Fig. 11 *Lamprocyclas maritalis*

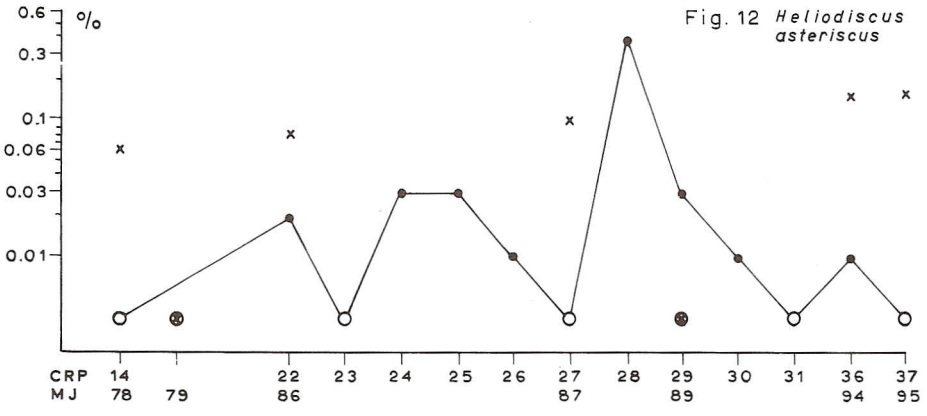


Fig. 12 *Heliodiscus asteriscus*

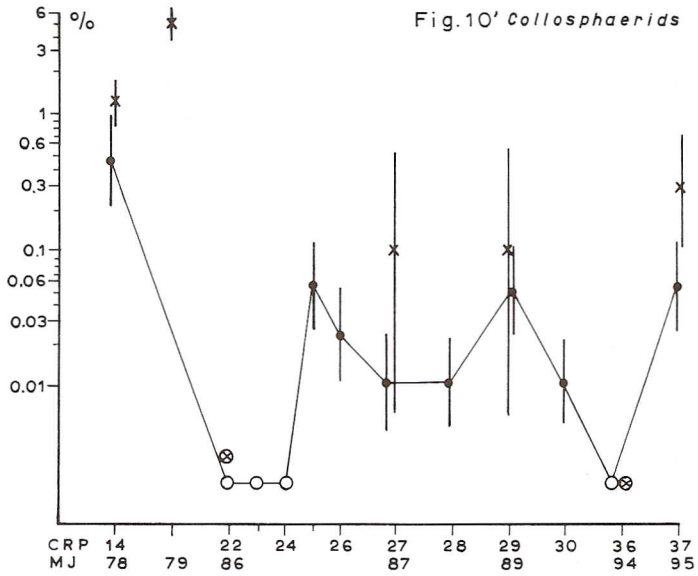


Fig.10' *Collosphaerids*

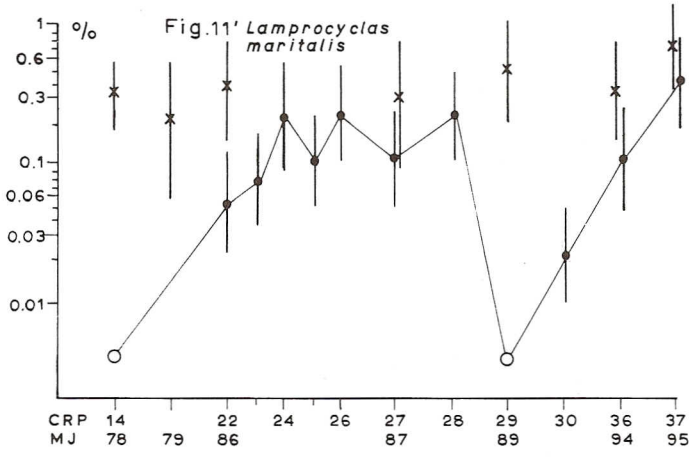


Fig.11' *Lamprocyclas maritalis*

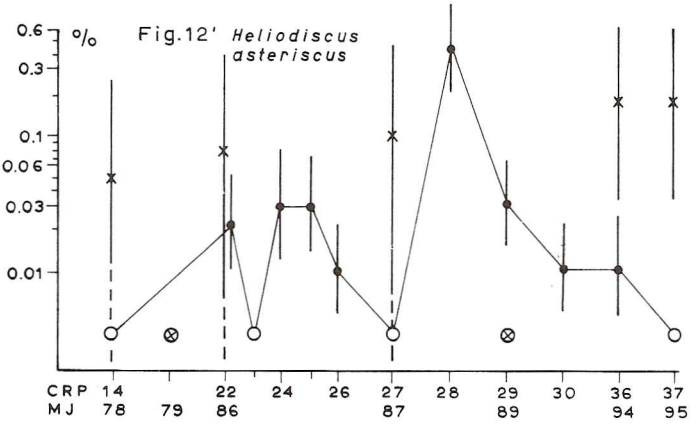


Fig.12' *Heliodiscus asteriscus*

Some other forms, such as collosphaerids (Fig. 10), *Lamprocyclas maritalis* (Fig. 11) and *Heliodiscus asteriscus* (Fig. 12) seem to vary idiosyncratically.

A possible clue to the significance of the coherently varying abundances of the first four taxa (and the inversely varying eighth) lies in the fact that in CRP samples 14, 30 and 31, and to a lesser extent in sample 37, specimens of *Stichocorys peregrina* have the distinctive morphology characteristic of low-latitude assemblages (distinctly conical third segment, and annular, usually wider fourth segment, as illustrated by Riedel, Sanfilippo and Cita, 1974, Pl. 60, fig. 8), while in the other samples the morphology of the species is that characteristic of higher latitudes (less distinctly differentiated segments, and somewhat more robust shell wall, as illustrated herein, Pl. 5, figs. 5–7). This suggests that samples 22–29 and 36 may have been deposited under slightly cooler-water conditions than samples 14, 30, 31 and 37.

As a tentative working hypothesis it may be postulated that the co-varying group of four radiolarians first mentioned may characterize an environment of high biological productivity, with upwelling causing somewhat lower surface temperatures than prevailed during the deposition of samples 14, 30, 31 and 37, and possibly also during the deposition of the calcareous oozes lacking siliceous microfossils. The assemblages in samples 30, 31 and 37 seem to represent conditions transitional from a highly productive to a more stably stratified water column (this latter preventing nutrients being brought into the photic zone by upwelling), and the isolated occurrence of siliceous microfossils in sample 14 may reflect a slight increase in productivity associated with upwelling not sufficiently intense to cause a notable decrease in near-surface water temperature. These possible relationships are sketched in Figure 13.

Before this suggestion can be taken very seriously, it is obviously desirable to determine whether an increased relative abundance of *Eucecryphalus elisabethae, Pseudocubus vema,* cannobotrythids, *Stylosphaera angelina, Druppatractus irregularis,* pterocorythids and artostrobiids is characteristic of assemblages deposited in known areas or at times of upwelling in other parts of the Neogene oceans.

RE-EVALUATION

The above part of the text was completed in May 1976, shortly after Riedel's counting stay in Utrecht. The error analysis of the so-called logarithmic method was finished afterwards. It was considered worth-while to evaluate the possibility of "wishful thinking" in the theories outlined above. Ten of the twelve figures 1–12 are reproduced as figures 1′–12′ with the

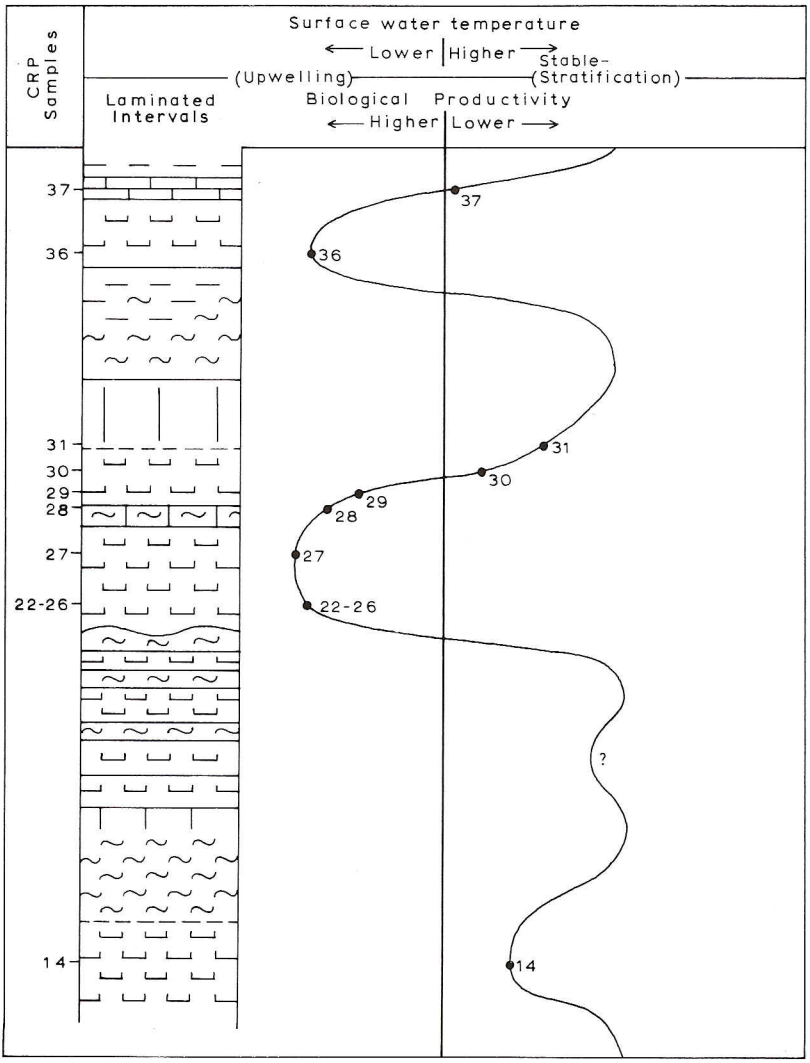


Fig. 13 Possible relationships between radiolarian assemblages and paleoenvironmental conditions, in the section at Capo Rossello.

95% confidence intervals inserted.

Most of the five lateral samples CRP 22–26 give comparable counting data. Apart from two taxa groups, which have zero scores in only part of the samples, there are five obvious deviations for *E. elisabethae, P. vema* and *T. grecoi.* They all concern samples CRP 22, 24 and 25. Samples CRP 23 and 26 seem to give better "average" faunal compositions of the layer.

The frequencies assumed to be higher in samples CRP 14, 30 and 37 than in CRP 22–29 and 36 are confirmed for *E. elisabethae, P. vema* and *S. angelina.* As was expected, this difference is not confirmed for *D. irregularis* and the pterocorythids, but the supposed inverse frequency relations for *T. grecoi* and collosphaerids are not distinct either.

None of the trends confirmed above is apparent from the data of Sanfilippo. Significant counting differences occur in 23 out of 60 comparisons, which high proportion asks for an explanation. The primary reason may be that the MJ samples were not taken from exactly the same layers as the corresponding CRP samples. This is especially true for the couple MJ 78–CRP 14, and possibly also for MJ 87–CRP 27 and MJ 89–CRP 29. On the other hand there are clear indications of difference in appreciation in recognizing individuals of certain taxa. It seems highly likely that Sanfilippo recorded more individuals of *H. hootsi, L. maximalis* and *H. asteriscus* than Riedel.

As a result it may be concluded that minor differences in the sampling spots and subjective differences in species determinations are sufficient to suggest or deny paleoenvironmental interpretations based on rare taxa.

SYSTEMATIC SECTION

Below are listed practically all of the radiolarians encountered (one tholoniid was found in the MJ series, and a few specimens of *Lithopera bacca* in CRP 14, but these are not included in the systematic descriptions). Some forms are identified only to family or genus, pending thorough taxonomic investigation of the group involved. For additional comments on the species treated herein, see the systematic section and illustrations in Riedel *et al.* (1974).

Suborder SPUMELLARIA Ehrenberg, 1875

Family **Collosphaeridae** Müller 1858
Plate 1, figures 1–4

Remarks – The more common forms tabulated under the name "collosphaerids" are illustrated.

Family **Actinommidae** Haeckel, emend. Riedel, 1967a

Actinommids indet.
Plate 1, figures 5–10

Remarks – In addition to the actinommids identified to species, and those recorded as "artiscins indet.", there are a number of unidentified actinommids, the most common of which are illustrated.

Artiscins indet.
Plate 1, figures 11–13

Remarks – Under this name are tabulated cortical shells lacking the polar structures needed for further identification.

Genus **Druppatractus** Haeckel, 1887

Druppatractus irregularis Popofsky, 1912
Plate 1, figures 14–16

1912 *Druppatractus irregularis* Popofsky, p. 114, text-figs. 24–26.
1974 *Druppatractus irregularis* – Riedel *et al.*, p. 704, pl. 54, fig. 1.

Remarks – Specimens range from irregular forms such as those illustrated by Popofsky (1912) and Riedel *et al.* (1974) to more regular ones with thicker, more regularly ellipsoidal cortical shell and longer polar spines (sometimes not collinear) as illustrated herein.

Genus **Haeckeliella** Hollande and Enjumet, 1960

Haeckeliella inconstans Dumitrica, 1973
Plate 1, figures 17–19

1973 *Haeckeliella inconstans* Dumitrica, p. 833, pl. 7, figs. 1, 2; pl. 18, figs. 7–22.
1974 *Haeckeliella inconstans* – Riedel *et al.*, p. 704, pl. 54, figs. 2, 3.
1975 *Haeckeliella inconstans* – Sanfilippo and Riedel, p. 63.

Plate 1

Figs. 1–4. Collosphaeridae genn. et spp. indet.

1. Sample MJ 79, Sl. 5, 018/0, 195 X.
2. Sample MJ 79, Sl. 5, F15/0, 195 X.
3. Sample MJ 95, Ph. 2, G20/3, 195 X.
4. Sample MJ 87, Cs. 1, V40/1, 135 X.

Figs. 5–10. Actinommidae genn. et spp. indet.

5. Sample MJ 87, Cs. 1, D40/0, 135 X.
6. Sample MJ 87, Cs. 1, H40/0, 135 X.
7. Sample MJ 89, Cs. 2, V10/4, 135 X.
8. Sample MJ 89, Cs. 2, U3/4, 135 X.
9. Sample MJ 89, Cs. 2, E7/0, 135 X.
10. A form similar to *Hexacontium hootsi*, but with larger cortical shell with coarser pores. Sample MJ 89, Cs. 1, P6/3, 190 X.

Figs. 11–13. Artiscinae genn. et spp. indet.

11. Sample MJ 95, Sl. 8, Q42/2, 135 X.
12. Sample MJ 86, Cs. 2, F19/3, 135 X.
13. Sample MJ 89, Ph. 1, Y45/3, 135 X.

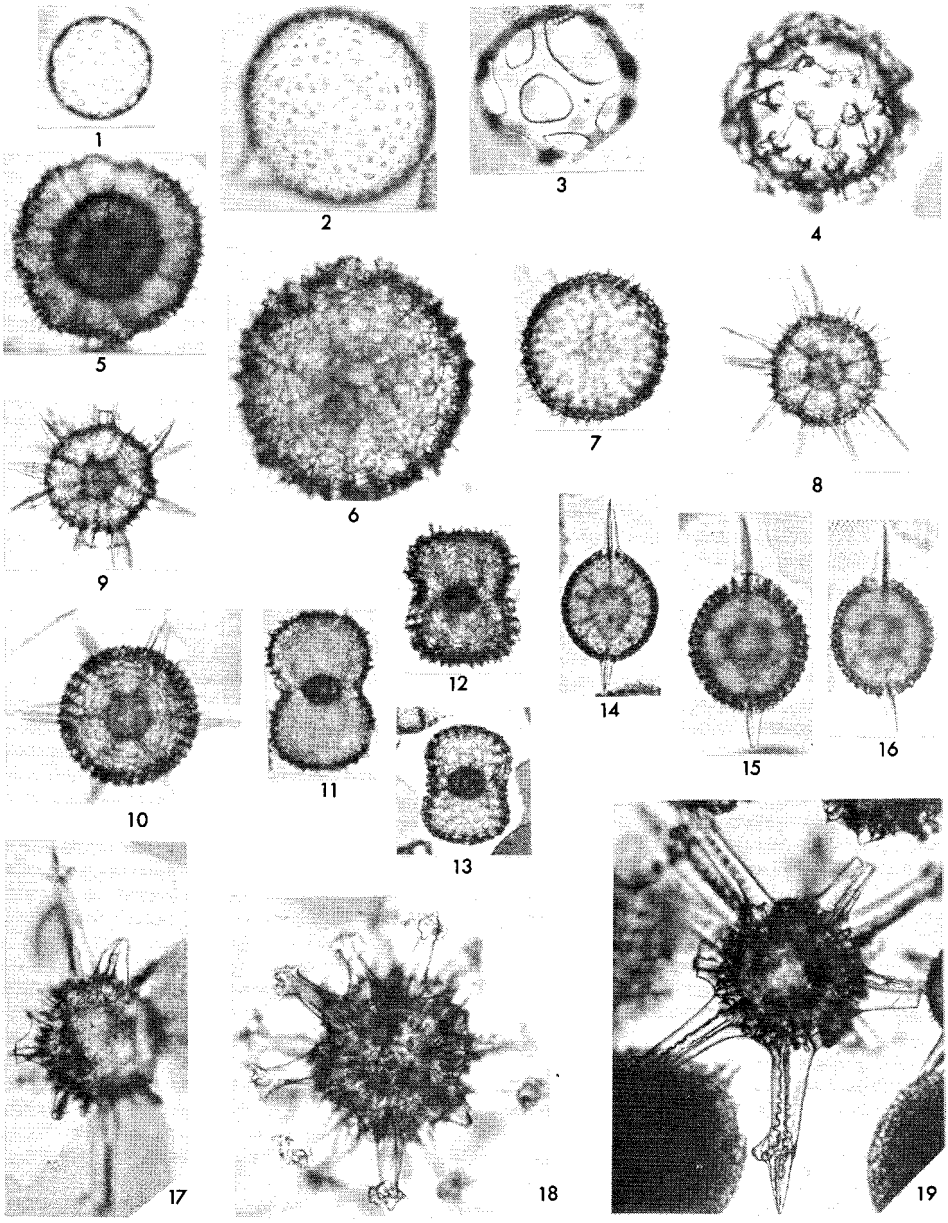
Figs. 14–16. *Druppatractus irregularis* Popofsky.

14. Sample MJ 89, Ph. 1, D16/3, 195 X.
15. Sample MJ 87, Ph. 2, N34/3, 195 X.
16. Sample MJ 87, Ph. 1, K3/3, 195 X.

Figs. 17–19. *Haeckeliella inconstans* Dumitrica.

17. Sample MJ 89, Cs. 2, K16/0, 135 X.
18. Sample MJ 89, Cs. 2, Q27/1, 135 X.
19. Sample MJ 78, Cs. 1A, J14/0, 135 X.

Plate 1



Remarks – Forms that we include here in this species correspond with the description and illustrations in Riedel *et al.* (1974). In some specimens there are rows of pits along the spines (Pl. 1, fig. 19). We do not include specimens with longer, more delicate spines and relatively smaller medullary shell (Pl. 2, figs. 1–3).

Genus **Hexacontium** Haeckel, 1881

Hexacontium hootsi Campbell and Clark
Plate 2, figure 4

1944 *Hexacontium hootsi* Campbell and Clark, p. 14, pl. 2, fig. 5.
1974 *Hexacontium hootsi* – Riedel *et al.*, p. 705, pl. 54, figs. 4–6; pl. 61, fig. 9.

Remarks – Specimens correspond well with those described and illustrated previously, but in the present material a few have up to eight spines. The proportions between the diameters of the three shells are uniform.

Genus **Hexalonche** Haeckel, 1881

Hexalonche heracliti Haeckel
Plate 2, figure 5

1887 *Hexalonche heracliti* Haeckel, p. 187, pl. 22, fig. 7.
1974 *Hexalonche heracliti* – Riedel *et al.*, p. 705, pl. 55, fig. 1; pl. 61, fig. 10.

Remarks – Specimens conform with those previously described and illustrated from the "trubi", but they differ from Haeckel's illustration in that the spines are not bladed distally. Not included in this species is a rather similar form having more than six, commonly longer and more pronouncedly bladed spines (Pl. 2, figs. 6, 7).

Hexalonche philosophica Haeckel?
Plate 2, figure 8

?1887 *Hexalonche philosophica* Haeckel, p. 186, pl. 22, fig. 4.
1974 *Hexalonche philosophica*? – Riedel *et al.*, p. 706, pl. 55, fig. 2.

Remarks – In this species, the cortical shell is larger and more robust than in *Hexacontium hootsi*. There are six, regularly arranged, bladed spines (in rare specimens two opposite spines have atrophied, though their internal bars remain). The cortical shell tends to be flattened around the bases of the spines, so that when two pairs of opposite spines are parallel to the slide the cortical shell outline is flat on four sides, when one pair of opposite spines is parallel to the slide only those two sides of the outline are flat, and when the points of three spines are resting on the slide the outline is circular.

Genus **Ommatartus** Haeckel, emend. Riedel, 1971

Ommatartus avitus (Riedel, 1953)
Plate 2, figure 9

1953 *Panartus avitus* Riedel, p. 808, pl. 84, fig. 7.
1971 *Ommatartus avitus* – Riedel and Sanfilippo, p. 1588, pl. 4, fig. 6.
1975 *Ommatartus avitus* – Sanfilippo and Riedel, p. 66.

Remarks – Although the tubercles on the cortical shell are always small, they are more pronounced in some specimens than in the illustrated one.

Ommatartus didymus (Ehrenberg, 1844)
Plate 2, figures 10, 11

1844 *Haliomma didymum* Ehrenberg, p. 83.
1973 *Ommatartus didymus* – Sanfilippo *et al.*, p. 216, pl. 2, figs. 1, 2.
1974 *Ommatartus didymus* – Riedel *et al.*, p. 706, pl. 55, figs. 3–5.

Remarks – The specimen illustrated is one with relatively large caps, identified as this species in accordance with the comments by Riedel *et al.* (1974).

Ommatartus tetrathalamus (Haeckel, 1887)
Plate 2, figures 12–14

1887 *Panartus tetrathalamus* Haeckel, p. 378, pl. 40, fig. 3.
1971 *Ommatartus tetrathalamus* – Riedel and Sanfilippo, p. 1588, pl. 1C, figs. 5–7.
1974 *Ommatartus tetrathalamus* – Riedel *et al.*, p. 706, pl. 55, figs. 6, 7.
1975 *Ommatartus tetrathalamus* – Sanfilippo and Riedel, p. 66.

Remarks – Specimens may have polar caps as small as illustrated in Pl. 2, fig. 14, but are excluded from this species if they have a greater development of skeletal structure beyond the one proximal pair of caps than in the illustrated specimen.

Genus **Prunopyle** Dreyer, 1889, or **Larcopyle** Dreyer, 1889

Prunopyle or **Larcopyle** indet.
Plate 2, figures 15, 16

Remarks – Specimens recorded under this name vary from ones as large and regular as recorded by Riedel *et al.* (1974, pl. 56, fig. 1) to smaller and less regularly constructed specimens as illustrated here.

Plate 2

Figs. 1–3. *Haeckeliella* (?) cf. *H. inconstans* Dumitrica.
1. Sample MJ 89, Cs. 2, X19/0, 135 X.
2. Sample MJ 87, Cs. 1, W5/2, 135 X.
3. Sample MJ 89, Cs. 2, L26/1, 135 X.

Fig. 4. *Hexacontium hootsi* Campbell and Clark.
Sample MJ 86, Cs. 2, H25/4, 135 X.

Fig. 5. *Hexalonche heracliti* Haeckel.
Sample MJ 89, Cs. 2, Z12/2, 135 X.

Figs. 6, 7. *Hexalonche* (?) cf. *H. heracliti* Haeckel.
6. Sample MJ 87, Cs. 2, Q44/0, 135 X.
7. Sample MJ 87, Cs. 1, R28/0, 135 X.

Fig. 8. *Hexalonche philosophica* Haeckel?
Sample MJ 94, Cs. 1, R30/4, 135 X.

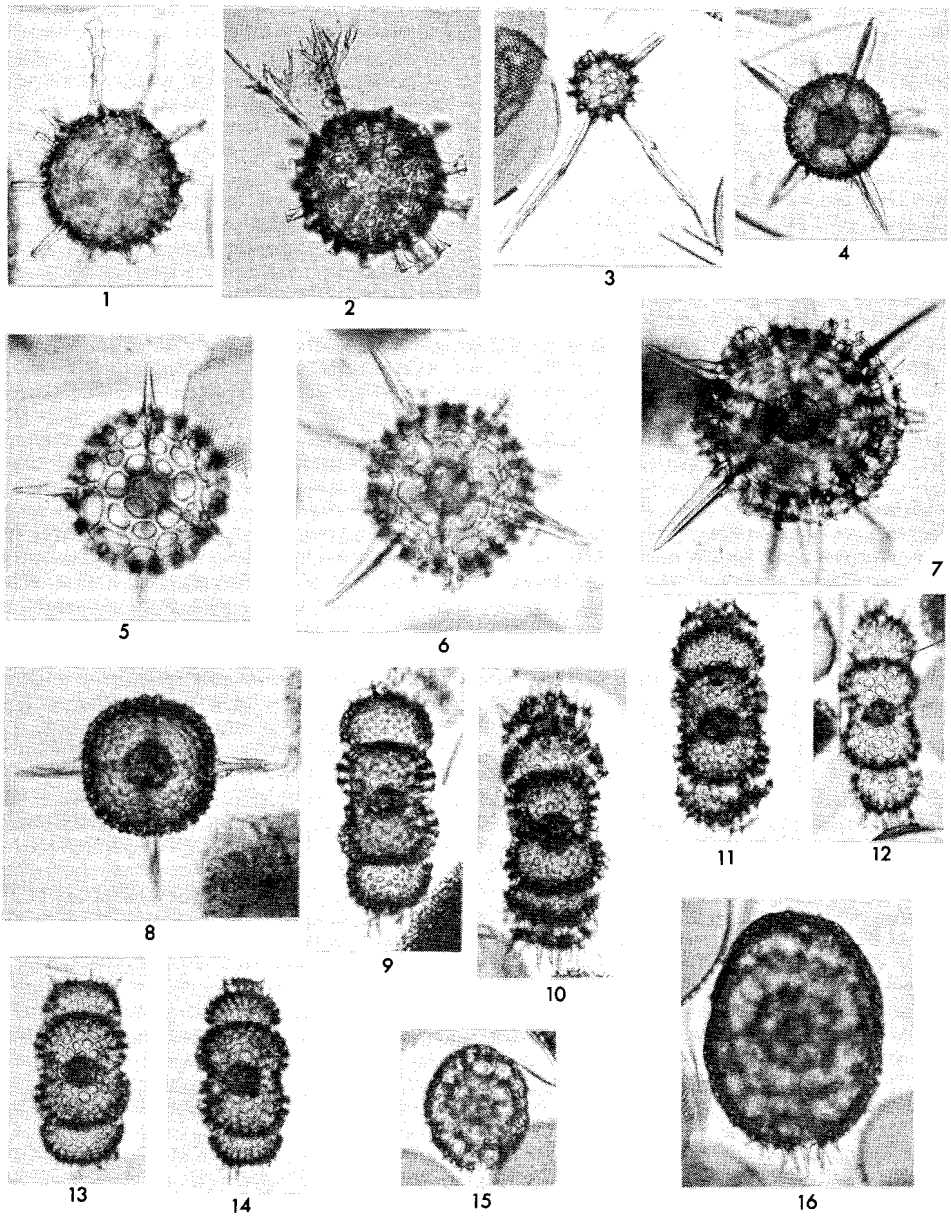
Fig. 9. *Ommatartus avitus* (Riedel).
Sample MJ 87, Cs. 2, R31/3, 135 X.

Figs. 10, 11. *Ommatartus didymus* (Ehrenberg).
10. Sample MJ 87, Cs. 2, J36/2, 135 X.
11. Sample MJ 87, Cs. 1, D38/2, 135 X.

Figs. 12–14. *Ommatartus tetrathalamus* (Haeckel).
12. Sample MJ 78, Sl. 2, U37/0, 135 X.
13. Sample MJ 87, Cs. 2, F26/3, 135 X.
14. Sample MJ 87, Cs. 2, D11/0, 135 X.

Figs. 15, 16. *Prunopyle* or *Larcopyle* indet.
15. Sample MJ 89, Sl. 6, T31/2, 195 X.
16. Sample MJ 89, Ph. 1, T43/0, 195 X

Plate 2



Genus **Stylosphaera** Ehrenberg, 1847

Stylosphaera angelina Campbell and Clark
Plate 3, figures 1–3

1944 *Stylosphaera angelina* Campbell and Clark, p. 12, pl. 1, figs. 14–20.
1974 *Stylosphaera angelina* – Riedel *et al.*, p. 706, pl. 56, fig. 2.

Remarks – In some specimens the two spines are not collineair, and very occasionally the cortical shell has a slightly irregular outline. In this respect, the specimens from the "trubi" correspond with the forms originally illustrated from California.

Genus **Thecosphaera** Haeckel, 1881

Thecosphaera grecoi Vinassa
Plate 3, figure 4

1900 *Thecosphaera grecoi* Vinassa, p. 568, pl. 1, fig. 8.
1908 *Thecosphaera leptococcos* Carnevale, p. 9, pl. 1, fig. 10.
1974 *Thecosphaera grecoi* – Riedel *et al.*, p. 707, pl. 56, fig. 3; pl. 62, figs. 2–4.

Remarks – Under this name are recorded specimens with a regularly spherical cortical shell with no external spines. Bars connecting medullary and cortical shells range from about 6–12 in number.

Family **Phacodiscidae** Haeckel, 1881

Phacodiscids indet.
Plate 3, figures 5–7

Remarks – Some of the specimens recorded as unidentified phacodiscids have more delicate cortical shells than those illustrated.

Genus **Heliodiscus** Haeckel, 1862

Heliodiscus asteriscus Haeckel
Plate 3, figure 6

1887 *Heliodiscus asteriscus* Haeckel, p. 445, pl. 33, fig. 8.
1967 *Heliodiscus asteriscus* – Nigrini, p. 32, pl. 3, figs. 1a, b.
1974 *Heliodiscus asteriscus* – Riedel *et al.*, p. 707, pl. 56, fig. 4.

Remarks – Specimens conform well with that illustrated by Riedel *et al.* (1974), varying only in the number of marginal spines.

Heliodiscus echiniscus Haeckel
Plate 3, figure 8

1887 *Heliodiscus echiniscus* Haeckel, p. 448, pl. 34, fig. 5.
1967 *Heliodiscus echiniscus* – Nigrini, p. 34, pl. 3, figs. 2a, b.
1974 *Heliodiscus echiniscus* – Riedel *et al.*, p. 707, pl. 56, fig. 5.

Remarks – Marginal spines in some specimens are unbranched, shorter than those illustrated in Pl. 3, fig. 8. We have counted as unidentified phacodiscids, specimens with branches anastomosing to the extent illustrated in Pl. 3, fig. 7.

Family **Spongodiscidae** Haeckel, emend. Riedel 1967a

Genus **Euchitonia** Ehrenberg, 1860

Euchitonia (?) spp.

1974 *Euchitonia* (?) spp. – Riedel, *et al.*, p. 707, pl. 56, figs. 6, 7; pl. 57, figs. 1–4.

Remarks – The six specimens illustrated by Riedel *et al.* (1974) adequately cover the range of variation of forms included under this name.

Genus **Spongaster** Ehrenberg, 1860

Spongaster pentas Riedel and Sanfilippo, 1970
Plate 3, figure 9

1970 *Spongaster pentas* Riedel and Sanfilippo, p. 523, pl. 15, fig. 3.
1975 *Spongaster pentas* – Sanfilippo and Riedel, p. 67.

Remarks – In this material, the number of rays varies from five to seven.

Spongodiscid sp. A
Plate 3, figures 10, 11

1971 Spongodiscid, gen. et sp. indet., Riedel and Sanfilippo, p. 1589, pl. 1D, fig. 14.
1974 Spongodiscid sp. A – Riedel *et al.*, p. 708, pl. 58, fig. 1.

Remarks – Specimens vary somewhat in size, density, and in the degree of external expression of the pylome. Some have marginal indentations, no more pronounced than illustrated in Pl. 3, fig. 11.

Spongodiscid sp. B
Plate 3, figure 12

1974 Spongodiscid sp. B – Riedel *et al.*, p. 708, pl. 58, fig. 2.

Remarks – Under this name we have recorded specimens with marginal indentations more pronounced than in Pl. 3, fig. 11.

Spongodiscids gen(n). et spp. indet.

1974 Spongodiscids gen(n). et spp. indet. – Riedel *et al.*, p. 708, pl. 58, figs. 3–5.

Remarks – The range of variation of forms included under this name is indicated by Riedel *et al.* (1974).

Family **Pyloniidae** Haeckel, 1881

Pyloniid gen. et sp. indet.
Plate 3, figures 13–14

1974 Pyloniid gen. et sp. indet. – Riedel *et al.*, p. 708, pl. 58, fig. 6.

Remarks – Rare specimens with three gates occur among the majority with two gates. Forms with elliptical girdles vary in degree of elongation.

Family **Litheliidae** Haeckel, 1862

Litheliids genn. et spp. indet.
Plate 3, figures 17–20

Remarks – Representatives of this family are either tightly or loosely coiled to form a subspherical skeleton, loosely coiled around the long axis to form a subellipsoid, or irregularly coiled and enclosed in a subellipsoidal lattice-shell.

Suborder NASSELLARIA Ehrenberg, 1875

Spyrida Ehrenberg, emend. Petrushevskaya, 1971

Spyrids gen. et spp. indet.
Plate 4, figures 1, 2

1974 Spyrids gen. et spp. indet. – Riedel *et al.*, p. 708, pl. 59, figs. 1–3.

Remarks – Spyrids of the forms illustrated occur very rarely, and cannot yet be identified satisfactorily.

Tholospyris rhombus (Haeckel) emend. Goll
Plate 4, figure 3

1887 *Archicircus rhombus* Haeckel, p. 942, pl. 81, fig. 7.
1972 *Tholospyris rhombus* (Haeckel) emend. – Goll, p. 455, pl. 16, figs. 1–11.
1975 *Tholospyris rhombus* – Sanfilippo and Riedel, p. 68, pl. 1, figs. 15, 16.

Remarks – The very rare specimens found do not vary substantially from that illustrated.

Genus **Zygocircus** Bütschli, 1881

Zygocircus productus (Hertwig)
Plate 4, figure 4

1879 *Lithocircus productus* Hertwig, p. 69, pl. 7, fig. 4.
1881 *Zygocircus productus* – Bütschli, p. 496.
1971 *Zygocircus productus* – Petrushevskaya, p. 281, figs. 16 II and 145 X, XI.
1974 *Zygocircus productus* – Riedel *et al.*, p. 709, pl. 59, figs. 4, 5.

Remarks – In addition to forms similar to those illustrated by Riedel *et al.* (1974), there are rare specimens with a loose shell formed of few bars.

Cyrtida Haeckel, emend. Petrushevskaya, 1971

Family **Plagoniidae** Haeckel, emend. Riedel, 1967a

Genus **Lophophaena** Ehrenberg, 1847

Lophophaena sp(p).

1974 *Lophophaena* sp(p). – Riedel *et al.*, p. 709, pl. 59, figs. 6, 7.

Remarks – In some specimens, the thorax is less developed than in those illustrated by Riedel *et al.* (1974).

Genus **Pseudodictyophimus** Petrushevskaya, 1971

Pseudodictyophimus gracilipes (Bailey)

1856 *Dictyophimus gracilipes* Bailey, p. 4, pl. 1, fig. 8.
1971 *Pseudodictyophimus gracilipes* – Petrushevskaya, pp. 93–95, figs. 47–49.
1974 *Pseudodictyophimus gracilipes* – Riedel *et al.*, p. 709, pl. 59, fig. 8.

Remarks – In some specimens, the feet are curved gently downward.

Family **Theoperidae** Haeckel, emend. Riedel 1967a

Theoperids genn. et spp. indet.
Plate 4, figures 5–7

Plate 3

Figs. 1–3. *Stylosphaera angelina* Campbell and Clark.
1. Sample MJ 89, Cs. 2, N34/0, 135 X.
2. Sample MJ 86, Cs. 1, H46/0, 135 X.
3. (teratological specimen – Sample MJ 87, Cs. 1, V39/0, 135 X.

Fig. 4. *Thecosphaera grecoi* Vinassa.
Sample MJ 78, Ph. 1, L30/4, 135 X.

Figs. 5, 7. Phacodiscidae genn. et spp. indet.
5. Sample MJ 78, Sl. 6, Y37/1, 135 X.
7. Sample MJ 94, Cs. 2, S27/0, 135 X.

Fig. 6. *Heliodiscus asteriscus* Haeckel.
Sample MJ 89, Cs. 2, F6/2, 135 X.

Fig. 8. *Heliodiscus echiniscus* Haeckel.
Sample MJ 89, Cs. 2, G7/2, 135 X.

Fig. 9. *Spongaster pentas* Riedel and Sanfilippo.
Sample MJ 78, Sl. 6, F41/4, 135 X.

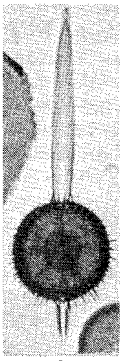
Figs. 10, 11. Spongodiscid sp. A.
10. Sample MJ 94, Cs. 1, P7/0, 135 X.
11. Sample MJ 94, Cs. 1, P33/2, 135 X.

Fig. 12. Spongodiscid sp. B.
Sample MJ 94, Cs. 1, O34/0, 135 X.

Figs. 13–16. Pyloniidae genn. et spp. indet.
13. Sample MJ 87, Cs. 2, W46/0, 135 X.
14. Sample MJ 94, Ph. 1, F14/2, 135 X.
15. Sample MJ 87, Cs. 2, S16/4, 135 X.
16. Sample MJ 89, Sl. 2, O45/1, 135 X.

Figs. 17–20. Litheliidae genn. et spp. indet.
17. Sample MJ 87, Sl. 6, W14/2, 195 X.
18. Sample MJ 87, Sl. 6, Z8/4, 195 X.
19. Sample MJ 87, Sl. 6, Q41/0, 195 X.
20. Sample MJ 87, Sl. 6, T35/3, 195 X.

Plate 3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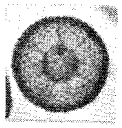
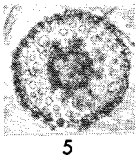
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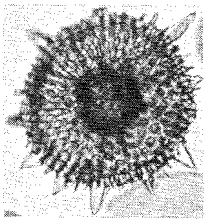
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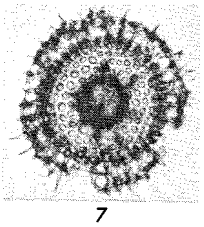
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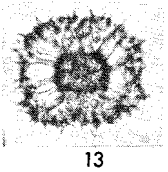
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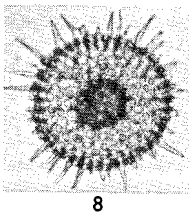
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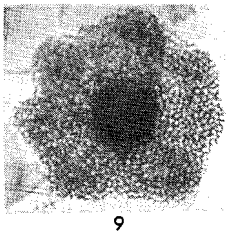
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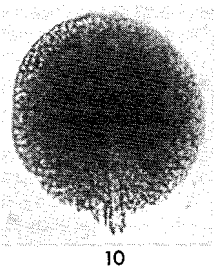
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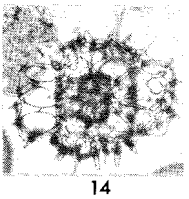
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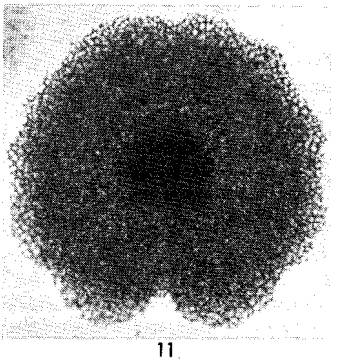
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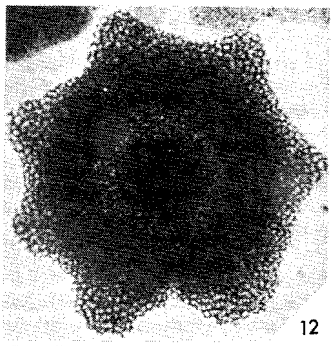
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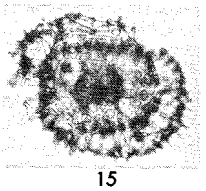
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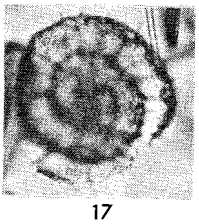
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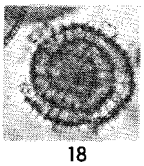
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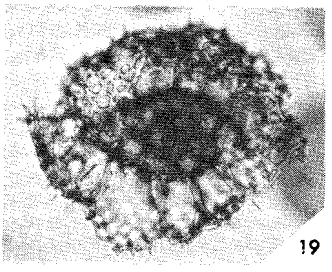
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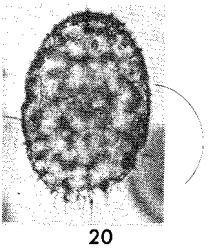
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Remarks – Only the most common of the forms tabulated as indeterminate theoperids are illustrated.

Cornutella profunda Ehrenberg
Plate 4, figure 8

1854a *Cornutella clathrata? β profunda* Ehrenberg, p. 241.
1854b *Cornutella clathrata β profunda* Ehrenberg, pl. 35B, B, IV, fig. 21.
1858 *Cornutella profunda* Ehrenberg, p. 31.
1967 *Cornutella profunda* – Nigrini, p. 60, pl. 6, figs. 5 a-c.

Remarks – The outer form of the conical shell can be less regular than in the specimen illustrated, and the shell wall can be thicker with smaller pores.

Genus **Eucecryphalus** Haeckel, 1860

Eucecryphalus elisabethae (Haeckel)
Plate 4, figure 9

1887 *Corocalyptra elisabethae* Haeckel, p. 1323, pl. 59, fig. 10.
1971 *Eucecryphalus elisabethae* emend. – Petrushevskaya, p. 224, fig. 105.
1974 *Eucecryphalus elisabethae* – Riedel *et al.*, p. 710, pl. 59, fig. 10.

Remarks – The width of the abdominal brim can vary between that illustrated here and the specimen illustrated by Riedel *et al.* (1974).

Genus **Eucyrtidium** Ehrenberg, 1847

Eucyrtidium cienkowskii Haeckel group, Sanfilippo *et al.*
Plate 4, figures 10–13

cf. 1887 *Eucyrtidium cienkowskii* Haeckel, p. 1493, pl. 80, fig. 9.
1973 *Eucyrtidium cienkowskii* group – Sanfilippo *et al.*, p. 221, pl. 5, figs. 7–11.
1974 *Eucyrtidium cienkowskii* group – Riedel *et al.*, p. 710, pl. 59, fig. 11.

Remarks – The specimen illustrated by Riedel *et al.* (1974) has the characters regarded as "most typical" of this species group. Specimens illustrated herein demonstrate the principal variations in characters encountered, namely the occasional presence of three small wings on the thorax or the third segment, segments down to about the fifth involved in the conical part of the shell, and irregularity of sutures between segments.

Eucyrtidium punctatum (Ehrenberg) group, Sanfilippo *et al.*
Plate 4, figures 14–16

cf. 1844 *Lithocampe punctata* Ehrenberg, p. 84.
cf. 1847 *Eucyrtidium punctatum* – Ehrenberg, p. 43.
1973 *Eucyrtidium punctatum* group – Sanfilippo *et al.*, p. 221, pl. 5, figs. 15, 16.
1974 *Eucyrtidium punctatum* group – Riedel *et al.*, p. 710, pl. 59, fig. 12; pl. 62, fig. 6.

Remarks – Variable characters include the presence or absence of inconspicuous wings on the thorax, the regularity of pore arrangement, and the degree of constriction of the shell mouth.

Genus **Lampromitra** Haeckel, 1881

Lampromitra erosa Cleve

1900 *Lampromitra erosa* Cleve, p. 10, pl. 4, figs. 2, 3.
1913 *Lampromitra erosa?* – Popofsky, pp. 345–346, text-fig. 52.
1974 *Lampromitra erosa* – Riedel *et al.*, p. 710, pl. 59, fig. 13; pl. 62, fig. 7.

Remarks – The thorax in some specimens is smaller than that illustrated by Riedel *et al.* (1974).

Genus **Lithomelissa** Ehrenberg, 1847

Lithomelissa campanulaeformis Campbell and Clark

1944 *Lithomelissa campanulaeformis* Campbell and Clark, p. 41, pl. 6, fig. 1.
1974 *Lithomelissa campanulaeformis* – Riedel *et al.*, p. 711, pl. 60, figs. 1, 2; pl. 62, fig. 11.

Remarks – The very rare specimens of this species correspond well with those illustrated by Riedel *et al.* (1974), but some have thinner skeletal bars and less prominent spinules.

Lychnodictyum audax Riedel, 1953
Plate 4, figure 17

1953 *Lychnodictyum audax* Riedel, p. 810, pl. 85, fig. 9.
1975 *Lychnodictyum audax* – Sanfilippo and Riedel, p. 66.

Remarks – Very rare specimens occur in samples MJ85 and MJ89, some with slightly more abdominal meshwork than the holotype.

Genus **Pterocanium** Ehrenberg, 1847

Pterocanium sp(p).
Plate 4, figure 18; plate 5, figure 1

1974 *Pterocanium* sp(p). – Riedel *et al.*, p. 711, pl. 60, figs. 3–6.

Remarks – Representatives of this genus vary markedly in the shape of the

Plate 4

Figs. 1, 2. Spyrida genn. et spp. indet.
1. Sample MJ 89, Sl. 2, V22/3, 195 X.
2. Sample MJ 94, Ph. 2, L15/1, 195 X.

Fig. 3. *Tholospyris rhombus* (Haeckel).
Sample MJ 89, Sl. 2, Y24/1, 195 X.

Fig. 4. *Zygocircus productus* (Hertwig).
Sample MJ 87, Ph. 1, O10/1, 195 X.

Figs. 5–7. Theoperidae genn. et spp. indet.
5. Sample MJ 87, Ph. 1, T8/1, 195 X.
6. Sample MJ 87, Ph. 2, U20/0, 195 X.
7. Sample MJ 89, Sl. 3, Z17/0, 195 X.

Fig. 8. *Cornutella profunda* Ehrenberg.
Sample MJ 89, Ph. 2, Q20/0, 195 X.

Fig. 9. *Eucecryphalus elisabethae* (Haeckel).
Sample MJ 86, Cs. 1, Z7/4, 135 X.

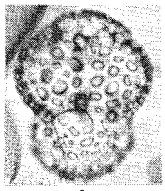
Figs. 10–13. *Eucyrtidium cienkowskii* Haeckel group.
10. Sample MJ 89, Ph. 1, J27/0, 195 X.
11. Sample MJ 89, Ph. 2, P7/3, 195 X.
12. Sample MJ 89, Sl. 5, R21/2, 195 X.
13. Sample MJ 89, Ph. 2, K45/3, 195 X.

Figs. 14–16. *Eucyrtidium punctatum* (Ehrenberg) group.
14. Sample MJ 89, Ph. 2, P27/0, 195 X.
15. Sample MJ 89, Ph. 2, N18/0, 195 X.
16. Sample MJ 89, Ph. 2, F23/1, 195 X.

Fig. 17. *Lychnodictyum audax* Riedel.
Sample MJ 85, Cs. 1, X28/0, 195 X.

Fig. 18. *Pterocanium* sp.
Sample MJ 86, Cs. 2, R27/1, 195 X.

Plate 4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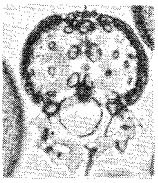
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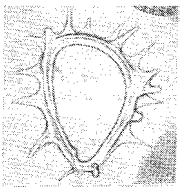
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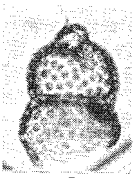
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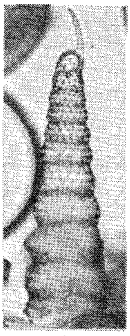
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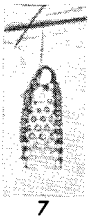
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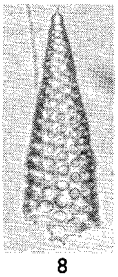
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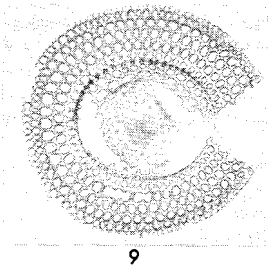
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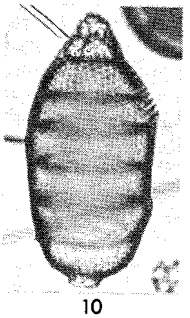
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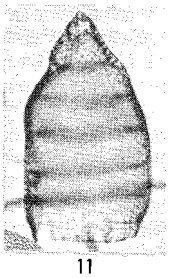
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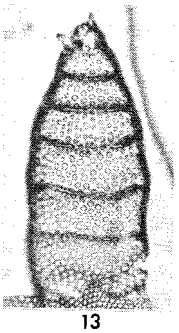
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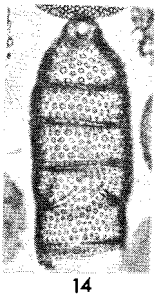
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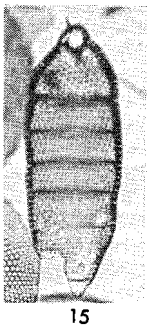
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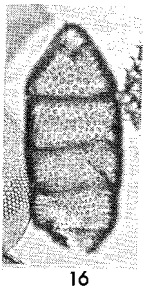
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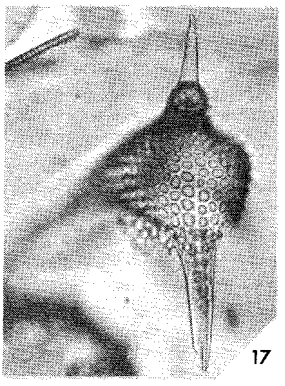
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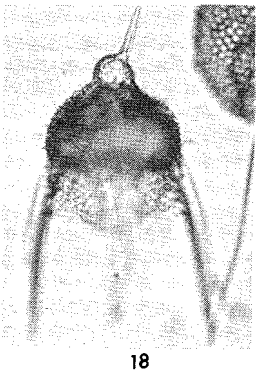
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thorax and degree of divergence of the feet, as indicated by the specimens illustrated herein and by Riedel *et al.* (1974).

Genus **Stichocorys** Haeckel 1881

Stichocorys delmontensis (Campbell and Clark)
Plate 5, figures 2–4

1944 *Eucyrtidium delmontense* Campbell and Clark, p. 56, pl. 7, figs. 19, 20.
1970 *Stichocorys delmontensis* – Sanfilippo and Riedel, p. 451, pl. 1, fig. 9.
1974 *Stichocorys delmontensis* – Riedel *et al.*, p. 711, pl. 60, fig. 7.
1975 *Stichocorys* sp. cf. *S. delmontensis* – Sanfilippo and Riedel, p. 67, pl. 1, figs. 12, 13.

Remarks – As is shown by the illustrated specimens, this species varies in the degree of distinctness of the conical portion of the shell formed by the first three segments, the width and length of subsequent segments, and the degree of constriction distally.

Stichocorys peregrina (Riedel)
Plate 5, figures 5–7

1953 *Eucyrtidium elongatum peregrinum* Riedel, p. 812, pl. 85, fig. 2.
1970 *Stichocorys peregrina* – Sanfilippo and Riedel, p. 451, pl. 1, fig. 10.
1974 *Stichocorys peregrina* – Riedel *et al.*, p. 712, pl. 60, figs. 8, 9.
1975 *Stichocorys peregrina* – Sanfilippo and Riedel, p. 68, pl. 1, fig. 14.

Remarks – The thorax tends to be truncate-conical, and the fourth segment is of approximately the same width as the third.

Family **Pterocorythidae** Haeckel, emend. Riedel, 1967a

Pterocorythids genn. et spp. indet.
Plate 5, figures 8–11

Remarks – Under this name are recorded a form which has terminal teeth and is narrower and more compact than *Pterocorys* sp. aff. *P. hertwigii*, and others not sufficiently complete or distinctive for identification.

Genus **Anthocyrtidium** Haeckel 1881

Anthocyrtidium ehrenbergi (Stöhr)
Plate 5, figure 12

1880 *Anthocyrtis ehrenbergi* Stöhr, p. 100, pl. 3, figs. 21a, b.
1887 *Anthocyrtium ehrenbergii* – Haeckel, p. 1277.
1957 *Anthocyrtium ehrenbergii* – Riedel, pp. 83–87, pl. 2, figs. 1–5.
1974 *Anthocyrtidium ehrenbergi* – Riedel *et al.*, p. 712, pl. 60, fig. 10; pl. 61, fig. 1.

Remarks – The specimens illustrated here and by Riedel *et al.* (1974) illustrate the variations in shape of the thorax. Terminal teeth vary markedly in their degree of development.

Genus **Lamprocyclas** Haeckel, 1881

Lamprocyclas maritalis Haeckel
Plate 6, figures 1, 2

1887 *Lamprocyclas maritalis* Haeckel, p. 1390, pl. 74, figs. 13, 14.
1967 *Lamprocyclas maritalis maritalis* Haeckel and *L. maritalis polypora* Nigrini – Nigrini, pp. 74–77, pl. 7, figs. 5, 6.
1974 *Lamprocyclas maritalis* – Riedel *et al.*, p. 712, pl. 61, figs. 2, 3.

Remarks – The shape of the thorax and abdomen, and the degree of development of the teeth, vary as shown by the illustrations here and in Riedel *et al.* (1974).

Genus **Pterocorys** Haeckel, 1881

Pterocorys sp. aff. **P. hertwigii** (Haeckel)
Plate 6, figures 3, 4

aff. 1887 *Eucyrtidium hertwigii* Haeckel, p. 1491, pl. 80, fig. 12.
aff. 1972 *Pterocorys hertwigii* – Petrushevskaya, fig. 1 (10).
1974 *Pterocorys* sp. aff. *P. hertwigii* – Sanfilippo and Riedel, pl. 4, figs. 1, 2.
1974 *Pterocorys* sp. aff. *P. hertwigii* – Riedel *et al.*, p. 712, pl. 61, fig. 4.

Remarks – This name is used to cover forms that vary widely in the size and shape of the abdomen, which can be subcylindrical, or expanded or contracted distally, with its termination undifferentiated or poreless and without teeth.

Family **Carpocaniidae** Haeckel, emend. Riedel 1967a

Genus **Carpocanistrum** Haeckel, 1887

Carpocanistrum Haeckel spp.
Plate 6, figures 5–9

1971 *Carpocanistrum* spp. Riedel and Sanfilippo, p. 1596, pl. 1G, figs. 1–6, 7 (?), 8–13, 14 (?), 15 (?); pl. 2F, figs. 5–16; pl. 30, figs. 1, 2, 3–5 (?), 6, 7, 8 (?), 9.
1974 *Carpocanistrum* spp. – Riedel *et al.*, p. 713, pl. 61, figs. 5, 6.

Remarks – Forms included here vary in the degree of longitudinal alignment of thoracic pores, degree of constriction of the mouth, and presence or absence of peristomial teeth.

Plate 5

Fig. 1. *Pterocanium* sp.
Sample MJ 94, Cs. 1, S29/0, 195 X.

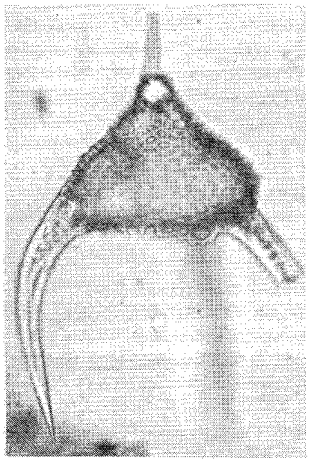
Figs. 2–4. *Stichocorys delmontensis* (Campbell and Clark).
2. Sample MJ 86, Cs. 2, D10/3, 195 X.
3. Sample MJ 87, Cs. 1, F11/2, 195 X.
4. Sample MJ 87, Cs. 1, X10/1, 195 X.

Figs. 5–7. *Stichocorys peregrina* (Riedel).
5. Sample MJ 87, Cs. 1, V14/0, 195 X.
6. Sample MJ 86, Cs. 2, R36/0, 195 X.
7. Sample MJ 87, Cs. 1, N12/3, 195 X.

Figs. 8–11. Pterocorythidae genn. et spp. indet.
8. Sample MJ 87, Sl. 1, E32/0, 135 X.
9. Sample MJ 87, Sl. 6, O25/2, 135 X.
10. Sample MJ 87, Sl. 1, S8/3, 135 X.
11. Sample MJ 89, Sl. 4, X18/1, 135 X.

Fig. 12. *Anthocyrtidium ehrenbergi* (Stöhr).
Sample MJ 89, Cs. 2, P34/4, 135 X.

Plate 5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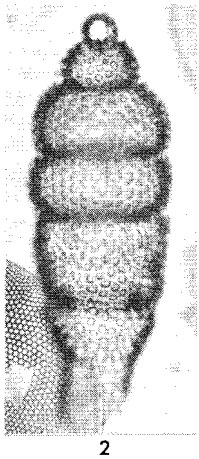
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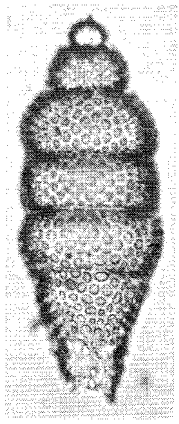
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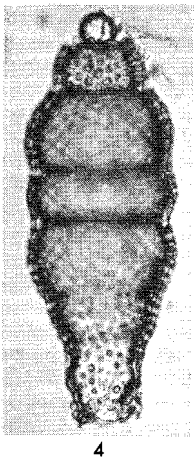
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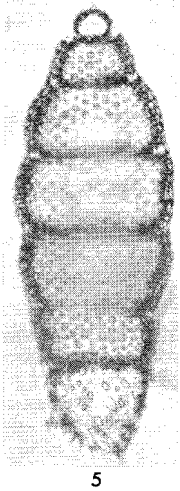
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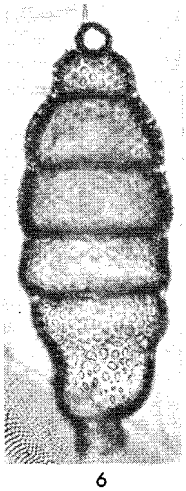
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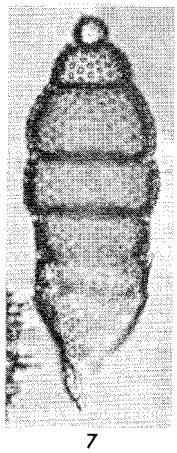
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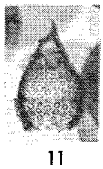
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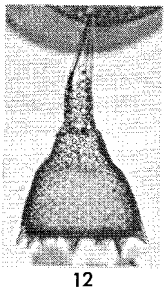
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Family **Artostrobiidae** Riedel, 1967b

Genus **Artostrobium** Haeckel, 1887

Artostrobium auritum (Ehrenberg) group
Plate 6, figures 10–12

1844 *Lithocampe aurita* Ehrenberg, p. 84.
1854b *Lithocampe aurita* – Ehrenberg, pl. 22, fig. 25.
1971 *Artostrobium auritum* group – Riedel and Sanfilippo, p. 1599, pl. 1H, figs. 5–8.
1974 *Artostrobium auritum* group – Riedel *et al.*, p. 713, pl. 61, fig. 7.

Remarks – As is indicated by the illustrations, forms included in this group vary in the degree of regularity and expansion of the post-thoracic segments, and in the number of pore-rows on each segment.

Lithomitra lineata (Ehrenberg) group
Plate 6, figure 13

1838 *Lithocampe lineata* Ehrenberg, p. 130.
1854b *Lithocampe lineata* – Ehrenberg, pl. 22, fig. 26; pl. 36, fig. 16.
1887 *Lithomitra lineata* – Haeckel, p. 1484.
1971 *Lithomitra lineata* (Ehrenberg) group Riedel and Sanfilippo, p. 1600, pl. 1I, figs. 1–11; pl. 21, figs. 14–16; pl. 3E, fig. 14.

Remarks – The number of transverse rows of pores on the third segment varies from 4 to 9, and its profile varies from straight to slightly wavy.

Siphocampe corbula (Harting)
Plate 6, figure 14

1863 *Lithocampe corbula* Harting, p. 12, pl. 1, fig. 21.
1967 *Siphocampe corbula* – Nigrini, p. 85, pl. 8, fig. 5; pl. 9, fig. 3.
1971 *Siphocampe corbula* – Riedel and Sanfilippo, p. 1601, pl. 1H, figs. 18–25.

Remarks – The fourth segment can be slightly longer or shorter than in the illustrated specimen.

Spirocyrtis sp.
Plate 6, figures 15, 16

1971 *Spirocyrtis* sp. cf. *S. scalaris* Haeckel – Riedel and Sanfilippo, p. 1601, pl. 1G, figs. 19–24; pl. 2H, figs. 15–18.

Remarks – Some specimens differ from those illustrated by having longer segments beyond the third, each with four or five transverse rows of pores, by these distal segments sometimes widening abruptly, and by the presence of small wings on the thorax.

Family **Cannobotrythidae** Haeckel, emend. Riedel, 1967a

Genus **Botryopyle** Haeckel, 1881

Botryopyle dictyocephalus Haeckel group Riedel and Sanfilippo
Plate 6, figure 17

cf. 1887 *Botryopyle dictyocephalus*, p. 1113, pl. 96, fig. 6.
1971 *Botryopyle dictyocephalus* group – Riedel and Sanfilippo, p. 1602, pl. 1J, figs. 21–26; pl. 2J, figs. 16–18; pl. 3F, figs. 9–12.

Remarks – Some specimens are slightly more or less porous than that illustrated, and have a longer or shorter thorax.

INCERTAE SEDIS

Genus **Carpocanarium** Haeckel, 1887

Carpocanarium sp.
Plate 6, figure 18

1971 *Carpocanarium* spp. Riedel and Sanfilippo, p. 1599, pl. 1I, figs. 17–25; pl. 2J, figs. 8, 9.

Remarks – Some specimens have a better developed and more constricted poreless peristome than the illustrated example, and slightly better developed wings.

Genus **Pseudocubus** Haeckel, 1887

Pseudocubus vema (Hays)
Plate 6, figures 19, 20

1965 *Helotholus vema* Hays, p. 176, pl. 2, fig. 3, text-fig. A.
1971 *Pseudocubus vema* – Petrushevskaya, p. 46, fig. 24I–IV.
1972 *Pseudocubus vema* – Keany and Kennett, p. 539, fig. 4, nos. 10, 11.
1975 *Pseudocubus vema* – Sanfilippo and Riedel, p. 67, pl. 1, figs. 8–11.

Remarks – The "trubi" specimens have the same range of variation as is illustrated for the specimens from Crete (Sanfilippo and Riedel, 1975).

Plate 6

Figs. 1, 2. *Lamprocyclas maritalis* Haeckel.
1. Sample MJ 89, Cs. 2, Y38/3, 135 X.
2. Sample MJ 89, Cs. 2, S16/1, 135 X.

Figs. 3, 4. *Pterocorys* sp. aff. *P. hertwigii* (Haeckel).
3. Sample MJ 87, Ph. 1, X9/0, 135 X.
4. Sample MJ 86, Ph. 1, Y10/0, 135 X.

Figs. 5–9. *Carpocanistrum* spp.
5. Sample MJ 94, Ph. 2, S10/1, 195 X.
6. Sample MJ 89, Ph. 1, X30/0, 195 X.
7. Sample MJ 94, Ph. 2, O33/3, 195 X.
8. Sample MJ 89, Ph. 1, V39/3, 195 X.
9. Sample MJ 89, Ph. 1, J35/3, 195 X.

Figs. 10–12. *Artostrobium auritum* (Ehrenberg) group.
10. Sample MJ 89, Ph. 1, V26/3, 195 X.
11. Sample MJ 87, Ph. 2, Q21/4, 195 X.
12. Sample MJ 89, Ph. 1, U13/0, 195 X.

Fig. 13. *Lithomitra lineata* (Ehrenberg) group.
Sample MJ 87, Sl. 6, Z12/1, 195 X.

Fig. 14. *Siphocampe corbula* (Harting).
Sample MJ 89, Sl. 2, M24/1, 195 X.

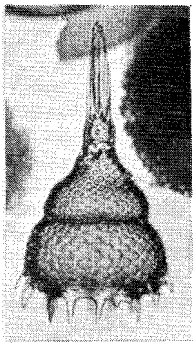
Figs. 15, 16. *Spirocyrtis* sp.
15. Sample MJ 87, Ph. 2, P13/1, 195 X.
16. Sample MJ 89, Sl. 3, Z11/4, 195 X.

Fig. 17. *Botryopyle dictyocephalus* Haeckel group.
Sample MJ 87, Ph. 2, O23/1, 195 X.

Fig. 18. *Carpocanarium* sp.
Sample MJ 89, Sl. 2, E26/1, 195 X.

Figs. 19, 20. *Pseudocubus vema* (Hays).
19. Sample MJ 87, Ph. 2, Z43/4, 195 X.
20. Sample MJ 87, Ph. 2, S43/4, 195 X.

Plate 6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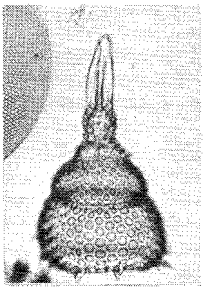
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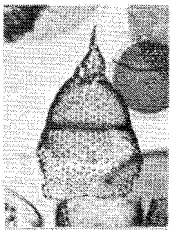
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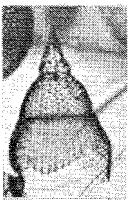
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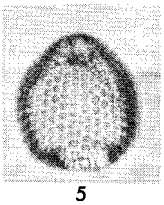
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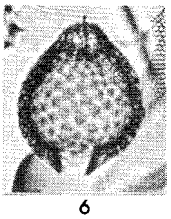
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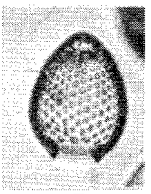
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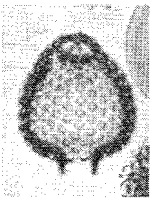
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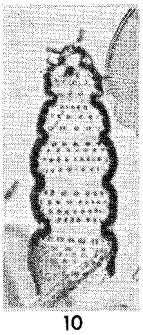
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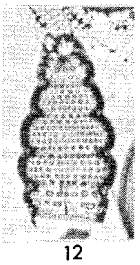
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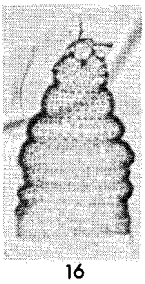
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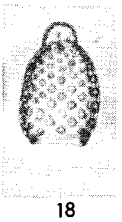
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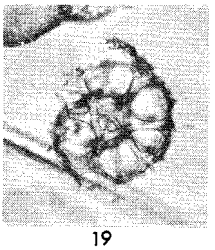
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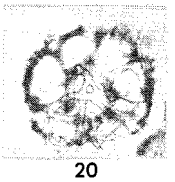
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DIATOMS AND SILICOFLAGELLATES

H.-J. SCHRADER and R. GERSONDE

DIATOMS

THE SAMPLES

The samples CRP 8–45 from the Capo Rossello section (M. J. Brolsma and J. A. Broekman, this volume) each cover a 5 cm thick interval. They consisted of 0.5 to 1.0 kg of dry material and were later broken into small pieces of less than 1 cm^3. These pieces were mixed mechanically and subsamples were available for the counting procedure in Utrecht (March-April, 1976). Although the amount of material needed for diatom research is usually rather small (Schrader, 1973a) we wanted to prevent additional fractionation. As a consequence, the entire subsample was used for preparation. The subsamples consisted of between 5.16 and 10.54 g of dry sediment. Since these subsamples represented approximately 1/100th part of the original sample there may be serious doubt as to whether our subsamples are representative for the 5 cm thick sample interval, especially with regard to the finely laminated parts. A sample from a laminated interval may contain different facies types and depending on the grade of later mixing may be representative for only a minor part of the sampled interval.

We recommend that sampling for future detailed quantitative analyses be carried out in different ways for the separate groups of microfossils; for diatoms samples must cover as thin a sediment interval as possible and no channel samples or mixed samples should be used for detailed analyses.

CLEANING OF RAW MATERIAL

In contrast to the proposed standard diatom cleaning procedure (Schrader, 1973a) the entire subsample was used for preparation. This procedure required considerably longer preparation times. The individual subsamples were gently pressed to break them into smaller pieces, dried for 24 hours at 60°C, and weighed on an analytical automatic balance. The material was then placed in beakers of 400 ml and boiled in a mixture of 25 ml chemically clean H_2O_2 (30%) and 25 ml chemically clean concentrated HCl until all carbonates had been dissolved and the strong boiling reaction stopped.

Strong foam formation was stopped by adding a few drops of ethanol. The residue was washed by adding approximately 350 ml demineralized water. After 90 minutes of settling time, the water together with the still suspended clay was gently removed using a vacuum pump until 50 ml of acid-resistant residue was left in the beaker. Again demineralized water was added and after thorough stirring and another 90 minutes of settling 50 ml was left. This procedure was repeated seven times. The final residue was transferred to a 50 ml Nalgene narrow-mouth storage bottle and diluted to exactly 50 ml; a few drops of chemically clean concentrated formaldehyde were added for preservation. The settling procedure had removed most of the clay fraction, along with which only a small proportion of weakly silicified very small diatoms and strongly fragmented larger diatom frustules had disappeared.

For the first rough check on diatom contents a 0.1–0.2 ml split was taken after thorough shaking of the residues. The only samples considered worth investigating were those that contained at least one complete or fragmented diatom frustule in this split. Only 17 of the 39 samples could therefore be said to contain diatoms. Four of the 17 samples were so poor (traces only) that they do not figure in the rangechart of figure 2: CRP 9, 13, 15 and 31.

PREPARATION OF PERMANENT MOUNTS

In order to obtain comparable distributions, sample splits were extracted in such a way that they correspond to 0.2 gram of the original sample, using an Eppendorf automatic pipette. The appropriate volume to be taken was calculated from the original sample weight. After the 50 ml Nalgene bottle had been shaken thoroughly the representative aliquot was taken from the homogenized suspension of the acid resistant residue. The fluid and accompanying residue were transferred to another Nalgene bottle and diluted to 50 ml with demineralized water. After shaking, a subsample of 0.2 ml was taken from this bottle with an Eppendorf pipette and placed on a cleaned 18 × 18 mm^2 cover-glass which had been previously wetted with 0.5 ml. aqua bidest. The subsample was spread on the cover glass in small circles to avoid strong fractionation, after which the water was evaporated at about 45°C; 2 or 3 drops of Aroclor 4465 (n_C = 1.665) dissolved in xylene were added and the xylene solvent was evaporated at 120°C.

COUNTING METHODS

All counting was done using a Leitz Orthoplan wide field microscope with aprochromatic objectives (Fl Oil 54 ×, 0.95 n.A.; Apo Oil 90 ×, 1.4

n.A.). The majority of the counts were carried out separately by both authors on the same slides using the highest magnification available. Diatom valves were counted as one unit (fig. 1) for:

A Circular Centrales (*Coscinodiscus*), in cases when half or more of a valve was present.

B Circular Centrales with pseudonodulus (*Actinocyclus*), in cases when one complete valve or a fragment with the pseudonodulus were present.

C Centrales with pseudonodulus (*Hemiaulus*), in cases when one complete valve or a fragment with the pseudonodulus were present.

D Angular Centrales (*Triceratium*), in cases when half or more of a valve was present.

E Pennales-Araphids (*Thalassionema*) in case of presence of one complete valve or of two apical ends.

F Pennales-Monoraphids and Biraphids (*Diploneis*), in cases when one complete valve or the central part with the central nodule was present.

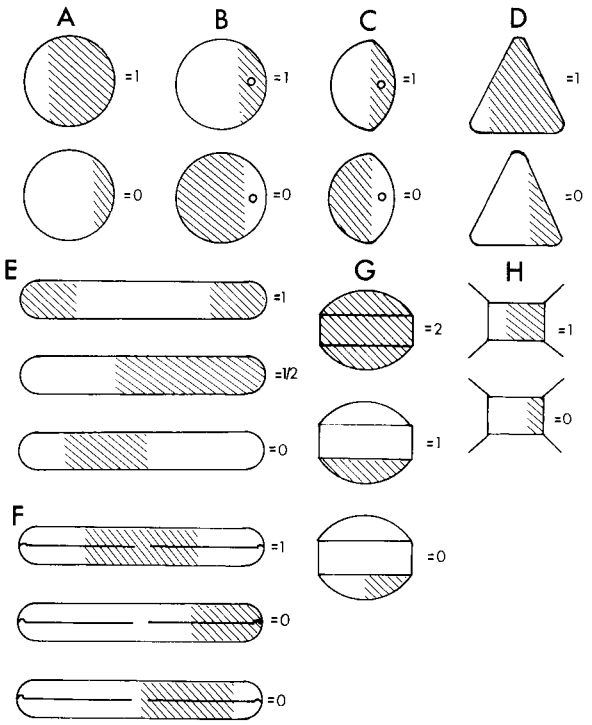


Fig. 1 Counting convention; for explanation see text. Shaded areas = fragments found in slides and used to define units.

G Spores of Centrales (*Chaetoceros*), when one complete valve or a fragment representing more than half of a valve was present.
H Centrales with filament (*Chaetoceros*), in cases when more than half of the main part of a valve was present.

TOTAL NUMBER ESTIMATES

In each slide the diatoms were counted along the traverses x and y (fig. 2). Each traverse measures 18,000 × 240 μ. From the number per traverse the contents of diatom valves per gram of original dry sediment were calculated in the following way:

(1) The counted diatoms (X) on one traverse are found on 18,000 × 240 = 432.10^4 μ^2.
(2) Each traverse represents 1/75 of the total surface of the cover glass; surface is 432.10^4 μ^2 × 75 = 18,000 × 18,000 μ^2 = 324.10^6 μ^2 (75 X).
(3) The diatom valves per total cover slide represent the number of valves in 0.2 ml sample split from the subsample (residue of 0.2 g of original sample in 50 ml) (250.75 X).
(4) Per 1 g of sediment the number of diatom valves is 5.250.75 X ~ 94.10^3 X.

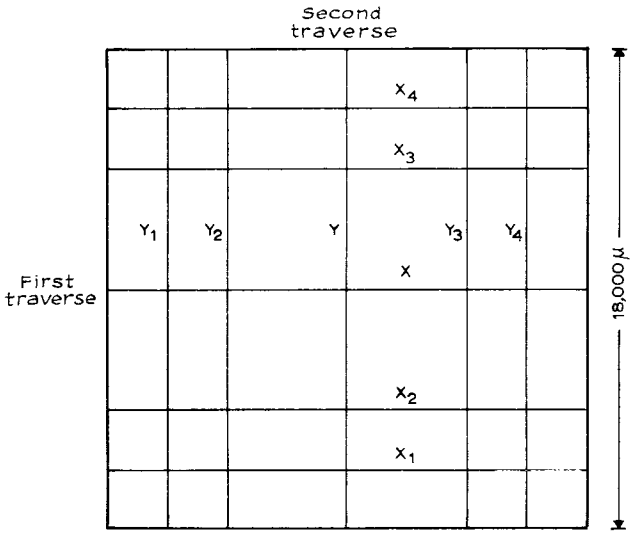


Fig. 2 Position of the two standard traverses (x and y) and of the eight additional traverses on the cover glass (x_1-x_4 and y_1-y_4). The extra traverses were laid parallel to the cover glass edges at 1/4 and 1/8 of the total width and each one measured 18,000 μ × 240 μ.

The counts on the two traverses (x and y) were used to calculate the mean. The mean deviation (M.D.) and the mean deviation in percentage values can be calculated as well.

Maximum numbers of valves per traverse range from 0 to 310 with maximum percentage deviations from the mean of 25% for two samples with both rather high and with rather low total numbers.

A test was performed on CRP 29A to get an idea about the random distribution of individuals over a total cover glass. This sample has a relatively high number of diatoms (20.10^6/g of sediment). A similar test was carried out on sample CRP 23 with a relatively low number of diatoms per gram (12.10^6). In addition to the x and y traverses eight other traverses were counted (fig. 2). These counts (table 1) demonstrate that the highest diatom accumulations occur in the central part of the cover glasses; numbers diminish towards the edges of the slide. The numbers decrease from the middle traverse to the outmost traverses in the ratio of 1 : 0.5 or 0.4 (table 2, fig. 3).

CRP	y_1	y_2	y	y_3	y_4	x_1	x_2	x	x_3	x_4
23	33	71	116	95	55	48	120	141	111	44
29A	131	151	212	154	116	105	118	220/213	148	91

Table 1. Counts in 10 traverses (compare fig. 2) over the same slide for samples CRP 23 and 29A.

	CRP 23 mean ± M.D.	CRP 29A mean ± M.D.
$\frac{x_1 + x_4 + y_1 + y_4}{4}$	45 ± 6	110.75 ± 9
$\frac{x_2 + x_3 + y_2 + y_3}{4}$	99.25 ± 11	142.75 ± 8
$\frac{x + y}{2}$	128.5 ± 13	215 ± 4

Table 2. Mean values of numbers of diatoms and corresponding M.D. values over the comparable traverses in samples CRP 23 and 29A.

Evidently diatom frustules are not randomly distributed over the slide, but they decrease in numbers from the middle traverses to the outside ones. The density in the marginal areas of a slide at 1/8 of its width is less than half the density in the middle traverses.

Differences in the total number counts of both authors were compared by counting exactly along the same traverse. Counting of an x traverse of sample CRP 29A by both authors revealed almost identical numbers (220 and 213), the difference being only 2%.

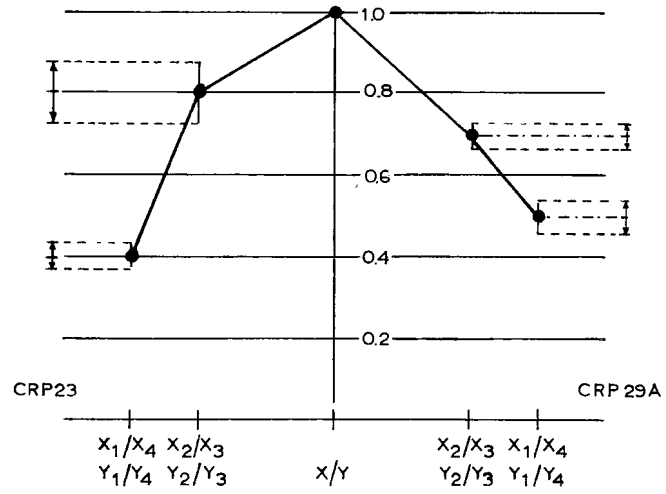


Fig. 3 Counting results over the 5 x and 5 y traverses for samples CRP 23 and 29A, shown as ratios (compare fig. 2 and table 1).

The results demonstrated above reveal that various errors are incorporated; these may be either avoidable or unavoidable. Avoidable errors are expected to be the result of:

1) Inaccurate sampling over too thick intervals with frequently changing sediment properties (laminated and homogeneous sediments).
2) Inaccurate sample cleaning, e.g. imperfect transferring of residue into the storage bottle after cleaning.
3) Inaccurate slide preparation, e.g. uneven spreading of the split on the cover slide.
4) Counting differences by different individuals.

Unavoidable and constant errors include:

1) Uneven distribution of diatom valves in the 50 ml Nalgene bottle when the subsample is taken, even after thorough shaking and homogenization of the residue.
2) Uneven distribution of diatom valves over the slide (shown above).

The avoidable errors 1 to 4 can be eliminated, and were not taken into account for the present calculations, since great care was taken to avoid such

errors. The constant errors have a greater effect on the quantitative results. Counts over the middle and over the edge traverses differ by 50% or more. The counts made over the middle of the slides should be corrected by minus 20%, to give a better approximation of the actual numbers per gram of sediment. In the present paper the numbers per gram of sediment presented have not been corrected by this factor.

Total calculated diatom numbers are recorded in table 3 and illustrated in figure 4. All samples from the homogeneous marls are devoid of diatoms with the exception of sample CRP 28, which was taken close to the boundary between a homogeneous marl and laminated diatomaceous sediment. The laminated marls on the other hand do not necessarily contain diatom skeletons (compare in figure samples CRP 9 through 14, with CRP 22 through 27).

In our calculation system samples with low diatom contents (less than 1.10^6 valves per g) may have error estimates of up to 100%. These high errors do not necessarily affect the order of magnitude of the calculated diatom content. In our system samples with higher diatom contents (over 1.10^6 valves per g) may incorporate an error of up to 25%. This error estimate cannot be eliminated if one counts only two traverses on a slide.

A major error component is caused by fecal pellets consisting of diatom valves and fragments. The occurrence of one fecal pellet (compare figures in Schrader, 1971a, plate 1, fig. 1–2, 4) covering a traverse may enlarge the total number of counted valves in this traverse by some 25%.

Comparison of samples CRP 29 and 29A (29A is a subsample of CRP 29 representing a 2 cm interval out of the 5 cm interval) shows a difference in the numbers of diatom valves per gram of 4.5×10^6, which is of the order of 10%. Since both samples represent the same interval this difference demonstrates that the methods applied result in comparable values. Greater differences were observed in samples CRP 22–26, and it might be argued that these samples were taken from slightly different horizons (fig. 4).

Total numbers of diatoms per given volume or weight are thought to allow qualitative estimates of primary production at the time of deposition. Since 90–99% of the produced biogenic opal may not reach the sediment (Lisitzin, 1971; for more accurate data compare Wollast, 1974) to become part of the geological record the observed numbers are of dubious value in this respect. The degree of dissolution of opal skeletons during settling, during exposure on the seafloor, and during early diagenesis, depends largely on water depth, descending time, exposure time on the seafloor, and on the hydrography of the area under discussion. Highly oxygenated waters are more aggressive than those with a lower oxygen content. Laminated sedi-

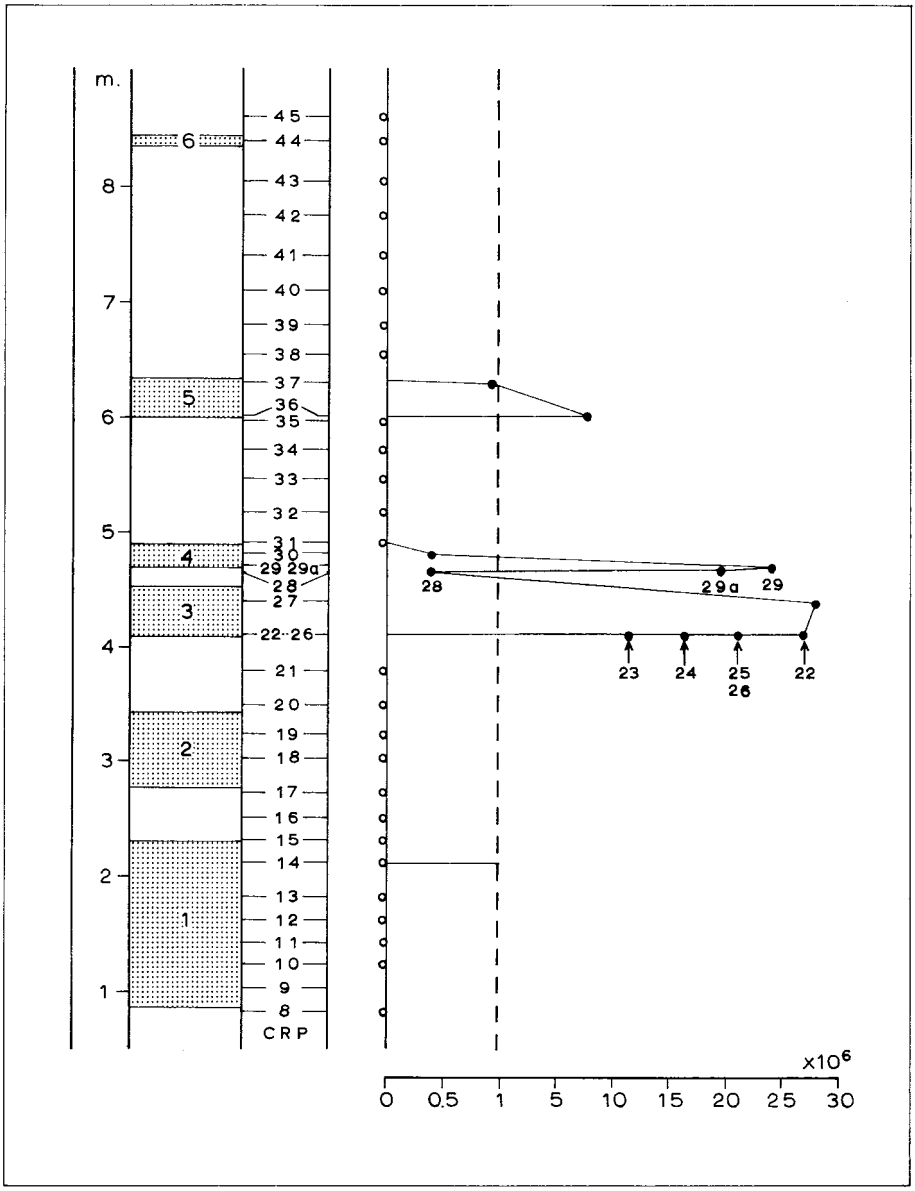


Fig. 4 Number of diatom valves per g of dry sediment in the samples of the Capo Rossello section. Note difference of scale between 0–1 and 1–30.

ments are known to exist today especially in the Santa Barbara Basin (Hülsemann & Emery, 1961), the Gulf of California (Calvert, 1966), and the Walvis Bay area (Calvert & Price, 1971), to mention only a few localities. In all these areas either anoxic or low oxygen bottom waters have been reported. Sediments underlying high productivity areas off Portugal and off North West Africa, on the other hand, contain but little biogenic silica (Schrader, 1971 a/b, 1972). Thus a direct connection between a high biogenic silica content or high numbers of diatoms and high standing stock cannot be given. Absolute numbers of diatom valves per gram dry sediment are not meaningful unless these numbers can be transformed to numbers of frustules per area and year. Data on diatoms/g sediment are presented in Kanaya & Koizumi (1966), who found highest values of 30.10^6 frustules/g sediment in the North Pacific, by Jouse (1972) of (20–50). 10^6/g sediment in the upwelling area off Peru and Chile and by Muhina (1973) of 100–300 frustules/g sediment in the upwelling area off South West Africa. In our samples we have comparable numbers of $(0–28.5)10^6$ frustules/g (table 3, fig. 4). Evidently, upwelling cannot be excluded for the Capo Rossello Lower Pliocene.

COUNTING OF THE SEPARATE TAXA

All taxon counts were based on the previously formulated definitions of a unit (fig. 1), and performed along the x and y traverses in the middle of a slide. Results are given in table 3. The different results between both authors in their counts of some selected species and species groups are given in figure 5.

Taxon counts are used to characterize a taphrocoenosis in order to obtain from its composition an interpretation of paleoecological conditions. Taxon counts are also used for biostratigraphic purposes, for instance presence/absence data. Former investigators merely indicated how much of a fraction they had investigated to arrive at a conclusion about the presence or absence of a species.

The following section is subdivided into two parts. The first part concentrates on the more common species, whereas part two discusses the rare species.

Method used for counting common species

In order to obtain information about the degree of subjectivity an identical sample split was counted by both authors along the same middle traverse

Capo Rosello (C.R.P.) samples / Diatom-species					SAME HORIZON 14		22		23		24		25		26		27		28		29		29A		36		37	
					S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G
Actinocyclus ehrenbergii			1	A	2	3	25	14	5	4	6	3	7	4	9	8	11	15	2	/	7	11	6	9	12	14		
A. ehrenbergii var. *tenella*		•	2	A			3	9	–	2			4	1	4	2					1	2	1	–	–	1		
A. elliphicus			3	C																					–	1	2	–
Achinophychus undulatus	(+)		4	A	71	23	41	33	8	11	13	7	19	9	18	20	30	21	24	/	34	29	6	8	40	30	4	1
Asterolampra acutiloba		•	5	C																/	1	–						
A. grerillei			6	C									–	1						/		1	1	1	1	1		
A. marylandica			7	A									2	–	–	1				/								
Asteromphalus arachne			8	C			8	14	1	3	3	2	2	3	7	2				/	13	7	–	1	4	9		
A. hookeri			9	C					–	1	–	1								/	2	–						
A. robustus			10	C			1	4	–	1			3	–						/	–	2	1	–	2	1		
Bacteriastrum spp.			11	B			1	2			–	1			2	–				/	–	2	2	–	1	1	–	1
Coscinodiscus			12	B			22	18	4	4	11	3	5	2	14	1	7	7	4	/	4	10	3	5	–	3	–	1
C. crenulatus			13	C																/	–	1						
C. lineatus			14	A	19	11	2	3	–	1	–	3	1	1			–	1	12	/	9	7	3	1	5	5	1	4
C. marginatus			15	A			13	14	4	4	7	7	14	5	5	5	4	11	58	/	7	1	4	4	191	191	11	18
C. nodulifer		•	16	A	46	23	2	3	–	1	1	3	2	–	3	1	2	1	17	/	12	6	3	3	58	52	19	12
C. obscurus			17	B			–	3					–	2	–	1	3	2		/	5	3	–	4				
C. oculus iridis			18	B			2	10	2	2	1	6	3	1	1	3	4	–	3	/	2	4			4	13		
C. aff. plicatus		•	19	D																								
C. stellaris			21	C													3	–		/								
C. symbolophorus			22	C			3	2	–	1			4	1	–	3	1	3	1	/	1	1			–	1		
C. vetutissimus		•	23	A			–	6	–	2	3	4	10	2	10	8	2	8	5	/	14	7	5	2	11	14		
C. indet.			24		2	5	3	13	–	3	1	3	–	4	–	4	5	6		/	–	18	–	2	2	11		
Chaetoceros spores			25	A	8	2	4	–	2	2	6	3	1	6	5	1	5	–	2	/	6	–	10	4	7	2	7	1
Cussia lancettula		•	26	C					–	1	–	4					7	2		/			3	4				
C. tatsunokuchiensis		•	27	C			6	–									1	–		/	12	5						
Cymalosira lorenaiana	(+)	•	28	C			4	7	–	1	–	5	5	4	–	2	6	3		/	11	12	1	1	1	–		
Dimerogramma spec. 1	+		29	A																/					1	2	129	131
Diploneis bombus	+		30	B																/	–	1			–	1		
D. smithii	+		31	B																/					–	1		
D. spec. 1			32	C	1		–	4	2	2	1	–	6	3	1	1	5	14		/	2	1	1	3				
Grammatophora arcuata	+		33	A													–	1		/								
G. oceanica	+		34	A	2		1	–					1	–						/	–	1	1	1	2	3	2	1
Hemidiscus cuneiformis			35	A	79	24	20	24	4	4	17	14	14	11	11	12	22	19	33	/	36	19	7	7	43	46	2	2
Mediaria splendida f. *fenera*		•	36	D			2	2	–	1	1	–	1	1	–	2	–	4		/	3	4	–	1				
Melosira sulcata	(+)		37	A	10	5	4	3	1	–	1	2	3	2	–	4			2	/	14	9	3	3	–	1	1	1
Nitzschia cylindrica		•	38	D									1	–			3	5			2	–	1	1				
N. fossilis		•	39	D			5	–									5	1			3	2						
N. jouseae		•	40	C			9	10	3	5	1	1	–	2	11	5	14	8	2	/	6	10			9	7		
N. kanayensis		•	41	D													1	–										
N. aff. porteri		•	42	D									11	2									1	2				
N. reinholdii		•	43	C	2	1	42	27	15	12	21	15	32	12	24	21	41	26	4	/	18	10	22	24	14	22	–	1
N. spec. 1			44	D			1	1									4	2		/	3	3			6	3		
N. aff. bicapitata			45	D			2													/	–	1						
Rhizosolenia alata			46	B			4	–	2	3	2	1	2	3	7	5	10	6		/	5	2	5	5				
R. barboi			47	B													1	–		/								
R. aff. hebetata f.			48	B			2	–												/	–	2			1	1		
R. styliformis			49	A	7		9	1	5	3	2	4	3	1	1	3	11	9		/	5	8	3	3				
Rouxia spec. 1		•	50	D													–	1		/								
Stephanopyxis turris			51	A			9	8	1	2	8	4	8	8	7	3	10	4	1	/	6	3			5	1	–	1
Thalassionoma nitzschioides			52	A	14	10	118	92	35	37	43	22	68	42	58	47	140	142	31	/	143	162	99	82	42	27	13	13
Thalassiosira convexa var. *aspinosa*		•	53	A	1	1	4	4	–	4	3	–	2	1	8	2	1	5	2	/	1				14	28	4	6
T. eccentrica			54	C			1	5	–	1	1	1	5	4	3	5	9	8	1	/	3	14	1	4	3	1		
T. aff. lineata		•	55	C			3	6	4	2	6	5	7	6	3	3	1	4		/	3	8						
T. natira		•	56	C							1	1					13	14			4	2	–	1				
T. oestrupii		•	57	C			27	44	6	5	15	15	18	15	13	18	9	59		/	5	14	12	10	1	7		
T. symmetrica			58	C																/	–	2	8	9				
T. indet.			59						–	4	2	4	1	5	2	2	–	7		/	–	7	2	8				
Thalassiothrix longissima			60	A	63	28	59	17	11	12	21	12	23	10	28	5	25	15	31	/	41	12	3	2	36	17	10	11
Tricoratium cinamomeum			61	C									–	1			1	–		/	1	–	2	2	–	1		
Total number of counted individuals					327	136	462	403	116	141	198	156	289	175	255	200	428	445	235	/	445	426	220	217	516	519	205	205
Individuals/gr. dry sediment x94 x 10^3					12	9	278	301	116	141	198	156	289	175	255	200	310	298	4	4	240	275	220-213		95	88	11	8
Individuals/gr. dry sediment x 10^6					0,95		27		12		17		21,5		21,5		28,5		0,4		24,5		20		8,5		0,9	
Abundance diatoms (subjective)					F	F	A	A	A	A	A	A	A	A	A	A	C	C	R	R	C	C	C	C	C	C	R	R
Preservation diatoms					M	M	G	G	G	G	G	G	G	G	G	G	G	G	P	P	G	G	G	G	M	M	P	P
Silicoflagellate species																												
Cannopilus spec. 1			62		4	/	4	/	3		0	/	0	/	0	/	3		3	/	4			/	1	–	18	–
Corbisema apiculata		•	63			/		/				/		/		/				/				/			–	2
Dictyocha aspera			64																						1	1	–	3
D. fibula		•	65		34	/	29	/	34	47	49	/	51	/	69	/	58	55	60	/	18	37	44	/	48	19	29	6
D. mutabilis		•	66		7		4		3	2					1		8	2	15		10	30	10		17	23	14	3
Distephanus boliviensis		•	67		12	/	1	/	1	–	2	/	2	/	4	/	4	–	7	/	6	–	7	/				
D. boliviensis var. *major*		•	68		2		13		21	46	6		7		33		12	25	12		9	14	5		7	6	4	–
D. speculum			69		11		100		100	78	100		100		150		150	97	150		190	103	122		49	49	19	7
Mesocena circulus		•	70		5	/	8	/	8	20	7	/	7	/	12	/	13	10	10	/	6	17	9	/	15	12	7	3
Total number of counted individuals					75	/	159	/	170	193	164	/	167	/	269	/	248	189	257	/	203	201	197	/	138	110	91	24

Table 3. Range chart with taxon counts of diatoms and silicoflagellates.

for sample CRP 29A (fig. 5). In no case were the differences between both authors and per species of such magnitude that they would influence the paleoecological interpretations. The differences are caused primarily by different experience in distinguishing between rather weakly silicified species (e.g. *Mediaria splendida, Thalassiosira nativa*), in determination of broken parts of valves (*Thalassionema nitzschioides*) and by different species concepts concerning taxonomical problematica (*Thalassiosira*).

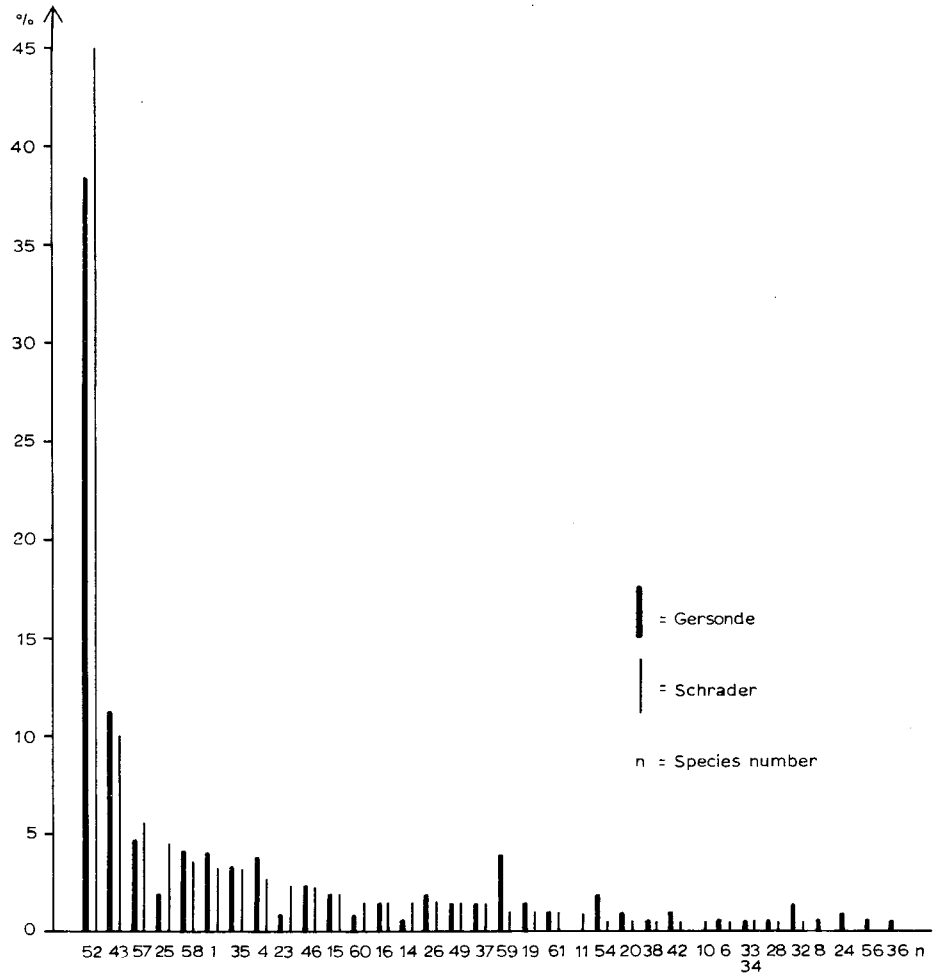


Fig. 5 Counting results of both authors on selected species and species groups for the same traverse of sample CRP 29A. For species code number compare legend of table 3.

The normal taxon counts per 200 or more are useful only for species with frequencies of more than 3–5 per cent in the assemblage (see M. M. Drooger, this volume). Thus each author counted 300 to 400 individuals per sample. In the samples from the same horizon (CRP 22–26) counts were made for

CRP 22		I		I + II		I + II + III	
		n	%	n	%	n	%
1	*Thalassionema nitzschioides*	46	33.3	118	25.7	210	24.5
2	*Thalassiothrix longissima*	15	10.9	59	12.8	93	10.8
3	*Nitzschia reinholdii*	12	8.7	42	9.1	69	8.0
4	*Actinoptychus undulatus*	9	6.5	41	8.9	74	8.6
5	*Thalassiosira oestrupii*	4	2.9	27	5.9	71	8.3
6	*Actinoptychus ehrenbergii*	8	5.8	25	5.4	39	4.5
7	*Hemidiscus cuneiformis*	8	5.8	20	4.3	44	5.1
8	*Coscinodiscus* aff. *radiatus*	9	6.5	22	4.7	40	4.6
9	*Coscinodiscus marginatus*	2	1.4	13	2.8	27	3.2
10	*Stephanopyxis turris*	4	2.9	9	2.0	17	2.0
11	*Rhizosolenia styliformis*	4	2.9	9	2.0	10	1.2
12	*Nitzschia jouseae*	3	2.2	9	2.0	19	2.2
13	*Asteromphalus arachne*	2	1.4	8	1.7	22	2.6
14	*Cussia tatsunokuchiensis*	2	1.4	6	1.3	6	0.7
15	*Nitzschia fossilis*	2	1.4	5	1.1	5	0.6
16	*Cymatosira lorenziana*	1	0.7	4	0.9	11	1.3
17	*Thalassiosira convexa*	–		4	0.9	8	0.9
18	*Chaetoceros* Spores	–		4	0.9	4	0.5
19	*Rhizosolenia alata*	–		4	0.9	4	0.5
20	*Melosira sulcata*	–		4	0.9	7	0.8
21	*Thalassiosira* aff. *lineata*	–		3	0.7	9	1.1
22	*Coscinodiscus* aff. *symbolophorus*	–		3	0.7	5	0.6
23	*Coscinodiscus* indet.	–		3	0.7	16	1.9
24	*Mediaria splendida*	2	1.4	2	0.4	4	0.5
25	*Coscinodiscus lineatus*	1	0.7	2	0.4	5	0.6
26	*Rhizosolenia hebetata* f. *subac.*	1	0.7	2	0.4	2	0.2
27	*Coscinodiscus oculus-iridis*	–		2	0.4	12	1.4
28	*Coscinodiscus nodulifer*	–		2	0.4	5	0.5
29	*Nitzschia* aff. *bicapitata*	1	0.7	1	0.2	1	0.1
30	*Nitzschia* spec. I	1	0.7	1	0.2	2	0.2
31	*Thalassiosira eccentrica*	1	0.7	1	0.2	6	0.6
32	*Grammatophora oceanica*	–		1	0.2	1	0.1
33	*Coscinodiscus* aff. *plicatus*	–		1	0.2	1	0.1
34	*Asteromphalus robustus*	–		1	0.2	5	0.6
35	*Bacteriastrum* spec.	–		1	0.2	3	0.3
total count		138	99.6	459	99.7	857	99.7

Table 4. Cumulative count of diatom species in sample CRP 22. The successive counts I, II and III consist of 138, 321 and 398 individuals, respectively.

some 200 individuals only. The 300–400 individual counts per sample have been tested and used in various paleoecological investigations (Imbrie & Kipp, 1971).

A cumulative test count on CRP 22 (table 4, fig. 6) up to 800 individuals demonstrates that only the components which constitute less than 2% of the total assemblage, change in percentage from the 400 to the 800 counts. Since for paleoecological interpretation only the more frequent species are used, these minor fluctuations are of little importance, but for biostratigraphical interpretations in which rare species are used more commonly these fluctuations of relative abundance might be of importance.

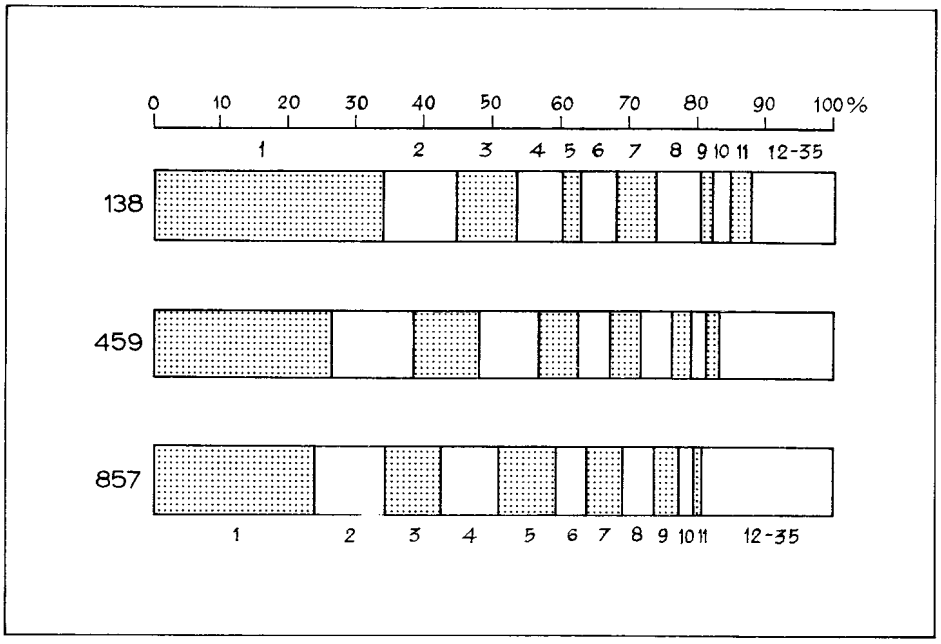


Fig. 6 Diagram of the cumulative counts of diatom species of sample CRP 22. Numbers correspond to species numbers in table 4. It would seem that the rare species are gradually recognized better in the course of the counting procedure, evidently at the expense of the most common species.

Method used for counting rare species

Since in a 300–400 count species which occur with a frequency of less than 5% may have very high relative errors (M. M. Drooger, this volume), an attempt was made to estimate the relative frequencies of such species with greater accuracy. The method applied uses the abundance of a species in a

nr. of fields of view	1	10	50		100		1,280		6,880		18,080	
nr. of "counted" frustules	0.4	4	20		40		512		2,752		7,232	
	n	n	n	%	n	%	n	%	n	%	n	%
Nitzschia reinholdii	–	–	–	–	2	5	27	5.27	141	5.12	274	3.78
Thal. convexa var. *asp.*	–	–	4	20	4	10	20	3.9	101	3.67	250	3.45
Nitzschia jouseae + cyl.	–	–	–	–	–	–	10	1.95	43	1.56	81	1.12
Thal. aff. *lineata*	–	–	–	–	1	2.5	6	1.17	21	0.76	35	0.48
Cymatosira lorenziana	–	–	1	5	1	2.5	4	0.78	13	0.47	33	0.45
Nitzschia kanayensis	–	–	–	–	–	–	–	–	14	0.5	28	0.38
Cussia lancettula	–	–	–	–	–	–	–	–	9	0.32	22	0.3
Mediaria splendida	–	–	–	–	–	–	2	0.39	8	0.29	13	0.17

Table 5. Frequencies of seven rare taxa during counting up to 18,080 microscopical fields; sample CRP 25.

number of microscopic fields of view and the estimate of the total number of individuals in 20 microscopic fields. From the data a better percentage of rare species can be calculated. This method has to be adjusted for each sample; the numbers given below pertain only to sample CRP 25. One microscopic field of view measured 70 × 110 μ^2; thus one traverse over the slide contains 257 fields of view; the average total number of diatom frustules per field of view was estimated to be 0.4.

During the scanning procedure eight rare species were counted (table 5) and their percentage was tabulated in the course of the counting up to 18,080 fields of view. A species is considered absent if it was not observed in an approximately 10,000 count, which in this specific case means a count of over 25,000 microscopical fields of view which equal about 97 traverses at the optical setting used (= half of the total slide).

We propose that a species is absent when it was *not* observed in a count of at least 5000 individuals. It would be helpful if authors record:

1. How many frustules cover one microscopical field of view,
2. The surface of one microscopical field of view,
3. How many fields of view were checked.

Such data would permit an evaluation of the results of different authors.

THE PRESERVATION OF THE OPAL SKELETONS

The diatom frustules were grouped in classes A = resistant, B = partially resistant, C = dissolvable, D = easily dissolvable after Schrader (1971a/b, 1972) and data were entered in table 3. The percentage of resistant individuals was plotted for each sample in figure 7. Samples 14, 28, 36 and 37 contain poorly preserved diatom assemblages of resistant species which

have almost no biostratigraphic value because of the high proportions of cosmopolitan and long ranging species. Biostratigraphic and paleoecological interpretation possibilities for these samples are rather limited. In contrast, samples CRP 22 to 27 and sample 29 contain fairly well preserved diatom assemblages, which permit better biostratigraphic and paleoecologic interpretations. Note the big difference in preservation within the relatively short Rossello section and the dubious character of the interpretation if one were to use only samples CRP 14, 28, 36 and 37 for detailed diatom-micropaleontological studies.

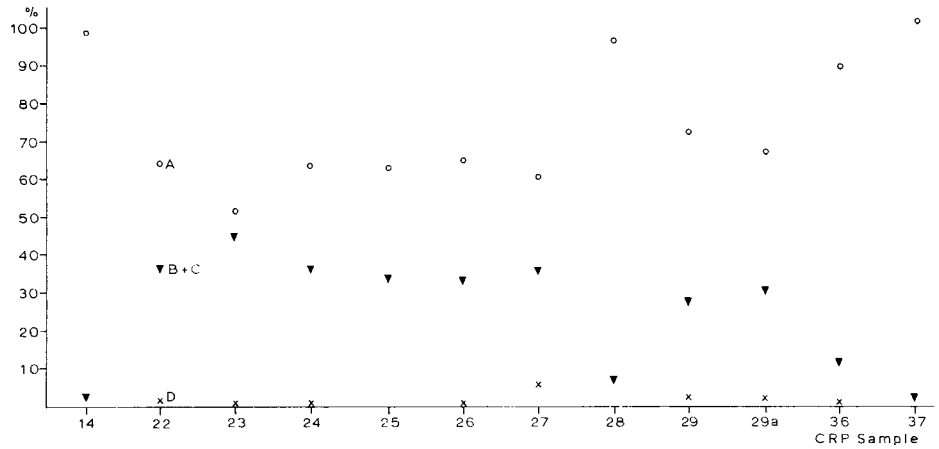


Fig. 7 Percentages of resistant (A), partially resistant (B + C) and easily dissolvable (D) individuals in the diatom-bearing samples.

PALEOECOLOGICAL INTERPRETATION

The diatom species were grouped into warm and cold water species using the ecological concepts of Jouse et al. (1962, 1971), Kanaya & Koizumi (1966), Simonsen (1974) and Hasle (1976). The relative percentage of cold water individuals was plotted in figure 8. The number of cold water individuals is distinctly higher in samples 28 and 36, but since both samples also differ considerably in preservation types (compare previous chapter) no paleontologic interpretation can be given.

All diatom samples from the Capo Rossello section contain a fully marine planktonic diatom association with admixtures of displaced benthic species (*Grammatophora*) of less than 2%. Only sample CRP 31 contains up to 65% of a hitherto unknown species which has been included in the genus *Dimero-*

gramma (plate 4, figures 3–4). Since all recent members of this genus are thought to be benthic, we have regarded these individuals as benthic as well. This would be in agreement with the strongly silicified character of the frustules. Since no increased relative numbers of benthonic foraminifera were observed (Brolsma, this volume) no clue can be given as to the meaning of this occurrence. The increase in the amount of resistant individuals may play an important role; 98.8% of the assemblage consists of class A (fig. 7).

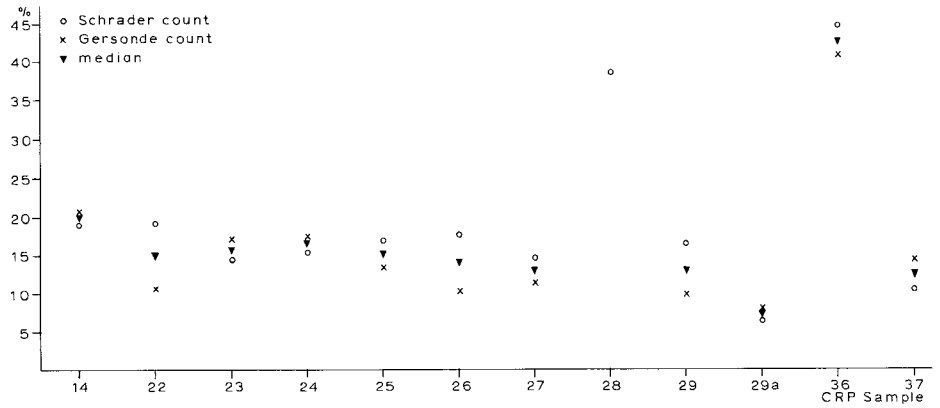


Fig. 8 Percentages of cold water individuals in the diatom-bearing samples. Cold water species: *Asteromphalus hookeri, Asterolampra acutiloba, Coscinodiscus marginatus, Cussia lancettula, Cussia tatsunokuchiensis, Mediaria splendida* f. *tenera, Nitzschia kanayensis, Rhizosolenia alata, Rhizosolenia barboi, Rhizosolenia hebetata* f. *hiemalis, Thalassiosira eccentrica, Thalassiothrix longissima.*

BIOSTRATIGRAPHIC INTERPRETATION

The frequent *Thalassiosira convexa* var. *aspinosa* (4% in CRP 25), associated with less numerous *Nitzschia jouseae,* causes the correlation between the interval CRP 22 to 36 (fig. 9) and the *Nitzschia jouseae* Partial Range Zone of Burckle (1972), which is placed in the Lower Pliocene. The *Nitzschia jouseae* Zone starts at the evolutionary entry of *Nitzschia jouseae* joining its immediate ancestor *Nitzschia cylindrica.* This is correlated with the "c" event of the Gilbert Reversed Magnetic Epoch in the Eastern Equatorial Pacific (Burckle, 1972).

The last occurrence of *Nitzschia cylindrica* was found in sample CRP 29 and the first occurrence of *Nitzschia jouseae* in CRP 22. This co-occurrence suggests that the Capo Rossello section contains the *Nitzschia jouseae – Nitzschia cylindrica* transition.

The interval of the Capo Rossello section demonstrates that for correct biostratigraphic positioning at least a minimum number of samples needs to contain well or moderately-well preserved diatom assemblages. For instance, almost no biostratigraphic interpretation could be made for samples CRP 9, 14, 30 and 37. An assignment to any of three successive zones of Burckle would be possible (*Thalassiosira convexa, Nitzschia jouseae, Rhizosolenia praebergonii* Zones).

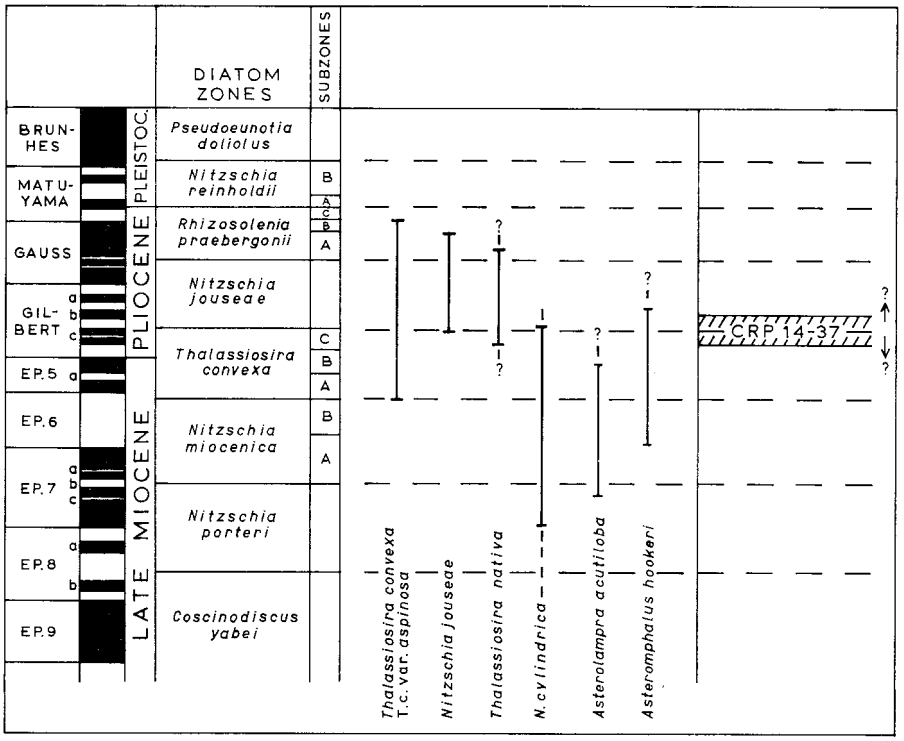


Fig. 9 Late Miocene to Pleistocene Diatom zones and subzones for the Equatorial Pacific with ranges of important zonal markers (after Burckle, 1972) and tentative placement of the eight meter Capo Rossello section.

Genera and species within genera are listed in alphabetic order.

Genus **Actinocyclus** Ehrenberg

Actinocyclus ehrenbergii Ralfs in Pritchard
Plate 1, Figures 3–4
Description: Hustedt (1930), p. 525, fig. 298.
Ecology: Facultative sublittoral species (Drebes, 1974).

Actinocyclus ehrenbergii var. *tenella* (Breb.) Hustedt
Plate 1, Figure 1–2
Description: Hustedt (1930), p. 530, fig. 302.

Actinocyclus ellipticus Grunow in Van Heurck
Plate 1, Figure 5
Description: Hustedt (1930), p. 533, fig. 303.
Occurrence: Only single specimens were found in samples CRP 36 and 37.

Genus **Actinoptychus** Ehrenberg

Actinoptychus undulatus (Bail.) Ralfs in Pritchard
Plate 1, Figure 6–7
Description: Hustedt (1930), p. 475, fig. 264.
Ecology: Facultative sublittoral species (Drebes, 1974).

Genus **Asterolampra** Ehrenberg

Asterolampra acutiloba Frenguelli in Tempere et Peragallo
Description: Schmidt et al. (1874), pl. 137, fig. 19 (unnamed); Forti in Tempere and Pergallo (1912), p. 337, No. 696–698.
Occurrence: Only one specimen was observed in sample CRP 29.

Asterolampra grevillei (Wall.) Greville
Plate 1, Figure 9
Description: Hustedt (1930), p. 489, fig. 274.
Occurrence: Only single individuals were rarely observed in samples CRP 25, 29, 29A, and 36.

Asterolampra marylandica Ehrenberg
Plate 1, Figure 8
Description: Hustedt (1930), p. 485, fig. 271.

Occurrence: Only single individuals in samples CRP 25 and 26.
Ecology: Kanaya & Koizumi (1966) – tropical or equatorial planktonic.

Genus **Asteromphalus** Ehrenberg

Asteromphalus arachne (Breb.) Ralfs in Pritchard
Plate 2, Figure 2
Description: Hustedt (1930), p. 493, fig. 276.
Ecology: Simonsen (1974) – tropical to subtropical species.

Asteromphalus hookeri Ehrenberg
Description: Hendey (1937), p. 270.
Ecology: Kanaya & Koizumi (1966) – antarctic to subantarctic species.

Asteromphalus robustus Castracane
Plate 2, Figure 1
Description: Hustedt (1930), p. 496, fig. 278.
Ecology: Kanaya & Koizumi (1966) – cold water species, boreal zone, subarctic water masses.

Genus **Bacteriastrum** Shadbold

Bacteriastrum species
Plate 2, Figure 3
Remarks: Fragments belonging to this genus were frequent in well-preserved samples. Specific determination can only be made in case full chains are present.

Genus **Chaetoceros** Ehrenberg

Chaetoceros species
Plate 2, Figure 4–7
Remarks: *Chaetoceros* bristles, fragments and spores were frequently observed in samples with moderate to well-preserved assemblages. Since complete vegetative cells are necessary for exact taxonomic treatment no further assignments were made. The classification by spores is still not solved.

Genus **Coscinodiscus** Ehrenberg

Remarks: A few *Coscinodiscus* frustules could not be placed into distinct species due to existing taxonomic confusion. Most of these individuals were placed into one of the following species: *C. obscurus, C. oculus-iridis C. radiatus.*

Plate 1

Figs. 1, 2 *Actinocyclus ehrenbergii* var. *tenella*, (1) CRP 22, (2) CRP 27.

Figs. 3, 4 *Actinocyclus ehrenbergii*, (3) CRP 22, (4) CRP 29.

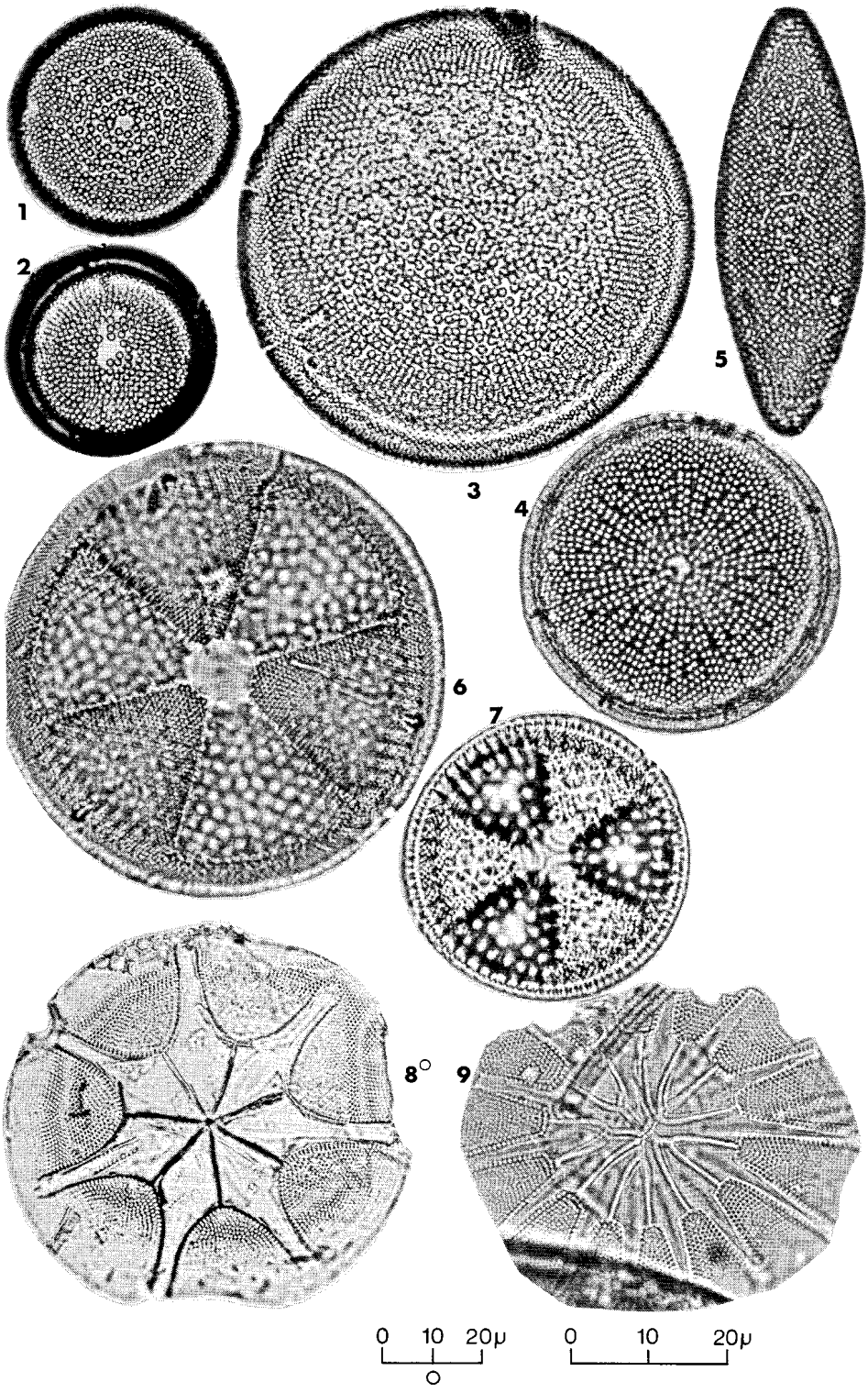
Fig. 5 *Actinocyclus ellipticus*, CRP 29.

Figs. 6, 7 *Actinoptychus undulatus*, (6) CRP 29, (7) CRP 22.

Fig. 8 *Asterolampra marylandica*, CRP 22.

Fig. 9 *Asterolampra grevillei*, CRP 29.

Plate 1



Coscinodiscus crenulatus Grunow

Plate 2, Figure 10

Description: Hustedt (1930), p. 411, fig. 219.
Occurrence: Rare specimens were observed in sample CRP 29.
Ecology: Kanaya & Koizumi (1966) – subtropical to tropical.

Coscinodiscus lineatus Ehrenberg

Plate 2, Figure 8

Description: Hustedt (1930), p. 392, fig. 204.
Remarks: Species with finer areolation (6–7 areolae in 10 μ) were also observed.
Ecology: Kanaya & Koizumi (1966) – tropical.

Coscinodiscus marginatus Ehrenberg

Plate 2, Figure 9; Plate 3, Figure 1

Description: Hustedt (1930), p. 416, fig. 223.
Ecology: Kanaya & Koizumi (1966) – cold water species.

Coscinodiscus nodulifer A. Schmidt

Plate 3, Figure 2; Plate 4, Figure 1

Description: Hustedt (1930), p. 426, fig. 229.
Remarks: The ornamentation of the central area and the position of the papillae are highly variable. Care has to be taken not to lump this species with *C. aeginensis* A. Schmidt, which differs by its distinct bean-like papille.
Ecology: Kanaya & Koizumi (1966) – warm water-tropical.

Coscinodiscus aff. *obscurus* A. Schmidt

Plate 4, Figure 2

Description: Hustedt (1930), p. 418, fig. 224.
Remarks: Included were individuals which showed the typical structure with interstitial meshes. They varied in size from 40 to 180 μ and were sometimes more finely areolated (2–6 areolae in 10 μ) than the typical.

Coscinodiscus aff. *oculus-iridis* Ehrenberg

Plate 3, Figure 6

Description: Hustedt (1930), p. 454, fig. 252.
Remarks: Specimens with a diameter over 100 μ, with a coarse areolation (2–5 areolae in 10 μ) were tentatively included into this species.

Coscinodiscus aff. *plicatus* Grunow

Description: Schrader (1973b), p. 703, plt. 6, fig. 23.

Coscinodiscus aff. *radiatus* Ehrenberg
Plate 3, Figure 4–5

Description: Hustedt (1930), p. 420, fig. 225.
Remarks: Included were individuals with a radial structure. The areolae were sometimes smaller (up to 7 in 10 μ close to the valve's middle part) than described for the species.

Coscinodiscus stellaris Roper
Plate 3, Figure 3

Description: Hustedt (1930), p. 396, fig. 207.
Occurrence: This species was found only in sample CRP 27.

Coscinodiscus symbolophorus Grunow

Description: Hustedt (1930), p. 396, fig. 208 as *C. stellaris* var. *symbolophora* (Grun.) Joergensen.

Coscinodiscus vetustissimus Pantocsek
Plate 2, Figure 11

Description: Hustedt (1930), p. 412, fig. 220.

Genus **Cussia** Schrader

Cussia lancettula Schrader

Description: Schrader (1974a), p. 914, plt. 19, figs. 14–16.

Cussia tatsunokuchiensis (Koizumi) Schrader
Plate 2, Figure 5

Description: Koizumi (1972), p. 349, plt. 42, figs. 3–4.

Genus **Cymatosira** Grunow

Cymatosira lorenziana Grunow
Plate 4, Figures 6–7

Description: Hustedt (1959), p. 127, fig. 648.
Ecology: Hustedt (1959) – marine littoral.

Genus **Dimerogramma** Ralfs in Pritchard

Dimerogramma species
Plate 4, Figures 3–4

Remarks: Similar species were not found in the available literature. With hesitation these individuals were placed into *Dimerogramma.*
Occurrence: This species was only observed in samples CRP 36 and 37. It is rare in sample CRP 36, but occurs in abundance (up to 60%) in sample CRP 37.

Plate 2

Fig. 1 *Asteromphalus robustus,* CRP 24.

Fig. 2 *Asteromphalus arachne,* CRP 22.

Fig. 3 *Bacteriastrum* species indet., CRP 22.

Fig. 4 *Chaetoceros* bristle, frequently misidentified as *Lyramula* (silicoflagellate species), CRP 22.

Figs. 5 – 7 *Chaetoceros* species indet., spores. (5) CRP 22, (6) CRP 27, (7) CRP 27.

Fig. 8 *Coscinodiscus lineatus,* CRP 29 A.

Fig. 9 *Coscinodiscus marginatus,* CRP 36.

Fig. 10 *Coscinodiscus crenulatus,* CRP 24.

Fig. 11 *Coscinodiscus vetustissimus,* CRP 29.

Plate 2

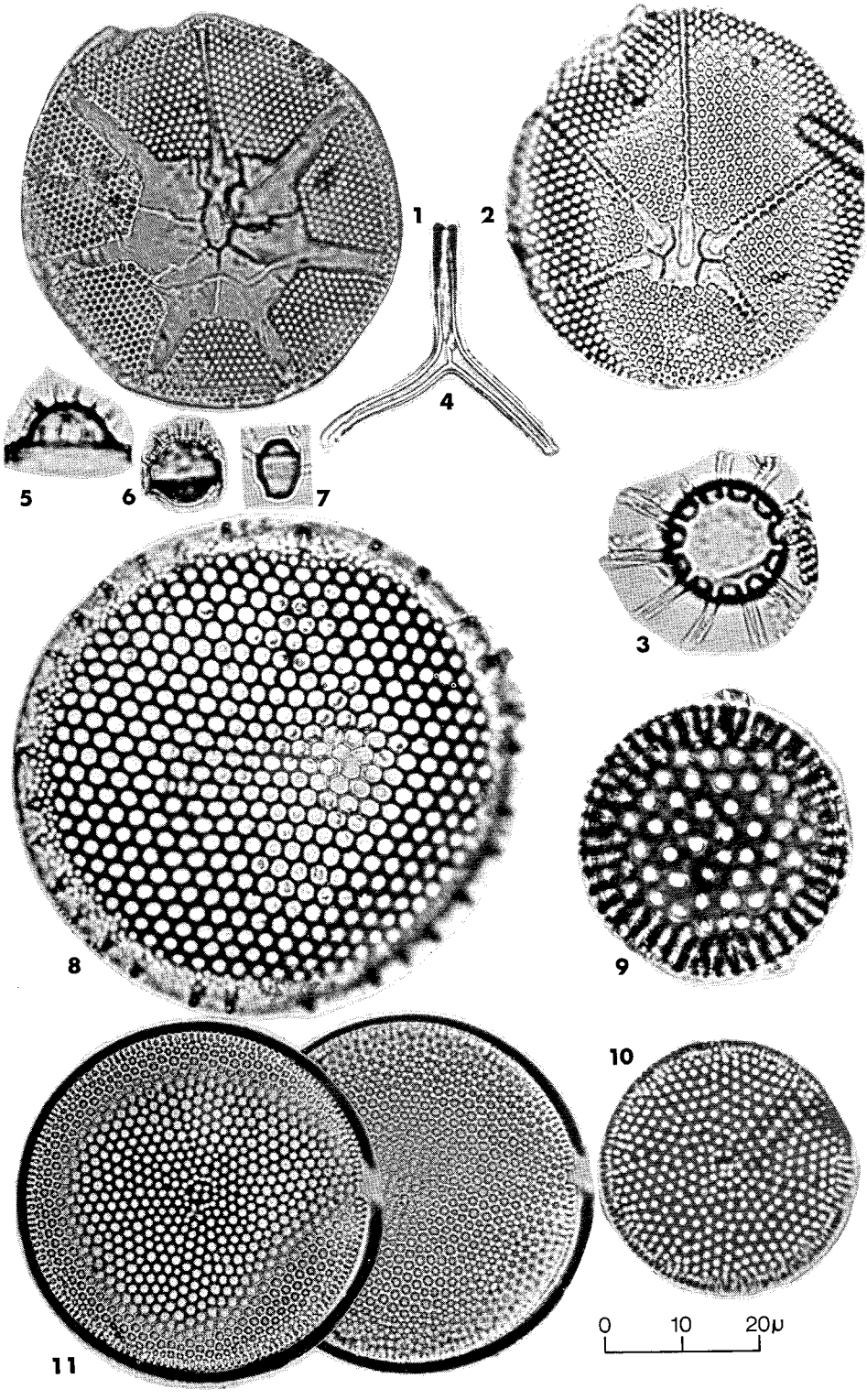


Plate 3

Fig. 1 *Coscinodiscus marginatus*, CRP 36.

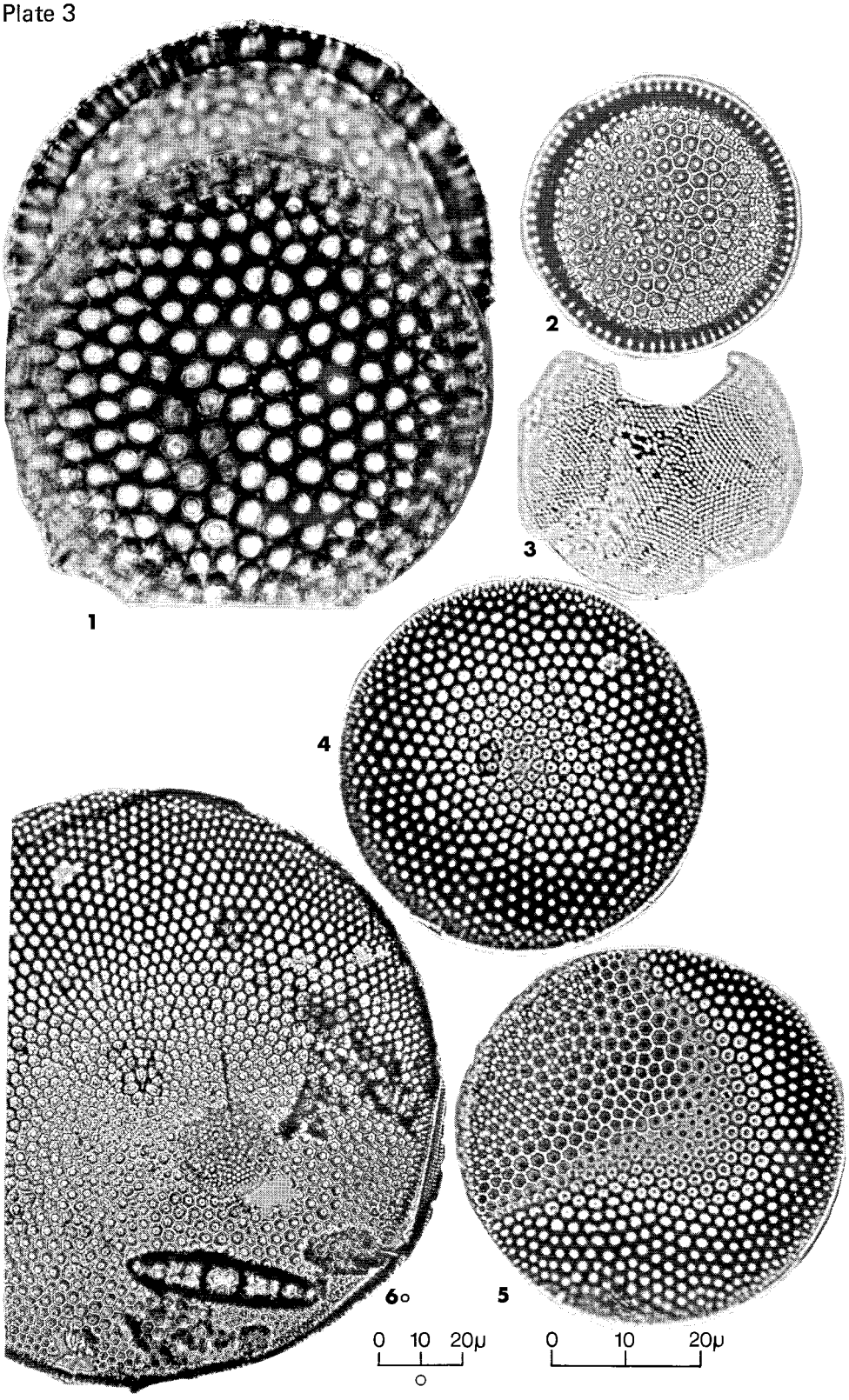
Fig. 2 *Coscinodiscus nodulifer*, CRP 36.

Fig. 3 *Coscinodiscus stellaris*, CRP 22.

Figs. 4, 5 *Coscinodiscus* aff. *radiatus*, (4) CRP 25, (5) CRP 22.

Fig. 6 *Coscinodiscus* aff. *oculus-iridis*, CRP 24.

Plate 3



Ecology: Because of its robust character and its tentative place in *Dimerogramma* this species is interpreted as marine-littoral.

Genus **Diploneis** Ehrenberg

Diploneis bombus Ehrenberg

Description: Hustedt (1959), p. 704, fig. 1086.
Remarks: This species was only observed in samples CRP 29 and 36.
Ecology: Marine-littoral.

Diploneis smithii (Breb.) Cleve

Description: Hustedt (1959), p. 647, fig. 1051.
Remarks: This species was only observed in sample CRP 36.
Ecology: Marine-littoral.

Diploneis spec. 1 (aff. *Diploneis didyma*)
Plate 4, Figures 8–9

Description: No similar individuals were observed in the available literature. They measured 15–20 μ in length, 8–10 μ in width over the middle part. Radial transapical ribs were 10 in 10 μ.
Occurrence: This species was occasionally observed in all moderate to well-preserved assemblages.

Genus **Grammatophora** Ehrenberg

Grammatophora arcuata Ehrenberg

Description: Hustedt (1959), p. 42, fig. 597.
Occurrence: Very rare in sample CRP 29.

Grammatophora oceanica (Ehr.) Grunow

Description: Hustedt (1959), p. 45, fig. 573.
Occurrence: Sporadical in all samples.

Genus **Hemidiscus** Wallich

Hemidiscus cuneiformis Wallich
Plate 4, Figures 11–13

Description: Hustedt (1930), p. 904, fig. 542.
Ecology: Kanaya & Koizumi (1966) – warm water species.

Genus **Mediaria** Sheshukova-Poretzkaya

Mediaria splendida forma *tenera* Schrader

Description: Schrader (1973b), p. 706, pl. 3, fig. 13.

Genus **Melosira** Agardh

Melosira sulcata (Ehr.) Kützing
Plate 4, Figure 10
Description: Hustedt (1930), p. 276, fig. 119.

Genus **Nitzschia** Hassal

Nitzschia aff. *bicapitata* Cleve
Plate 5, Figures 12–13
Description: Hustedt (1958), p. 169, figs. 176–190.
Remarks: Simonsen (1974) states that this species is extremely variable in both structure and shape of the valves.

Nitzschia cylindrica Burckle
Plate 5, Figures 2–3
Description: Burckle (1972), p. 239–240, plt. 2, figs. 1–6.
Remarks: This species has approximately 6–11 costae in 10 μ and not 6–8 as stated in the original diagnosis (also Burckle pers. communication 1976 to the junior author). In the present material individuals with 9 or 10 costae in 10 μ were common.

Nitzschia fossilis (Frenguelli) Kanaya
Plate 5, Figure 7
Description: Schrader (1973b), p. 707, plt. 4, figs. 9–11, 24–25.

Nitzschia jouseae Burckle
Plate 5, Figures 1, 4–6
Description: Burckle (1972), p. 240, plt. 2, figs. 17–21.
Remarks: This species has approximately 6–11 costae in 10 μ and not 6–8 as stated in the original diagnosis (also Burckle pers. communication 1976 to the junior author). In the present material individuals with 9–10 costae in 10 μ were common.

Nitzschia kanayensis Schrader
Description: Schrader (1974b), p. 547, figs. 6, 23, 25, 28.
Occurrence: Only one individual was observed in sample CRP 27.

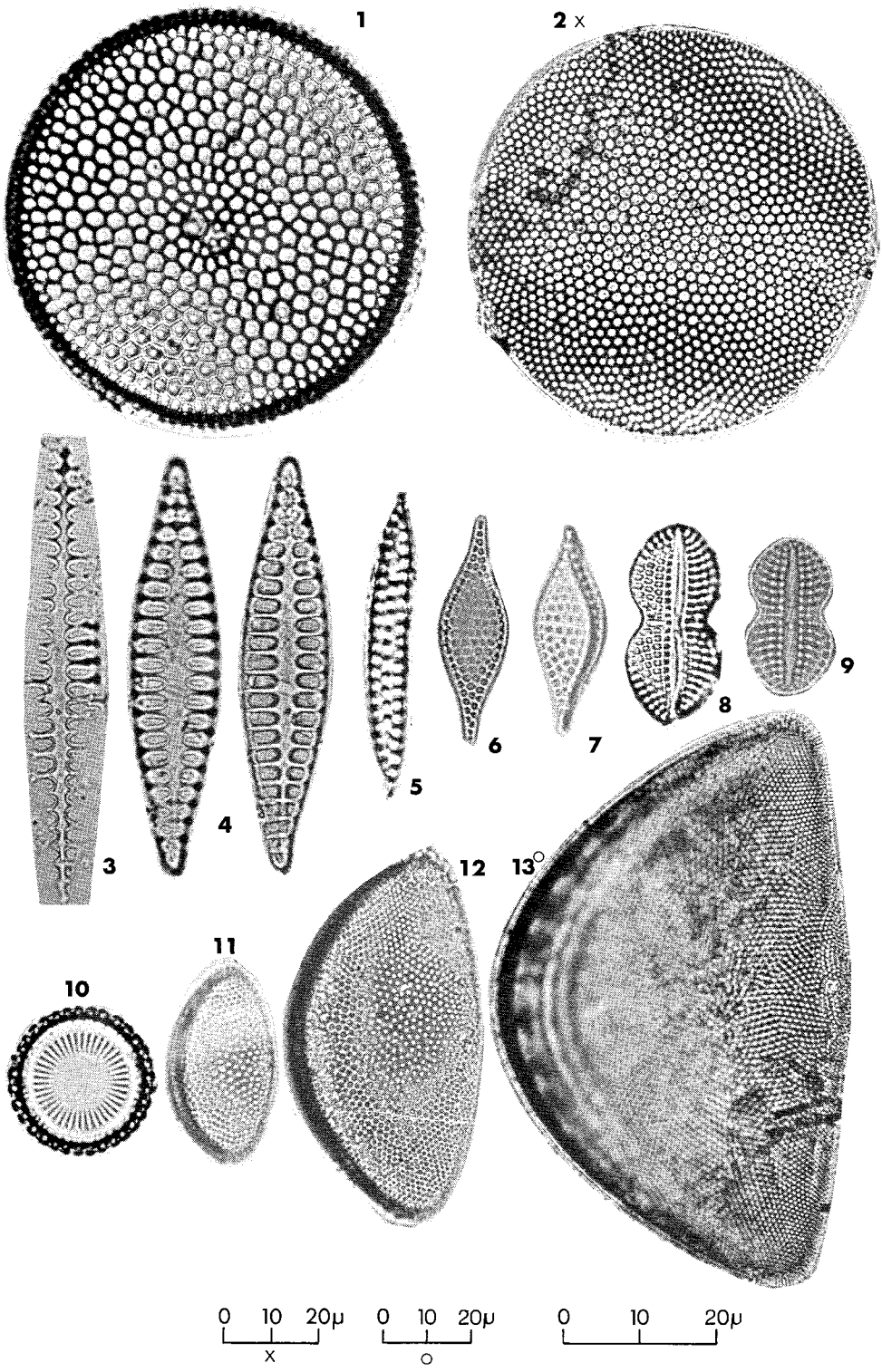
Nitzschia aff. *porteri* Frenguelli
Description: Frenguelli (1949), p. 116, plt. 1, figs. 33–34.
Occurrence: Only single frustule in sample CRP 29A.

Nitzschia reinholdii Kanaya ex Schrader
Plate 5, Figures 8–10
Description: Schrader (1973b), p. 708, plt. 4, figs. 12–16.

Plate 4

Fig. 1	*Coscinodiscus nodulifer,* CRP 29A.
Fig. 2	*Coscinodiscus* aff. *obscurus.*
Figs. 3, 4	*Dimerogramma* species indet., CRP 37.
Fig. 5	*Cussia tatsunokuchiensis,* CRP 29A.
Figs. 6, 7	*Cymatosira lorenziana,* (6) CRP 29, (7) CRP 26.
Figs. 8, 9	*Diploneis* species, (8) CRP 27, (9) CRP 26.
Fig. 10	*Melosira sulcata,* CRP 22.
Figs. 11 – 13	*Hemidiscus cuneiformis,* (11) CRP 29, (12) CRP 26, (13) CRP 26.

Plate 4



Nitzschia species 1
Plate 5, Figure 11

Remarks: The structure is similar to that of *N. reinholdii* with approximately 13 costae in 10 μ; the individuals measured 40 μ in length, and about 9–10 μ in width over the middle part of the valve. Apical fields broadly rounded.

Genus **Rhizosolenia** Ehrenberg

Rhizosolenia aff. *alata* Brightwell
Plate 5, Figure 21

Description: Hustedt (1930), p. 600, fig. 344.
Remarks: The individuals were strongly silicified and had partly a coarse structure.

Rhizosolenia barboi Brun

Description: Donahue (1970), p. 136.
Occurrence: Only one individual was observed in sample CRP 27.

Rhizosolenia hebetata forma *hiemalis* Gran
Plate 5, Figures 22–23

Description: Hustedt (1930), p. 590, fig. 337.
Remarks: see *R. styliformis.*
Occurrence: Single individuals were observed in samples CRP 22, 29, 36.
Ecology: Kanaya & Koizumi (1966) – cold water species.

Rhizosolenia styliformis Brightwell
Plate 5, Figures 24–25

Description: Hustedt (1930), p. 584–588, figs. 333–335.
Remarks: During the counting procedure individuals of *R. hebetata* may have been included in this species because all questionable specimens were counted as *R. styliformis.*

Genus **Rouxia** Brun et Heribaud

Rouxia species
Plate 5, Figure 16

Remarks: Only one moderately well preserved individual was observed in sample CRP 27.

Genus **Stephanopyxis** Ehrenberg

Stephanopyxis turris (Grev. et Arn.) Ralfs
Plate 5, Figures 14–15

Description: Hustedt (1930), p. 304, figs. 140–144.

Genus **Thalassionema** Grunow

Thalassionema nitzschioides Grunow
Plate 5, Figures 17–20

Description: Hustedt (1959), p. 244, fig. 725.
Ecology: Kanaya & Koizumi (1966) – north and south boreal, subtropical, tropical, cosmopolitan.

Genus **Thalassiosira** Cleve

Thalassiosira convexa var. *aspinosa* Schrader
Plate 5, Figure 26

Description: Schrader (1974), p. 916, plt. 2, figs. 8–9, 13a–21.

Thalassiosira eccentrica (Ehr.) Cleve
Plate 6, Figure 3

Description: Sheshukova-Poretzkaya (1967), p. 141–142, plt. 14, fig. 4.
Ecology: Kanaya & Koizumi (1966), subtropical-tropical.

Thalassiosira aff. *lineata* Zhuse
Plate 6, Figures 1–2

Description: Jouse (1968), p. 13, plt. 1, figs. 1–2.
Remarks: Our individuals differ from the typical by the partially irregularly orientated tangential structure.

Thalassiosira nativa Shehshukova-Poretzkaya
Plate 6, Figures 4–6

Description: Sheshukova-Poretzkaya (1967), p. 145, plt. 14, fig. 7.

Thalassiosira oestrupii (Ostenf.) Proshkina-Lavrenko
Plate 6, Figures 7–9

Description: Hustedt (1930), p. 318, fig. 155 as *Coscinosira oestrupii* Hasle; (1960), p. 8, figs. 5–7, 11.
Ecology: Kanaya & Koizumi (1966) – subtropical.

Thalassiosira symmetrica Fryxell et Hasle

Description: Fryxell & Hasle (1972), p. 312, figs. 37–46.
Occurrence: Common only in sample CRP 29A.

Genus **Thalassiothrix** Cleve et Grunow

Thalassiothrix longissima Cleve et Grunow
Plate 6, Figures 10–11

Plate 5

Fig. 1 *Nitzschia jouseae,* CRP 28.

Figs. 2, 3 *Nitzschia cylindrica,* (2) CRP 26, (3) CRP 27.

Figs. 4 – 6 *Nitzschia jouseae,* (4) CRP 26, (5) CRP 36, (6) CRP 29.

Fig. 7 *Nitzschia fossilis,* CRP 22.

Figs. 8 – 10 *Nitzschia reinholdii,* (8) CRP 29, (9) CRP 26, (10) CRP 27.

Fig. 11 *Nitzschia* species 1, CRP 26.

Figs. 12, 13 *Nitzschia* aff. *bicapitata,* CRP 29A.

Figs. 14, 15 *Stephanopyxis turris,* (14) CRP 27, (15) CRP 29.

Fig. 16 *Rouxia* species, CRP 27.

Figs. 17 – 20 *Thalassionema nitzschioides,* (17) CRP 22, (18) CRP 27, (19) CRP 29, (20) CRP 27.

Fig. 21 *Rhizosolenia* aff. *alata,* CRP 29A.

Figs. 22, 23 *Rhizosolenia hebetata* forma *hiemalis,* (22) CRP 27, (23) CRP 29A.

Figs. 24, 25 *Rhizosolenia styliformis,* (24) CRP 29, (25) CRP 29A.

Fig. 26 *Thalassiosira convexa* var. *aspinosa,* CRP 36.

Plate 5

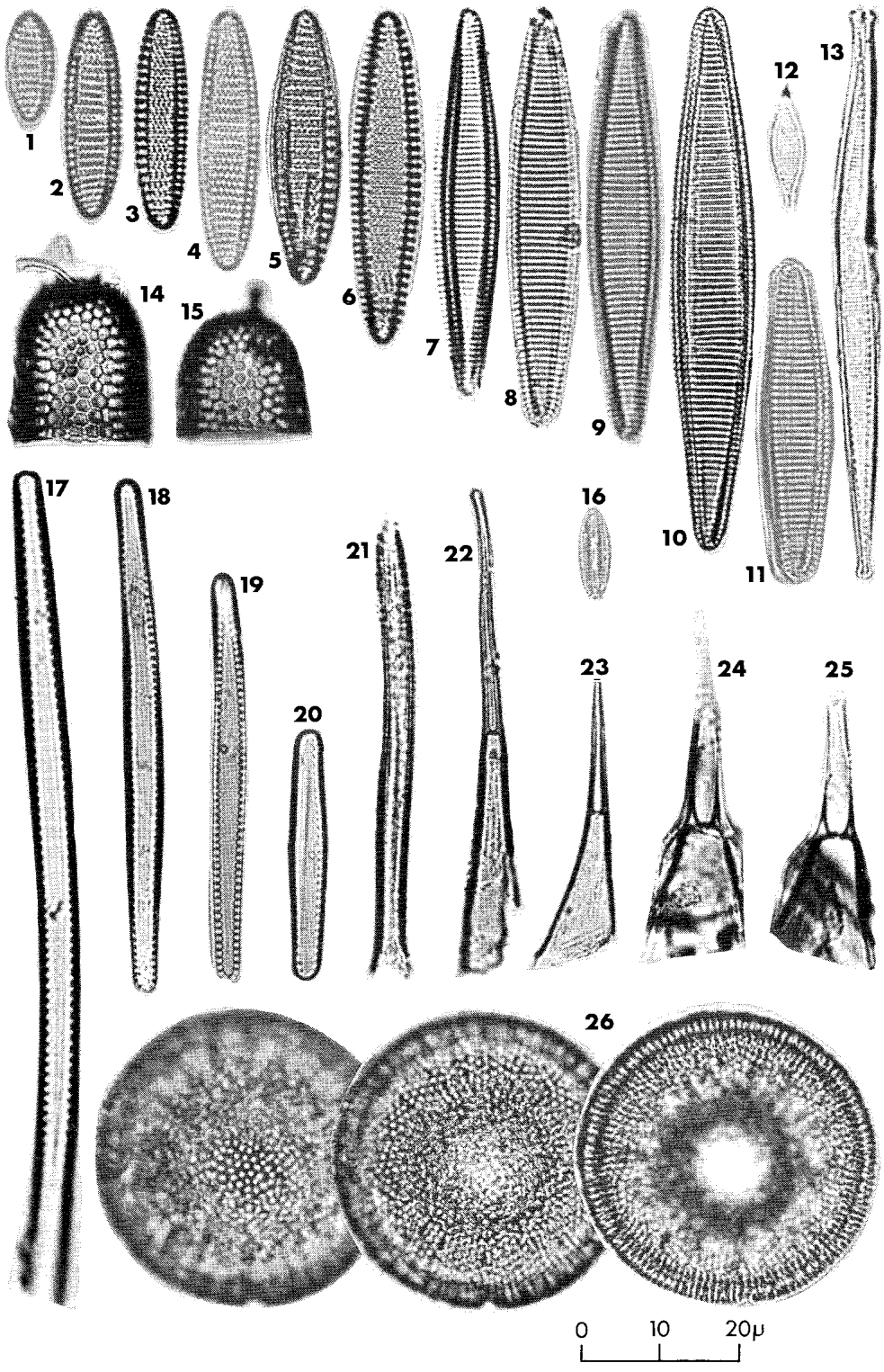
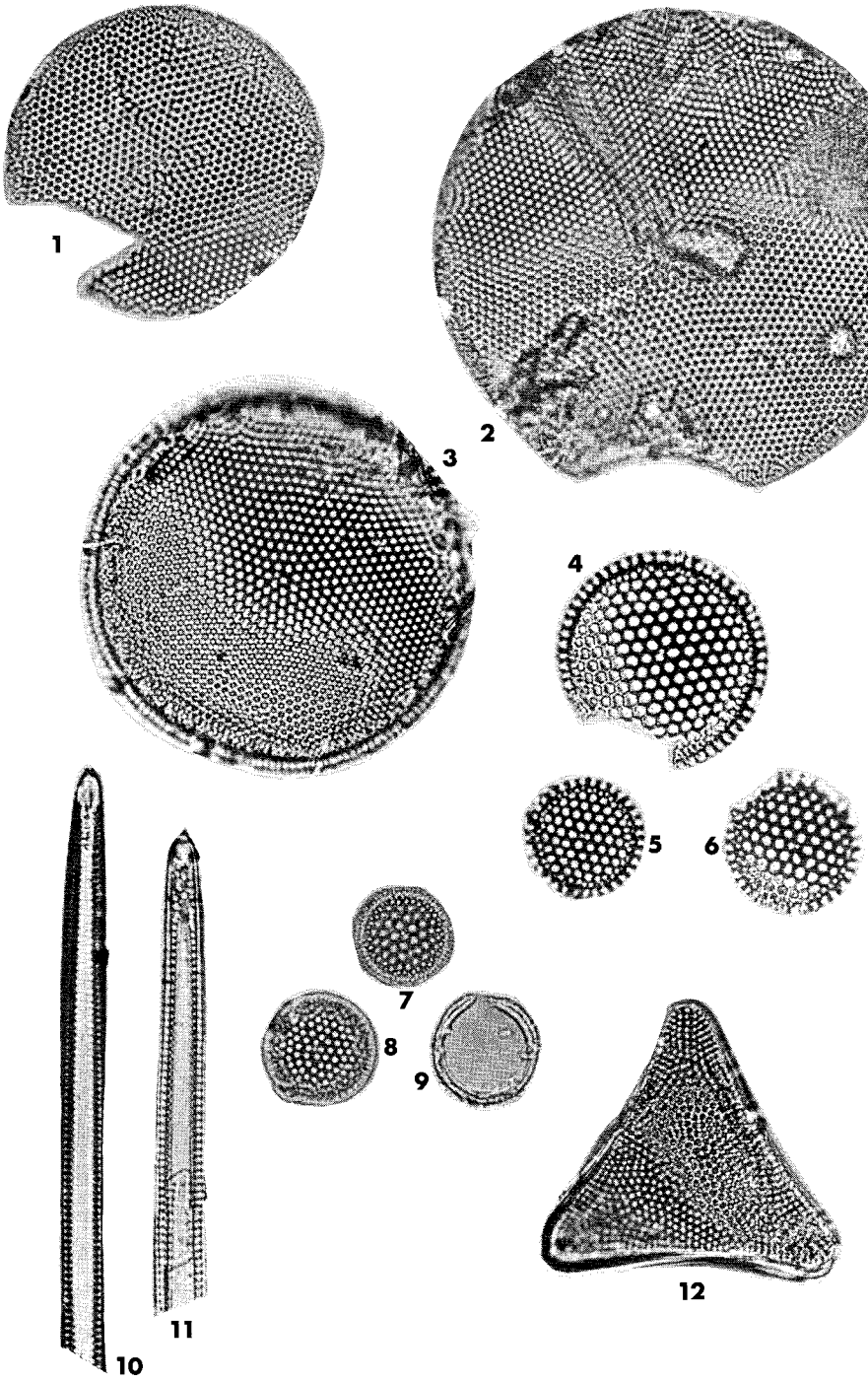


Plate 6

Figs. 1, 2	*Thalassiosira* aff. *lineata*, (1) CRP 25, (2) CRP 24.
Fig. 3	*Thalassiosira eccentrica*, CRP 27.
Figs. 4 – 6	*Thalassiosira nativa*, CRP 27.
Figs. 7 - 9	*Thalassiosira oestrupii*, (7) CRP 24, (8) CRP 25, (9) CRP 22 (girdle).
Figs. 10, 11	*Thalassiothrix longissima*, CRP 22.
Fig. 12	*Triceratium cinnamomeum*, CRP 27.

Plate 6



Description: Hustedt (1959), p. 247, fig. 276; Hasle & Mendiola (1967), p. 114, figs. 20, 53.
Ecology: Simonsen (1974) – one of the most common planktonic species, preferably in colder waters.

Genus **Triceratium** Ehrenberg

Triceratium cinnamomeum Greville
Plate 6, Figure 12
Description: Kolbe (1954), p. 47, plt. 2, fig. 18.
Ecology: Kanaya & Koizumi (1966) – warm water species-tropical.
Occurrence: Rare in samples CRP 25, 27, 36, 29A.

SILICOFLAGELLATES

INTRODUCTION

The same set of samples was used for the study of the silicoflagellates (compare diatom chapter).

For the silicoflagellate counts (compare chapter on diatoms), cleaning and mounting were the same as for the diatom studies.

Counting

For the counting a microscope was used with a high power dry objective. We did not sieve our material, but used normal diatom mounts. This type of preparation sometimes causes taxonomic identification problems with fragments. In order to eliminate such problems we counted only individuals represented by more than half of the original skeleton. Considerable problems were encountered in placing specific individuals in the appropriate taxonomic units. Our species concept was rather broad, following closely the concepts of Martini & Müller (1976) and Locker (1974).

The counting results (table 3) for the parallel samples CRP 22–26 are comparable within statistical limits. There are great differences between the counts of sample CRP 29 and its subsample CPR 29A; the same holds for the parallel counts carried out by both authors (CPR 29, CPR 36 and CPR 37). Some of these discrepancies can be explained by the considerably smaller number counted by one of the authors, others can be explained by different species concepts and/or by misidentifications of fragments of individuals.

Paleoecological interpretation

The silicoflagellate species were grouped into "cold" and "warm" water species, using the concepts proposed by Mandra (1970) and Ciesielski (1975). "Warm" water species are *Corbisema apiculata, Dictyocha aspera, Dictyocha fibula, Dictyocha mutabilis*; "cold" water species are *Cannopolis indet., Distephanus speculum, Distephanus boliviensis, Distephanus boliviensis* var. *mutabilis*. It must be emphasized that temperature values derived by this method have to be treated with great caution; they are no more than indications of warmer and colder surface waters (Poelchau, 1974).

Using the correlation of Mandra (1972) a surface water temperature range for the Capo Rossello assemblages of 4–25°C may be concluded whereas according to the scheme of Ciesielski (1975) the temperature range is 2.5–10°C; the scheme of Schrader & Richert (1974) would indicate a temperature range of 16–18°C (fig. 10). The comparably low surface water temperatures suggest some kind of upwelling, which would have caused increased nutrient supply favouring increased primary production. This result seems to match the results obtained from the diatom studies.

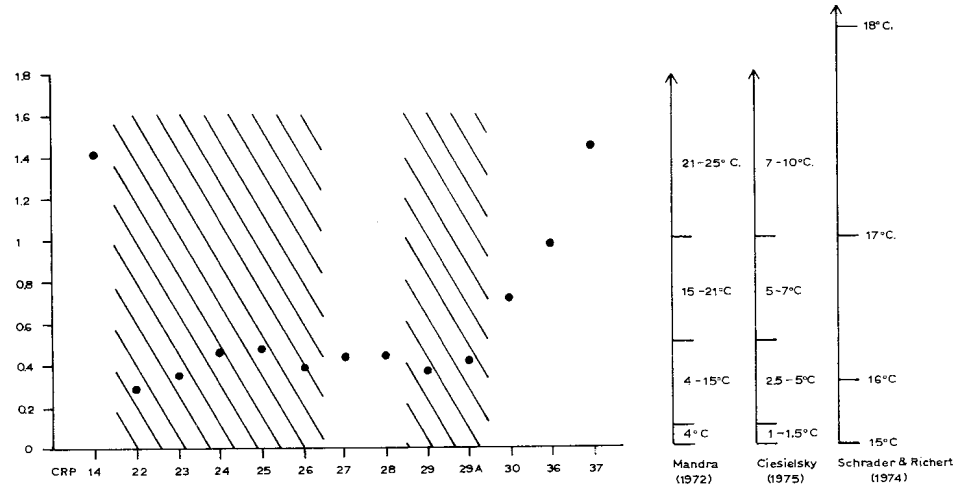


Fig. 10 Graph of the *Dictyocha/Distephanus* ratio in the Capo Rossello samples. The values given are the average of the results of both authors. Shaded areas indicate samples derived from the same sample horizon. On the right, surface water temperature interpretations are given based on the ratios presented by different authors.

Biostratigraphy

The co-occurrence of common *Mesocena circulus* and *Distephanus boliviensis* places the Capo Rossello interval in the *Mesocena circulus* and *Diste-*

phanus boliviensis Zones of Ling (1973) and Bukry and Foster (1973). A placement in either one or the other of these zones is impossible due to their overlapping ranges (compare Martini and Müller, 1976, for definition of datum indicators).

TAXONOMY

Genera and species within genera are arranged alphabetically, regardless of their position in the "natural" system.

Genus **Cannopilus** Haeckel

Cannopilus species indet.
Plate 1, Figure 2

Remarks: Individuals were so badly preserved, that a specific determination was impossible. Also individuals of the *Dictyocha polyactis* Ehrenberg group (fide Ciesielski, 1975) may have been included in this category.
Ecology: These forms are interpreted as "cold" water inhabitants.

Genus **Corbisema** Hanna

Corbisema apiculata (Lemmermann) Hanna
Plate 1, Figure 1

Description: Ciesielski, (1975), p. 654, pl. 2, figs. 4–11; Perch-Nielsen (1975), p. 685, pl. 2, figs. 15–16, 19, pl. 3, figs. 19–20, 24, pl. 15, figs. 1–2.
Ecology: "Warm" water species (Ciesielski, 1975).

Genus **Dictyocha** Ehrenberg

Dictyocha aspera (Lemmermann) Bukry and Foster
Plate 1, Figures 4–5, 7

Description: Bukry & Foster (1973), p. 826, pl. 2, figs. 4, 6.
Ecology: "Warm" water species (Ciesielski, 1975).

Dictyocha fibula Ehrenberg
Plate 1, Figures 3, 6, 8, 9

Description: Mandra (1968), p. 251, figs. 14–18.
Ecology: "Warm" water species (Ciesielski, 1975).

Dictyocha mutabilis Deflandre
Plate 2, Figure 1

Description: Deflandre (1950), p. 197, figs. 203–210.
Ecology: "Warm" water species (Ciesielski, 1975).

Genus **Distephanus** Stoehr

Distephanus boliviensis Frenguelli

Description: Frenguelli (1940), p. 44, fig. 4.
Ecology: "Cold" water species (Ciesielski, 1975).

Distephanus boliviensis var. major (Frenguelli) Ciesielski
Plate 2, Figure 2

Description: Ciesielski (1975), p. 660, pl. 8, figs. 1–5.
Ecology: "Cold" water species (Ciesielski, 1975).

Distephanus speculum Ehrenberg
Plate 2, Figures 3–5, Plate 3, Figure 1

Description: Mandra, (1968), p. 254, figs. 61, 74, 76, 79.
Ecology: "Cold" water species (Ciesielski, 1975).

Genus **Mesocena** Ehrenberg

Mesocena circulus Ehrenberg
Plate 3, Figure 2

Description: Ling (1972), p. 175, pl. 28, figs. 5–6.

ACKNOWLEDGEMENTS

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Plate 7

Fig. 1	*Corbisema apiculata,* CRP 37.
Fig. 2	*Cannopilus* species indet., CRP 27 (860 X).
Fig. 3	*Dictyocha fibula,* CRP 36.
Figs. 4, 5	*Dictyocha aspera,* CRP 27.
Fig. 6	*Dictyocha fibula,* CRP 29A.
Fig. 7	*Dictyocha aspera,* CRP 29A.
Figs. 8, 9	*Dictyocha fibula,* (8) CRP 28, (9) CRP 25.

Plate 7

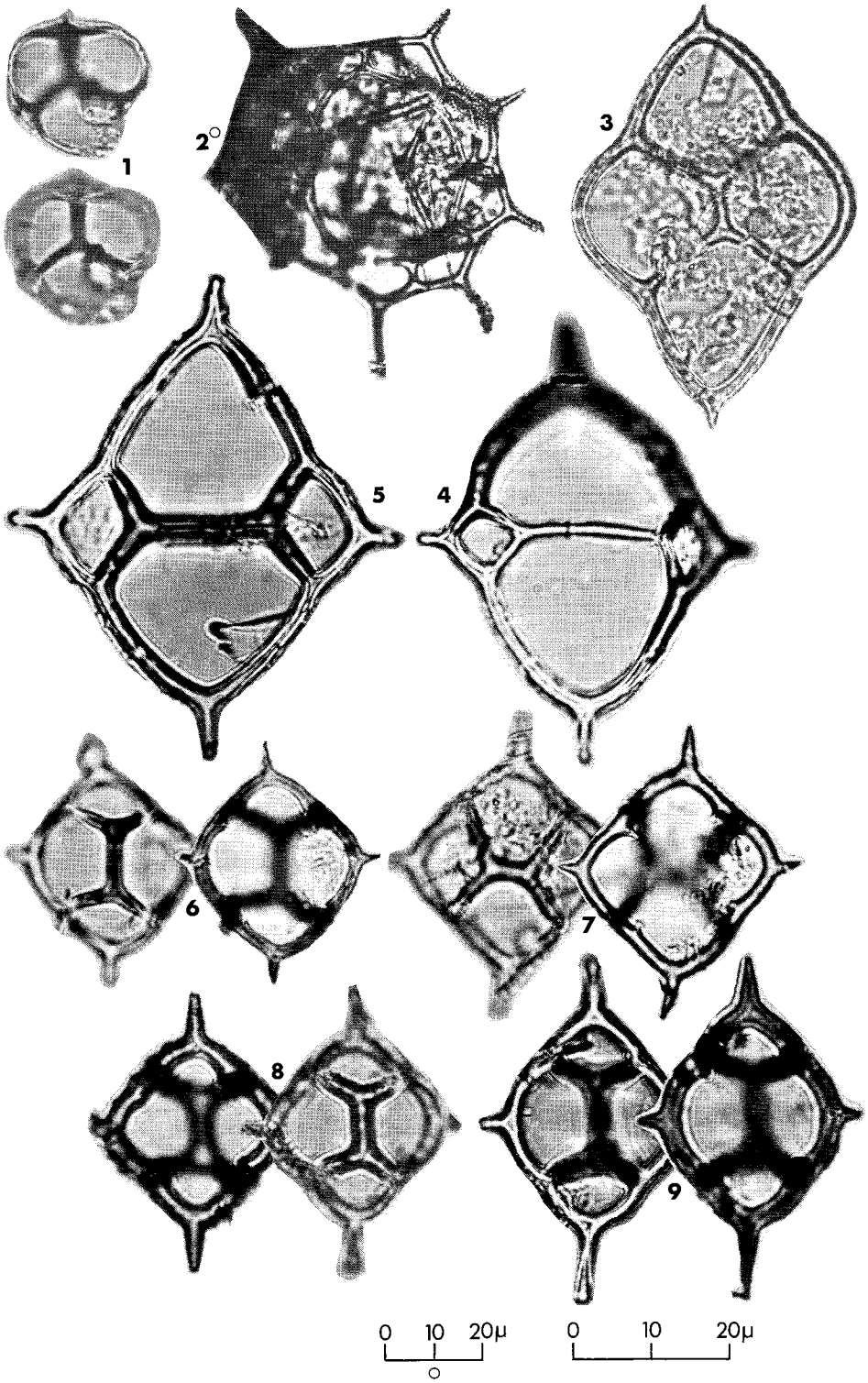

Plate 8

Fig. 1 *Dictyocha mutabilis,* CRP 36.

Fig. 2 *Distephanus boliviensis* var. *major.* CRP 24.

Figs. 3 – 5 *Distephanus speculum,* (3) CRP 25, (4) CRP 26, (5) CRP 22.

Plate 8

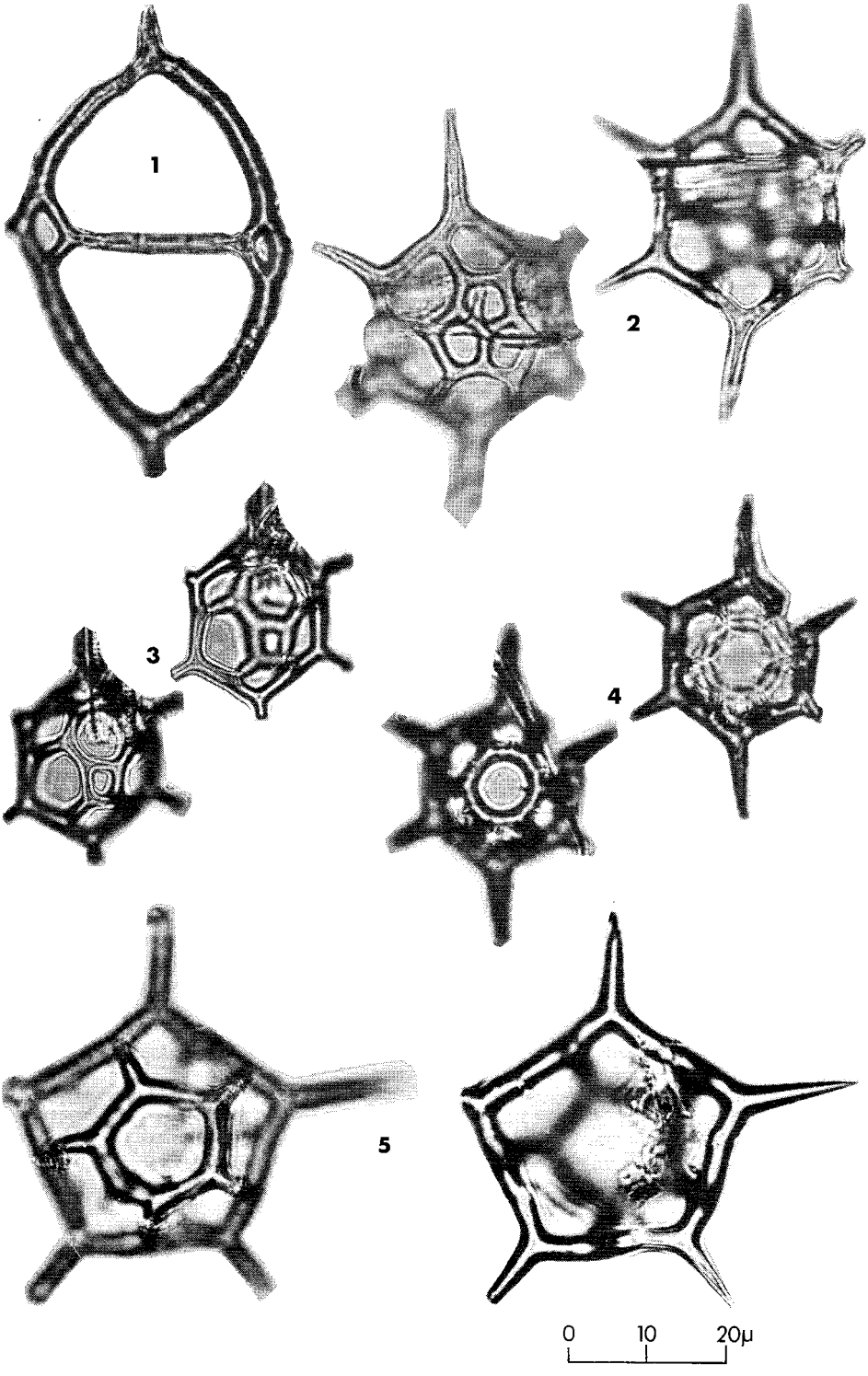

Plate 9

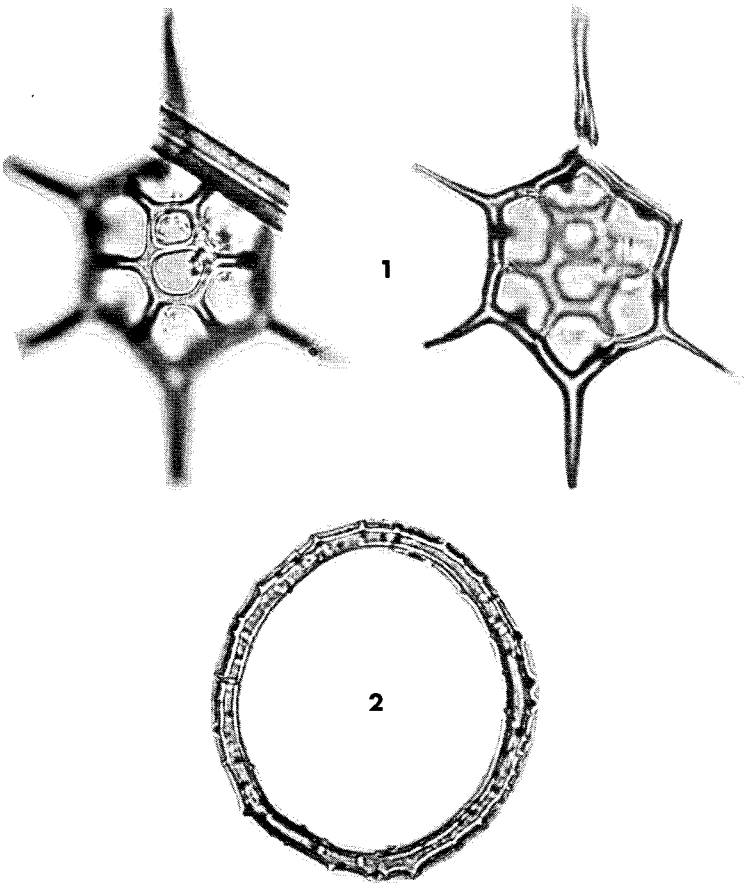

Plate 9

Fig. 1 *Distephanus speculum*, CRP 29A.

Fig. 2 *Mesocena circulus*, CRP 27.

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PLANKTONIC FORAMINIFERA

W. J. ZACHARIASSE

INTRODUCTION

Because a good qualitative analysis of the taxa is a prerequisite for the quantitative investigation, we needed to first establish the basis for our species concept, formulate operational species definitions and decide on a uniform labelling procedure.

In our quantitative study three different counting procedures were applied successively to the CRP samples. With the first procedure we established per sample numbers of specimens of each species per 200 counted planktonic forams in % values in the greater than 125 μ sieve fractions. The second procedure gave the numbers for each species in percentage values, based on 600 counted specimens (in six sets of 100 each) in the greater than 63 μ fractions. In the third procedure we made estimates per sample of the total numbers of planktonic forams, benthonic forams and radiolaria per 100 gram dry weight of sediment. Percentage estimates per sample were calculated for each planktonic species; these percentage estimates were based on total number estimates and the number of specimens per species actually counted in an established n^{th} portion of the 100 gram of the original sediment.

Procedure 1 was completed for all samples; procedures 2 and 3 were applied to 16 samples (CRP 13 up to and including CRP 32 but not CRP 23–26) covering the middle part of the section, where there is a rapid alternation of laminated and homogeneous sediments (Brolsma and Broekman, this volume).

The Capo Rossello interval is considered to be "per definition" of Early Pliocene age. The combined presence of *Globorotalia margaritae, G. scitula subscitula* and *Globigerina nepenthes* suggests a correlation with the Mediterranean *G. margaritae* Zone (Bizon and Bizon, 1972; Zachariasse, 1975; Cita, 1975), which may be equated with some part of the N18–N19 zonal interval of Blow (1969). The absence of *Globigerinoides elongatus* would indicate that the interval does not contain the uppermost part of the *G. margaritae* Zone (Zachariasse, 1975). However, the presence of *Globorotalia puncticulata* in the Arenazzolo underlying the Trubi (Brolsma, 1975) and its sudden re-appearance in considerable quantities in the higher part of the

Trubi overlying our section (Brolsma, 1978) seems to invalidate this earlier zonal assignment. In fact, the two successive entries of *G. puncticulata* in Capo Rossello present a problem, namely which of the two entries is the one that correlates with the "*G. puncticulata* datum" of the various Mediterranean zonal schemes.

DISTINCTION OF THE TAXONOMIC UNITS

Our species concept is based on the assemblage per sample, an assemblage being defined as a morphologically inseparable homogeneous group of individuals, i.e. showing continuous variation. The taxonomic units were established after examination of both the horizontal and the vertical variation of their assemblages. Species based on this concept, therefore, display a wide range of morphologic diversity and may include variants which are reconcilable with different names in the literature. Single assemblages in which such different variants are present are labelled in accordance with the name of the most abundant variant (method also adopted by Cifelli and Smith, 1970, and Cifelli, 1976a).

Thus, the entire assemblage derives its specific name from the predominant form. Because a variant may correlate to "certain" ecological conditions and/or may be of biostratigraphic value, such variants were informally counted in the work according to procedure 1 under species names with the qualifier "type".

For instance, assemblages of *Globigerina bulloides* s.l. where the *Globigerina falconensis* form dominates over the *G. bulloides* form were tabulated as *G. falconensis*. Similar choices were made for assemblages of *Globigerinoides obliquus* and of *Neogloboquadrina acostaensis*; in all CRP assemblages the *G. obliquus* form and the *N. acostaensis* form are completely gradational to and consistently dominant over the *G. extremus* and *N. humerosa* forms, respectively. Assemblages of *Globigerinoides trilobus* include the *G. sacculiferus* type. Amongst the assemblages attributable to the genus *Globigerinita,* the predominant *G. glutinata* form is associated with and gradational to the *G. uvula* form. The latter two forms may in reality belong to different species with considerable overlap in morphological variation. In the absence of adequate criteria for morphological separation both forms have been designated as *G. glutinata.* Assemblages referred to as *Globigerina quinqueloba* show a wide variation and include some taxa from the literature. Because of its small size *G. quinqueloba* was given a broad interpretation.

Notwithstanding the broad species concept and the procedures described for labelling the assemblages, it is still comparatively difficult to define the

species limits. If optimum accuracy is sought for the percentage estimates, which inevitably depend on reliable identifications of the single specimens, precise operational definitions are needed to delimit the morphological range of the species, prior to the counting. In some cases the morphological limit definitions could be chosen in such a way that they left no possibility of ambiguity. For instance, the *N. acostaensis* type is distinguished from the *N. humerosa* type by the number of chambers in the final whorl; this is $\leqslant 5$ for the *N. acostaensis* forms and more than 5 in the *N. humerosa* specimens. The distinction between the *G. obliquus* and *G. extremus* types is more subjective, the determining factor being the equatorial chamber outline. In contrast to the *G. obliquus* forms the specimens designated as the *G. extremus* type have all chambers in the final whorl compressed in a lateral-oblique manner. Still less reliable criteria had to be used to establish morphological limits within the *G. bulloides* s.l. group. Considerable overlap in variation in some of the CRP samples posed problems for the distinction of *Globigerina apertura* from *G. nepenthes,* and of *G. apertura* from *Globigerinoides obliquus* (see Remarks on the species). These examples suffice to make it clear that our specific identifications may have been arbitrary, and, therefore, may have added to the inaccuracy of the percentage estimates. Creation of intermediate units has been avoided; such categories shift species limits and multiply the number of problems rather than reducing them.

Convergence in morphology of different species towards the small-sized specimens causes additional differentiation problems. In two of the counting procedures the 63–125 μ sieve residues are included. Notwithstanding the fairly good preservation of the faunas, the intensive study of size variation and the use of all observable specific characteristics, the identification of part of the small-sized specimens remains arbitrary. In the greater than 125 μ fraction, representatives of *G. bulloides* s.l. and of *G. glutinata* can easily be separated, but below this mesh-width distinction is often difficult; in the small-sized specimens the characteristic test-surface structure of *G. glutinata* is hardly applicable any more when a normal stereomicroscope is used. Occasionally, the separation between *G. quinqueloba* and small-sized *N. acostaensis* appeared to be difficult and the same is true for the discrimination between small-sized *Globorotalia margaritae* and *G. scitula subscitula.* In contrast to these identification problems for small-sized specimens, it may be more difficult to distinguish between *G. apertura, G. obliquus,* and *G. nepenthes* in the greater than 125 μ fraction.

Laminated intervals	Species / Samples	Neogloboquadrina acostaensis (dextral)	N. acostaensis (sinistral)	N. humerosa-type	Globigerina falconensis	G. bulloides-type	G. apertura	G. nepenthes	G. quinqueloba	Globigerinoides obliquus	G. extremus-type	G. trilobus	G. sacculiferus-type	Globigerinita glutinata	Orbulina universa	Globigerinella siphonifera	Globorotalia margaritae	G. scitula subscitula	Indeterminable	Total number of counted specimens
	45	45	2		64		6		1	37				12	1		26	1	5	200
6	44	50	4		64	3	19	3	1	37		3		16			1	2	5	208
	43	54	5		29		24		1	53		1	1	13	1		16		2	200
	42	44	6		41	2	21		1	45		4	3	9	6		11		7	200
	41	51	6		39		5		1	49		7	2	18	2		9	1	10	200
	40	36	14		41	2	14		6	40	1	8	5	24	1	1			7	200
	39	45	6	1	27	1	9		2	65		2	2	27	1	1	7		4	200
	38	72	1		40	1	16			33		1	1	24	2		3	1	5	200
	37	52	1		49		6		2	35		13	3	30	1	1		1	6	200
5	36	44	6		58	5	12	1	4	44				16	4	3	1		2	200
	35	71	7		42		11			45		2	1	20	3		1		4	207
	34	51	4		67	1	3	1		58				3	4				8	200
	33	56			42	1	14		5	45		10	1	13	3	1	6		3	200
	32	42	2		66		14		3	40				15	2		15		1	200
	31	44	3		48	1	8			42	2	15	2	16	3	1	1	2	7	195
4	30	50	1		49		14		4	36		18	2	14	3		5		4	200
	29	54	1		37		4	6	5	51	1	6	3	22	4		1		5	200
	28	39	3	1	31	1	8	6		68		9	3	23	4		3		1	200
	27	39	7		94	2	5		3	32		1	1	7	3		1		5	200
	26	27	6		98	1	12		2	31		4	1	9	1				3	200
3	25	32	7		76		12		1	48		5	3	6	6				4	200
	24	29	6		67	6	12		4	51		6	2	12	2			1	2	200
	23	40	5		82		10		2	46		6	1	4	1				3	200
	22	50	10		66		12		2	36	3	1	1	11	2				6	200
	21	31			112		2	1		28		2		10	1		2		7	197
	20	33	2		81		14		6	26				23	3		5		7	200
2	19	39			79	3	9	1		39				11	9	1	1	2	6	200
	18	45	6		83		13	1	2	31				15	1				3	200
	17	51			74		5	1	2	36		1		28			2		5	205
	16	23	13		70		12			36		24	4	8	4		3		3	200
	15	55	9		33	3	10			48		6	3	20	1		7		5	200
	14	34			42	1	5		4	57		6	3	24	3		18		3	200
	13	65			46	3	4		3	47		2		19	3	1	1	3	1	200
1	12	75	1		32		12		6	42				24	4	1	1	1	1	200
	11	51	5		43	5	14			37		3	4	23	8			3	4	200
	10	63	1		34	3	12	1	1	52	4		1	21	2			1	6	202
	9	77	3		19	3	15		5	43	3	2	1	22	3				4	200
	8	81	8		4	3	38		3	22				31	2			2	15	209

Table 1. Data matrix for the counts of procedure 1. For each taxonomic unit the number of specimens per sample is tabulated. The heavy line encloses the data of the lateral samples CRP 22–26.

Species list

The following species were recognized: *Neogloboquadrina acostaensis* (*N. humerosa*), *Globigerina falconensis* (*G. bulloides*), *G. apertura, G. nepenthes, G. quinqueloba, Globigerinoides obliquus* (*G. extremus*), *G. trilobus* (*G. sacculiferus*), *Globigerinita glutinata, Orbulina universa, Globigerinella siphonifera, Globorotalia margaritae* and *G. scitula subscitula.* Names in brackets refer to variants reconcilable with names from the literature and counted separately in procedure 1. In addition, sample CRP 27 contains some specimens of *Streptochilus globigerum* (Schwager). The taxonomic units are described in the final chapter; they are illustrated in Plates 1 to 8.

COUNTING PROCEDURES

Procedure 1

Samples of about 0.5 kg were washed through a sieve with a 125 μ mesh width, after which the residue was oven-dried. The sample was repeatedly split with an Otto microsplitter to get a subsample which contained a convenient number of planktonic forams. This subsample was distributed as evenly as possible over a rectangular extraction-tray.

In order to diminish the effects of sorting according to size and shape of the specimens over the tray, counting was done along cross-shaped traverses through the centre of the tray. Counting was stopped as soon as 200 specimens had been seen. In cases when less than 200 specimens could be counted along these traverses, counting was continued along adjoining traverses.

Broken specimens, where at least half of the test was intact, have been included in the counts. The counts were performed by M. J. Brolsma, who tried to follow the present author's species concepts as closely as possible.

Results

The results of Brolsma's counts are given in table 1 and represented graphically in fig. 1. The results indicate that five out of twelve species occurred in the 200-counts of all samples: *Globigerina falconensis, G. apertura, Neogloboquadrina acostaensis, Globigerinoides obliquus,* and *Globigerinita glutinata.* Their joint frequency in the associations is approximately 80 to 90%. The remainder appeared in a discontinuous way in the counts and generally in low numbers.

Visually, figure 1 shows no coherent fluctuations in the frequency patterns of the species and their variants. Trends and correlations with the litho-

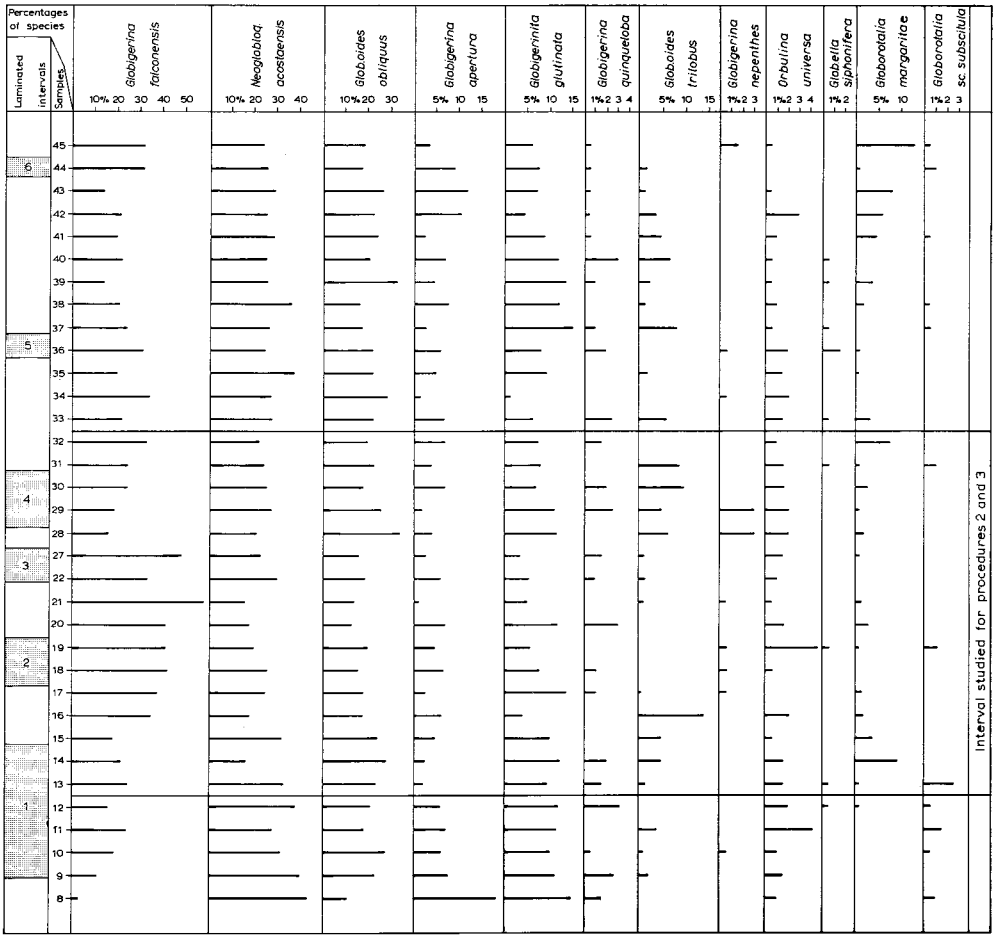


Fig. 1 Frequency patterns of the planktonic foraminiferal species in percentage values obtained from the counts of procedure 1.

logy are likewise absent in the percentage values of the individual species. To test these primary conclusions, the percentage values of the twelve species, based on the combined numbers of specimens of each species plus its variant, were compared in pairs and each one with the sediment categories laminated and non-laminated, by application of an R-mode programme. This programme analyzed the data for the entire section and for the CRP 13–32 interval chosen for counting procedures 2 and 3. No distinct correlations could be found between the paired categories (level of significance (α) = 0.05). A vertical trend in the frequency patterns of single species was reported only for *Globorotalia margaritae*; for the section as a whole the percentage values of this species seem to show an upwards increase (P = 0.03).

No special statistical attention was paid to the relative increase of *Globigerina falconensis* in the lower part of the column or to the significance of scattered peaks of other species. There is a significant difference between extreme percentages of sinistral *Neogloboquadrina acostaensis,* but again there is neither a trend along the entire column nor a correlation of the peaks with either of the two sediment types.

Of particular interest was the comparison of the quantitative composition of the five samples (CRP 22–26) taken over a lateral distance of five meters from the same layer. Calculated χ^2 values suggest that there is doubt in the case of only one pair of samples ($P < 0.01$) that the 200-counts could have been drawn from one association. The exception is the pair of samples CRP 22 and 26 (see table 2).

Kummerforms of most species have been counted, but no clear conclusions could be drawn from their relative frequencies.

pairs	χ^2	d.f.	P
22 – 23	11.31	6	.10
22 – 24	12.59	6	.05
22 – 25	9.71	6	.15
22 – 26	18.57	6	< .01
23 – 24	7.55	7	.40
23 – 25	4.09	7	.75
23 – 26	10.50	6	.10
24 – 25	4.53	7	.70
24 – 26	11.89	7	.10
25 – 26	13.24	7	.05

Table 2. Comparison of pairs of 200-counts for the lateral samples CRP 22–26 by means of the Chi-square test of homogeneity.

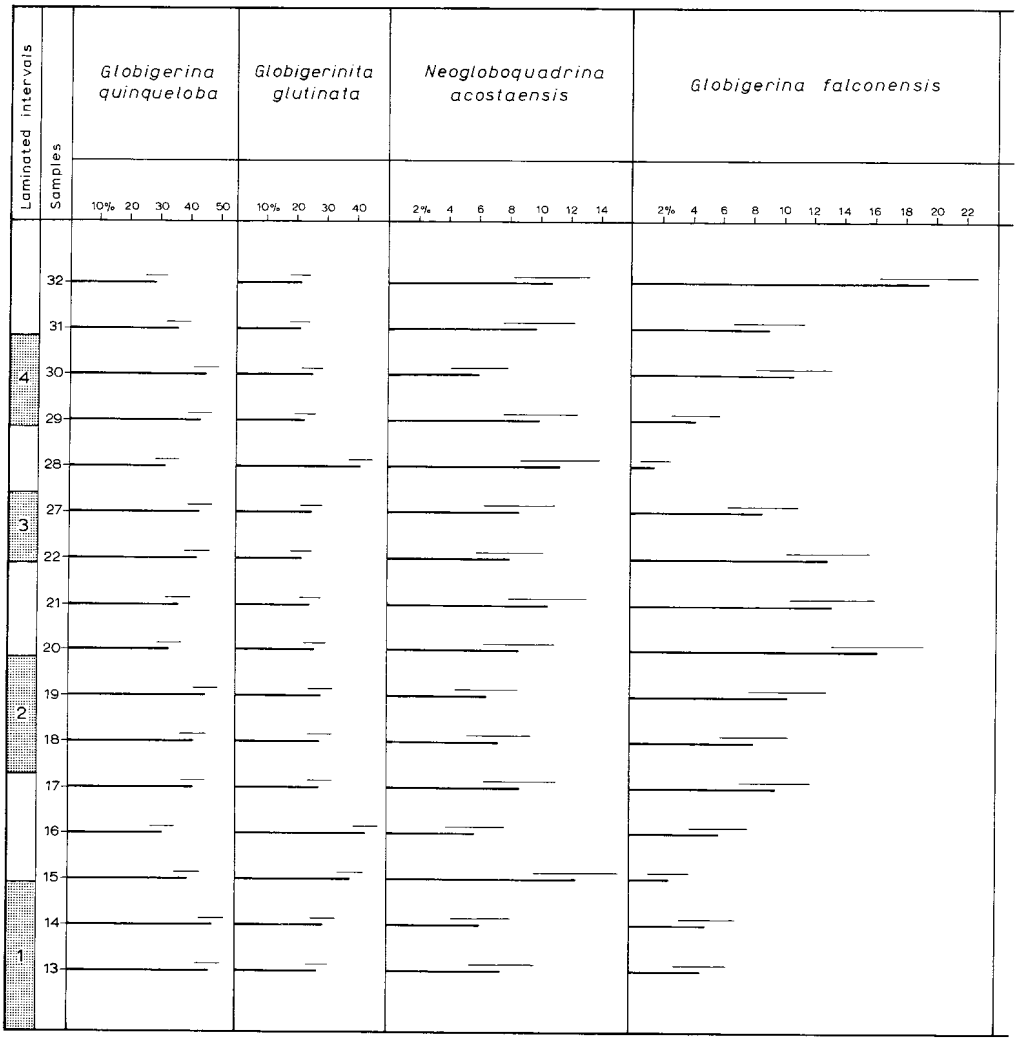
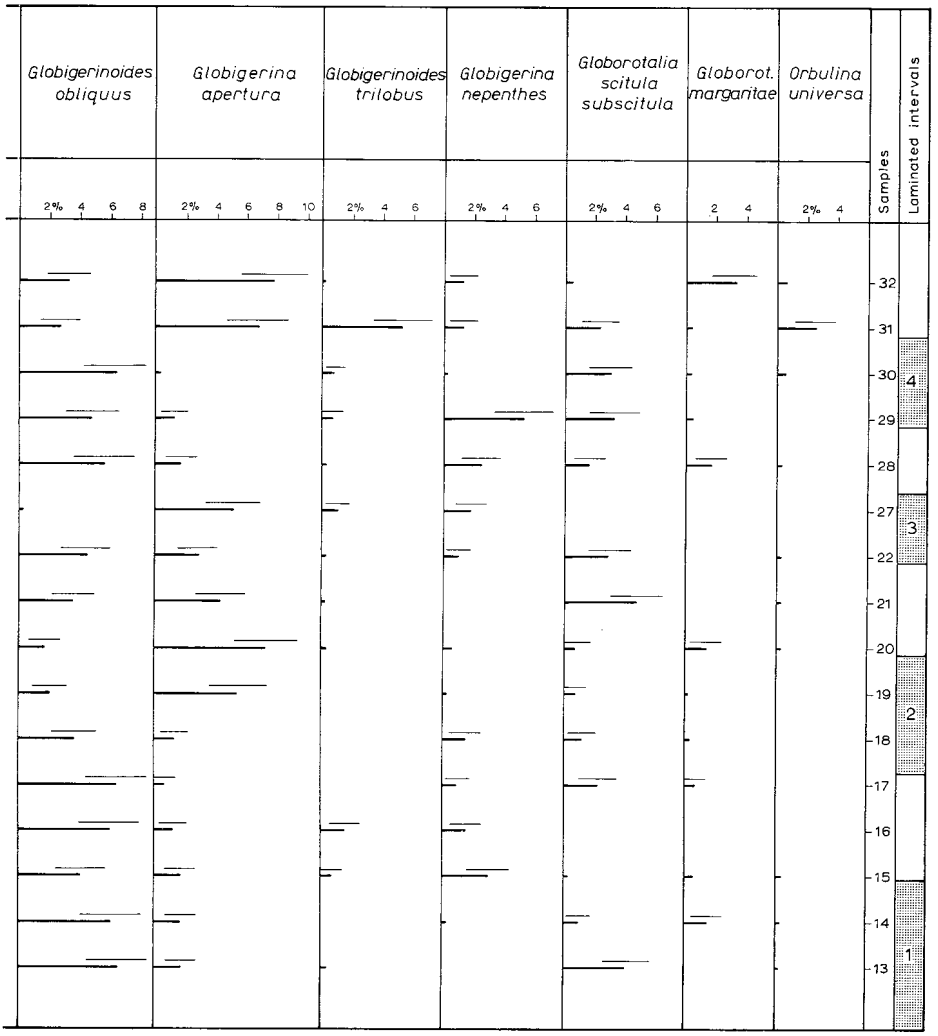


Fig. 2 Frequency patterns of species based on the percentages derived from the 600 counts of the > 63 μ fraction (procedure 2). For each calculated value the 95% confidence interval is plotted; if no interval is indicated, the proportions are based on a few observations only.

Procedure 2

The quantitative composition of the planktonic foraminiferal associations in the residues > 125 μ cannot be considered representative for the actual composition when all size classes are incorporated. The reason is the large differences in size-distribution of the specimens belonging to the individual



taxonomic units. A second set of counts was performed on splits of the $> 63\ \mu$ fraction. With the inclusion of the 63–125 μ fraction in the split, however, the distribution over the tray was more readily subject to clustering.

For each sample a total number of 600 specimens was collected in six sets each containing 100 individuals; each set was picked from more or less randomly positioned areas along cross-arranged traverses through the centre of a circular extraction-tray.

The 600 specimens per split were stored in a Chapman slide for future reference.

The numerical data on the repeated 100-counts of the 63–595 μ fraction are given in table 4. In figure 2 the percentage values for each species per 600 counted specimens are presented graphically.

Results

As expected, the frequency rank of the small-sized species *Globigerina quinqueloba* and *Globigerinita glutinata* in the > 63 μ fraction is high. Both species together make up 50 to 80% of the associations. Continuously present, but with a distinctly lower frequency rank, are *Globigerina falconensis, G. apertura, Neogloboquadrina acostaensis,* and *Globigerinoides obliquus.* Discontinuous occurrences, generally in percentage values of less than 5, were found for *Globigerina nepenthes, Globigerinoides trilobus, Orbulina universa, Globorotalia scitula subscitula* and *G. margaritae.*

An R-mode programme was applied to the frequencies of these 11 species, the unidentified specimens being considered as outside counts. Because the numbers of *Globigerinita glutinata* were suspected of causing a squeezing effect on the other numbers, the number of this species is deleted in another R-mode test (see M. M. Drooger, this volume).

In addition, the percentage values of species were tested for correlation with both types of lithology. The correlations between paired categories (species and lithology types) and their probability levels are shown in figure 9 and discussed and interpreted in the final conclusions and in the chapter on paleoenvironmental interpretation.

Prior to an interpretation of these correlation values in terms of paleoenvironmental "conclusions", however, an analysis of the reliability of the obtained percentage values of the species is required. To what extent can paired categories show correlation as a result of mere chance effects? If such correlations are real, they are expected to appear in repeated counts as well, i.e., the counts in the > 63 μ fraction should be representative for the split, and the split should be representative for the sample.

In order to investigate whether the counts are representative for the split, the six 100-counts from the samples CRP 13, 17, 19, 21, 27 and 30 were grouped as three sets of 200. All three 200 sets were derived from one split and had been counted during the same day. Two statistical tests were applied to these data.

The first test investigates whether for each sample the three groups of 200 specimens could have been drawn from a single association.

The results of this test indicate that for almost all samples the pairs of 200-counts can be considered as being drawn from one association ($P \geqslant 0.05$). An exception is sample CRP 13 for which there is a P value of 0.01.

As the previous test compares the overall composition in the samples, it gives no information about the reliability of the percentage values for individual species. A second test investigates whether the variation in the proportions of individual species might be the result of errors other than the statistical error.

Sampling errors other than the statistical error may be considered negligible if the observed variation in the proportions of a species in the successive 200 counts is within the range of the calculated binomial interval. The binomial interval of the proportion (p) of a species (expressed as percentage) in the successive 200 counts is according to the binomial model $\bar{p} \pm 2SD$ (confidence level 95%). In this equation, $\bar{p}$ refers to the mean proportion of a species in the counts and the standard deviation $SD = \sqrt{\frac{\bar{p}\,(100 - \bar{p})}{n}}$, in which n is 200 or 600.

The variation in the proportions of species in the three counts of 200 specimens per split from samples CRP 13, 17, 19, 21, 27 and 30 and the calculated binomial interval are plotted in figure 3. Generally, the observed variation and the calculated binomial interval are markedly concurrent, which indicates that the variation is mainly a result of the statistical error.

The results from the χ^2 statistic and those obtained from the comparison between the observed variation in the proportion of the species and the corresponding binomial interval suggest that the distribution of individual species over the tray and the manner of collecting 200 specimens were sufficiently random. These conditions being fulfilled the counts may be considered to be representative for the split.

In the same way, two sets of three 200-counts and their sum total of 600 from samples CRP 14 and 27 were tested. In this case, each set was derived from a different split, and the countings were separated by several months.

For sample CRP 14, the results of the χ^2 test suggest that all pairs of counts were drawn from one association ($P \geqslant 0.05$; see table 3). The comparison between the two sets of counts from sample CRP 27, however, showed that the count values of 5, 6, and 8 cannot be regarded as being drawn from the same association as the counts of 1, 2, 3, and 4 ($P = 0.01$; see table 3).

Comparison between the variation in the proportions of species in the two sets of 600 counts on CRP 14 and 27 and the corresponding binomial inter-

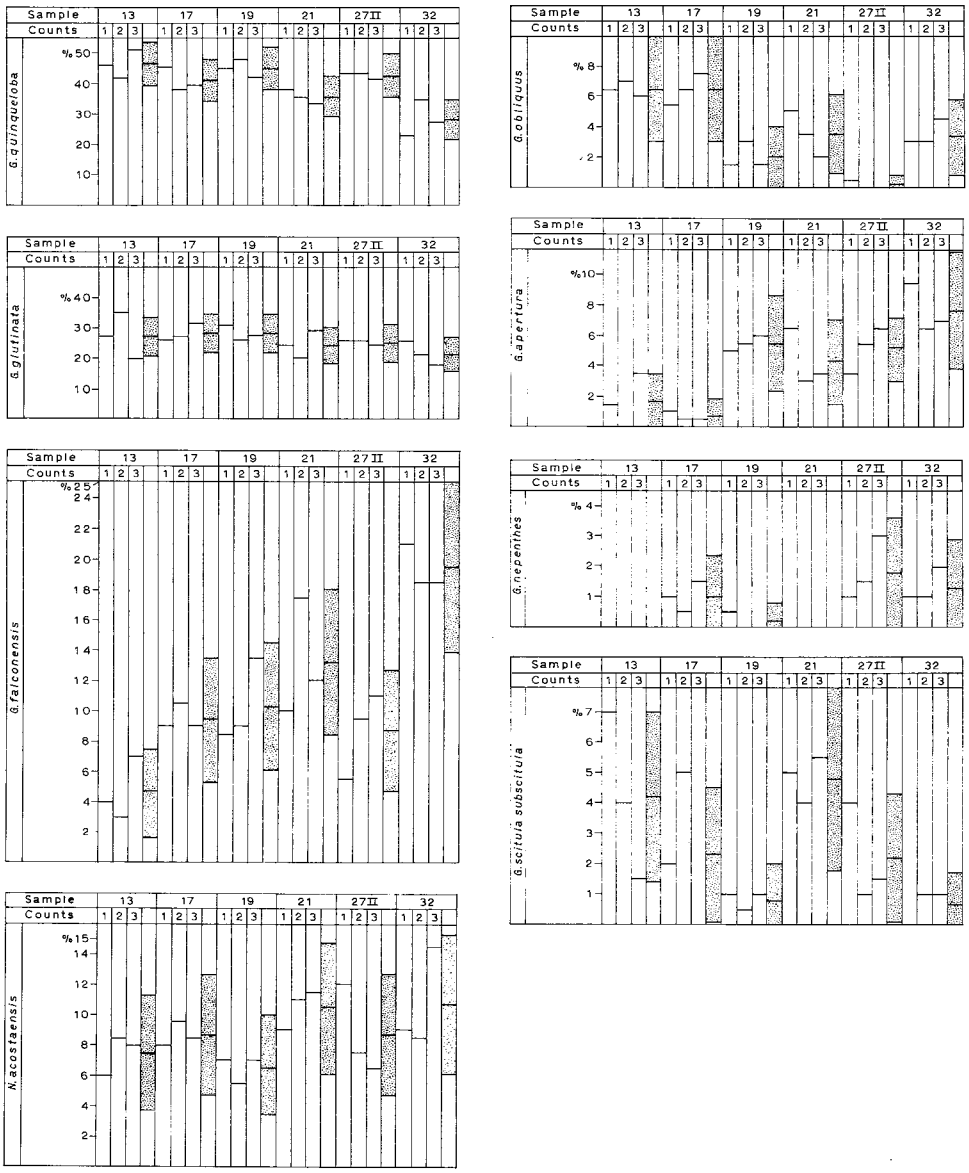


Fig. 3 Variation in the percentages of the species in three counts of 200 specimens in the same split. Shaded columns represent the calculated binomial interval at the 95% confidence level.

CRP 14 pairs	χ^2	d.f.	P	CRP 27 pairs	χ^2	d.f.	P
1 – 2	.55	4	.95	1 – 2	1.88	6	.95
1 – 3	1.86	5	.85	1 – 3	4.34	6	.60
1 – 4	.29	5	.99	1 – 4	1.53	6	.95
1 – 5	6.42	5	.30	1 – 5	31.43	6	< .001
1 – 6	2.50	5	.80	1 – 6	18.94	6	< .01
1 – 7	2.93	5	.70	1 – 7	12.38	6	.05
1 – 8	1.48	5	.90	1 – 8	35.14	6	< .001
2 – 3	1.70	5	.90	2 – 3	3.38	6	.80
2 – 4	.59	5	.99	2 – 4	1.06	6	.98
2 – 5	7.16	5	.20	2 – 5	27.13	6	< .001
2 – 6	4.95	5	.40	2 – 6	18.79	6	< .01
2 – 7	2.90	5	.70	2 – 7	11.32	6	.05
2 – 8	4.13	5	.50	2 – 8	29.22	6	< .001
3 – 4	1.63	5	.90	3 – 4	2.30	6	.90
3 – 5	1.79	5	.90	3 – 5	21.86	6	.001
3 – 6	4.24	5	.50	3 – 6	11.34	5	.05
3 – 7	3.91	5	.60	3 – 7	7.45	6	.30
3 – 8	2.77	5	.75	3 – 8	16.91	6	.01
4 – 5	8.37	5	.15	4 – 5	31.79	6	< .001
4 – 6	4.28	5	.50	4 – 6	21.48	6	.001
4 – 7	3.42	5	.60	4 – 7	13.00	6	.05
4 – 8	6.01	7	.50	4 – 8	50.55	7	< .001
5 – 6	4.38	5	.50	5 – 6	6.79	5	.25
5 – 7	2.13	5	.80	5 – 7	13.12	6	.05
5 – 8	1.25	5	.95	5 – 8	7.02	6	.30
6 – 7	6.07	5	.30	6 – 7	1.74	5	.90
6 – 8	3.02	5	.70	6 – 8	1.51	5	.90
7 – 8	1.87	5	.90	7 – 8	1.98	5	.85

Table 3. Comparison of two sets of three 200-counts and their sum of 600 for samples CRP 14 and 27 by means of the Chi-square test of homogeneity. Numbers 1, 2, 3, 5, 6, and 7 refer to the 200-counts; the 600-counts are indicated by numbers 4 and 8.

vals clearly indicates which of the species contribute to the differences in the overall composition between the counts on CRP 27 (see fig. 4). The observed variation in the proportions of *Globigerina nepenthes, G. falconensis,* and *Globigerinoides obliquus* exceeds the range of their binomial interval. In the repeated counts on CRP 14, the variation in the proportion of only one species (*G. falconensis*) exceeds the binomial interval. Reinvestigation of the slides on which the two sets of counts on CRP 27 were based indicated that the author's inconsistency in specific determinations greatly contributed to the differences in the quantitative composition. It appeared that part of the small-sized specimens of *Globigerinita glutinata* had errone-

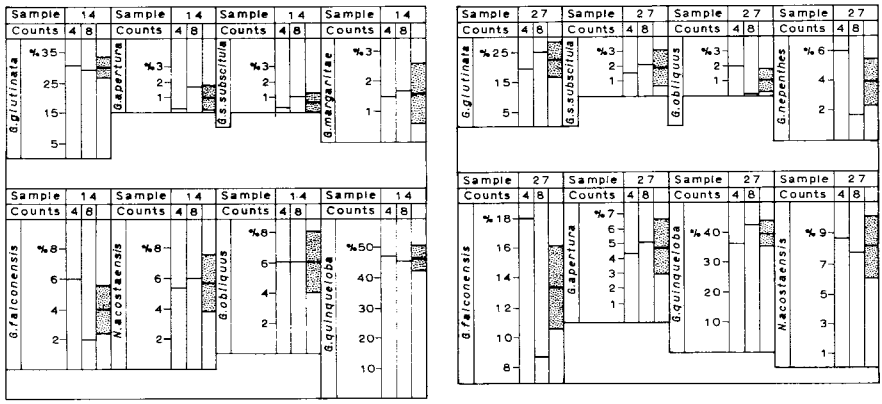


Fig. 4 Variation in the proportions of species in two sets of 600-counts based on two different splits. Shaded columns represent the calculated binomial interval of the 600-counts at the 95% confidence level.

ously been assigned to *G. falconensis* or to *G. nepenthes* in the first series of counts.

It would seem therefore that no reliable information can be obtained as to the extent to which the split may be considered as representative for the sample. Lack of consistency in specific determinations in the course of the investigation added to the inaccuracy range of the percentage values and thus to the differences in the inferred quantitative composition. The results of the counts on CRP 14, however, may indicate that the split is representative for the sample, which means that, the conditions of random distribution and random picking were fulfilled.

Summarizing the results, it is concluded that reproducibility of 200 or 600-counts derived from one or from two different splits and performed by the same person during the same day or separated by less than some months is fairly satisfactory. Reproducibility after a longer lapse of time may be doubtful.

Procedure 3

Percentage values based on counting procedures 1 and 2 have the disadvantage that the obtained proportion of a species may deviate considerably from the actual relative number in the associations, since these procedures deal with a rather low and fixed total number of specimens. The numbers 200 and even 600 are certainly too low to permit definite conclusions to be drawn about the frequency patterns of rare species or to as-

certain with fair reliability the presence or absence of a species. For a final evaluation of the faunal associations a method was sought which would give a better estimate of the actual proportions of rare taxa and which would permit more reliable conclusions regarding the presence or absence of important taxa (e.g. index fossils).

It appeared that the method applied for radiolaria by W. R. Riedel and A. Sanfilippo (this volume) could also be adopted with some modifications for the planktonic forams. This method aims at approximating the actual proportion of a species, on the basis of the number of specimens of a taxon actually seen and on an estimate of the total number of specimens per faunal category. This method is called procedure 3.

One hundred grams dry weight of sediment were washed through two sieves with a mesh width of 595 μ and 63 μ, respectively. The residues were dried and weighed to estimate the lost-weight of the clay-silt fraction. The residues of the 63–595 μ fraction were split into two parts. One part was stored for future reference, the other was repeatedly partitioned by means of the Otto microsplitter. The final split was distributed over the rectangular extraction-tray divided into 45 fields. The part of the split which had fallen beyond the area of the 45 fields was "brushed" inside. Each field is separated from the adjacent ones by slightly elevated ridges of approximately 1 mm. In the counts performed on a field, specimens on half of the rim circumference were included.

Since the reliability of the percentage estimates depends on the density, it is necessary to calculate the density from a sufficiently high number of fields. In our case, this was done on 14 fields, more or less randomly positioned over the tray. The density of a faunal category can be given as $\bar{d} \pm SE_d$, in which $\bar{d}$ refers to the mean number of each category (planktonic or benthonic forams, radiolaria, etc.) in the 14 fields and SE_d to the standard error. An estimate of the total number in the faunal category per 100 grams dry sediment can be calculated from the formula $T = S \times Y (\bar{d} \pm SE_d)$, in which S is the ratio total residue/final split, and Y the number of fields per tray (= 45). It should be emphasized that one of the additional errors in the values obtained depends on the amount of residue in the fraction larger than 595 μ. In the CRP samples, however, this amount proved to be negligible, except in the case of samples CRP 18 and 29, in which the > 595 μ residues consist of a relatively large quantity of non-disintegrated sediment (24 and 37% of the total residue, respectively).

The proportion of a species can be estimated from the density ($\bar{d}$) and the number of fields investigated to find a sufficiently high number of specimens of a species. The minimum number required to obtain useful results was

considered to be 10. The proportion of a species expressed as a percentage value is $p = \frac{100 \cdot K}{M \cdot \bar{d}}$, in which M is the number of fields investigated to find a certain number (K) of specimens. Statistical errors in the obtained proportions, induced by the estimated density and the number K, are discussed by M. M. Drooger (this volume). It is noted that if a number of 10 specimens could not be counted in 45 fields, no additional counts were performed on a second split because of the immense counting time involved. In such cases, however, the binomial error, induced by the factor K itself, becomes relatively large and starts to outweigh the error induced by the density.

Estimations of the density and of total numbers per unit weight of sediment were performed on planktonic forams (including a damaged and an undamaged category), on benthonic forams and on radiolaria (including fragments). For the benthonic forams two categories were counted separately: one including all taxa with the exception of *Oolina hexagona,* and one of *Oolina hexagona* itself. This subdivision was made because of the evident correlation between this species and the lithology (see Brolsma, this volume).

Percentage estimates were calculated for the planktonic foraminiferal species only. For rare species or for taxa which are easily subject to uneven distribution over the tray (e.g. *Orbulina universa*) all 45 fields were investigated. For species with a higher relative frequency (more than 1%) 9 fields were searched, even for species which are so frequent that the minimum number of 10 specimens could be counted in one or two fields already. We made an effort to count 9 fields even for species with a high frequency in order to reduce errors induced by their uneven distribution over the tray. Consequently, all planktonic forams on 9 adjoining fields of a traverse were actually counted. The total numbers obtained were used to test whether the estimated density ($\bar{d}$), based on the number of 14 fields, corresponds with the density of the 9 field-traverse. Moreover, these numbers may provide an opportunity for analyzing the reliability of the percentage estimates of some of the species (see final conclusions).

The numerical data obtained from procedure 3 are too bulky to be printed in this volume. For further research all data sheets are available in the Department of Micropaleontology of the Utrecht State University. Some examples of these data sheets are shown in table 4. Total number estimates are graphically represented in figure 5. In this figure only the replicate counts were used in cases when such counts had been made.

Results

The estimated total number of planktonic forams per 100 gram dry weight (T_P) varies between 0.7 and 6.7 $\times$ 10^6, that of benthonic forams (T_B) between 3.5 and 8.0 $\times$ 10^4. These data indicate that P/B ratios must be very high, on the average they are about 75. Radiolaria occur in two intervals (CRP 14 and CRP 22–31). Their total numbers (T_R) range from 4 to 100 $\times$ 10^4. Strongly fluctuating values were obtained for *Oolina hexagona* (T_O), with highest numbers calculated (up to 6.5 $\times$ 10^4) for the laminated sediments. Fluctuations in the relative number of damaged planktonic foraminiferal specimens are in the range of 10 to 27%.

The reliability of total number estimates depends on the error induced by the estimation of the density and on the error introduced by unequal portioning of the original residue by our Otto microsplitter. An estimate of the latter error, however, suggests that our microsplitter is surprisingly accurate; in case of S is 512, the error did not exceed 3% (see M. M. Drooger, this volume).

Apart from the errors stemming from the method and the mechanical procedures, it was considered worthwhile to check whether other errors, for instance errors based on subjective appreciation, could be ruled out. So, we checked to see whether the results of total number estimates of replicate counts were consistent with those of the original counts. For this purpose repeated total number estimates were performed on several samples for both planktonic and benthonic forams. *Oolina hexagona* was included in the latter category.

For the planktonic forams repeated counts were made on 8 samples (CRP 13, 14, 15, 20, 22, 27, 28, and 30); for the benthonic forams 9 samples were used (in addition to the samples listed above, also CRP 17). Except for the counts on CRP 13, the counts were separated by several months.

The results of the total number estimates based on repeated counts are given in figure 6.

These results are markedly concurrent for both the planktonic and benthonic forams in samples CRP 13, 20, and 28. The maximum differences in total number estimates of benthonic forams are found for samples CRP 17, 22, and 30; the results of the replicates differ by an order of magnitude of 1.5 to 3 larger than those of the original counts. Differences in repeated total number estimates of planktonic forams are less pronounced. For one sample (CRP 22) repeated total number estimates were made for radiolaria. The results are again dissimilar (4.7 $\times$ 10^5 versus 1.2 $\times$ 10^6).

These examples illustrate that the reproducibility of total number estim-

22 I	$\bar{d}$	SE_d	SD_d	T_p	S = 1024	$\bar{d}$	SE_d	SD_d	T_B/T_R
p_1	52.64	10.00	37.41	2,425,001 ± 460,800	b_1	0.36	0.17	0.63	16,588 ± 7,835
p_2	16.93	2.83	10.59	780,134 ± 130,425	b_2	—	—	—	—
p_3	69.57	12.63	47.25	3,225,600 ± 599,040	b_3	—	—	—	—
					R	10.24	2.76	10.32	471,859 ± 127,199

22 II	$\bar{d}$	SE_d	SD_d	T_p	S = 256	$\bar{d}$	SE_d	SD_d	T_B/T_R
p_1	238.79	25.35	94.85	2,750,860 ± 292,032	b_1	4.36	0.73	2.73	50,227 ± 8,409
p_2	60.93	5.86	21.92	701,913 ± 67,507	b_2	0.86	0.23	0.86	9,907 ± 2,649
p_3	299.71	30.92	115.70	3,452,659 ± 356,198	b_3	3.50	0.78	2.90	40,320 ± 8,985
					R	102.21	13.24	49.55	1,177,459 ± 152,524

21	$\bar{d}$	SE_d	SD_d	T_p	S = 256	$\bar{d}$	SE_d	SD_d	T_B
p_1	280.29	20.55	76.90	3,228,940 ± 236,736	b_1	4.21	0.72	2.72	48,499 ± 8,409
p_2	70.50	5.33	19.93	812,160 ± 61,401	b_2	0.14	0.09	0.36	1,612 ± 1,117
p_3	350.79	25.36	94.90	4,041,100 ± 292,147	b_3	4.07	0.71	2.65	46,886 ± 8,179

Tabel 4a. Total number estimates obtained from procedure 3 for samples CRP 21 and 22. $\bar{d}$ refers to the density per faunal category. SE_d and SD_d are the corresponding standard error and standard deviation, respectively. Density and total number estimates of planktonic forams are given as p_3 and Tp. Estimates for the categories undamaged and damaged planktonic forams are noted by p_1 and p_2. Density and total number estimates of benthonic forams are given as b_1 and T_B. The notations b_2 and b_3 refer to the categories *Oolina hexagona* (T_O) and T_B minus T_O, respectively. T_R gives the total number estimates of radiolaria.

22 II Species	K	M	c_1 = 99		c_2 = 102		c_3 = 101		c_4 = 99		c_5 = 98		c_6 = 100	
			nr.	%	nr.	%	nr.	%	nr.	%	nr.	%	nr.	%
N. acostaensis	131	9	10	10.0	4	7.0	8	7.3	9	7.7	7	7.6	10	8.0
G. falconensis	262	9	10	10.0	9	9.5	14	10.9	10	10.7	21	12.8	13	12.9
G. glutinata	503	9	14	14.0	24	19	26	21.2	24	21.9	21	21.8	20	21.5
G. obliquus	76	9	7	7.0	—	3.5	5	4.0	5	4.2	6	4.6	4	4.5
G.sc. subscitula	85	9	2	2.0	6	4.0	2	3.3	1	2.7	3	2.8	4	3.0
G.sc. subscitula	270	45												
G. margaritae	3	45												
G. apertura	75	9	2	2.0	4	3.0	2	2.6	5	3.2	1	2.8	3	2.8
G. quinqueloba	1129	9	50	50.0	49	49.5	38	45.4	40	44.1	36	42.7	40	42.2
G. trilobus	69	45	—	—	—	—	—	—	—	—	—	—	1	0.2
O. universa	19	45	—	—	—	—	—	—	1	0.2	—	0.2	—	0.2
G. nepenthes	1	9	—	—	2	1.0	3	1.7	—	1.2	1	1.2	—	1.0
Indeterminable			4	4.0	4	4.0	3	3.6	4	3.7	2	3.4	5	3.7

21 Species	K	M	c_1 = 100		c_2 = 100		c_3 = 99		c_4 = 100		c_5 = 99		c_6 = 100	
			nr.	%	nr.	%	nr.	%	nr.	%	nr.	%	nr.	%
N. acostaensis	286	9	12	12.0	6	9.0	12	10.0	10	10.0	10	10.0	13	10.5
G. falconensis	362	9	9	9.0	11	10.0	18	12.7	17	13.8	13	13.7	11	13.2
G. glutinata	840	9	20	20.0	28	24.0	22	23.4	18	22.1	28	23.3	30	24.4
G. obliquus	99	9	6	6.0	4	5.0	5	5.0	2	4.3	2	3.8	2	3.5
G.sc. subscitula	103	9	5	5.0	5	5.0	3	4.3	5	4.5	4	4.4	7	4.8
G.sc. subscitula	280	45												
G. margaritae	26	45												
G. apertura	128	9	3	3.0	10	6.5	2	5.0	4	4.8	3	4.4	4	4.3
G. quinqueloba	1172	9	41	41.0	35	38.0	34	36.8	37	36.8	37	36.9	30	35.8
G. trilobus	14	45	1	1.0	—	0.5	—	0.3	—	0.3	—	0.2	—	0.2
O. universa	14	45	1	1.0	—	0.5	—	0.3	—	0.3	—	0.2	—	0.2
G. nepenthes	8	9												
Indeterminable			2	2.0	1	1.5	3	2.0	7	3.3	2	3.0	3	3.0

Table 4b. Numbers of specimens per species in counting procedures 2 and 3. The right-hand side of each matrix gives the number of specimens per species for each of the six sets of 100-counts (C_1–C_6) in procedure 2. The adjoining percentage values are based on the accumulation of the subtotals. The left-hand side presents the number of specimens per species (K) per number of fields (M) in the counts of procedure 3.

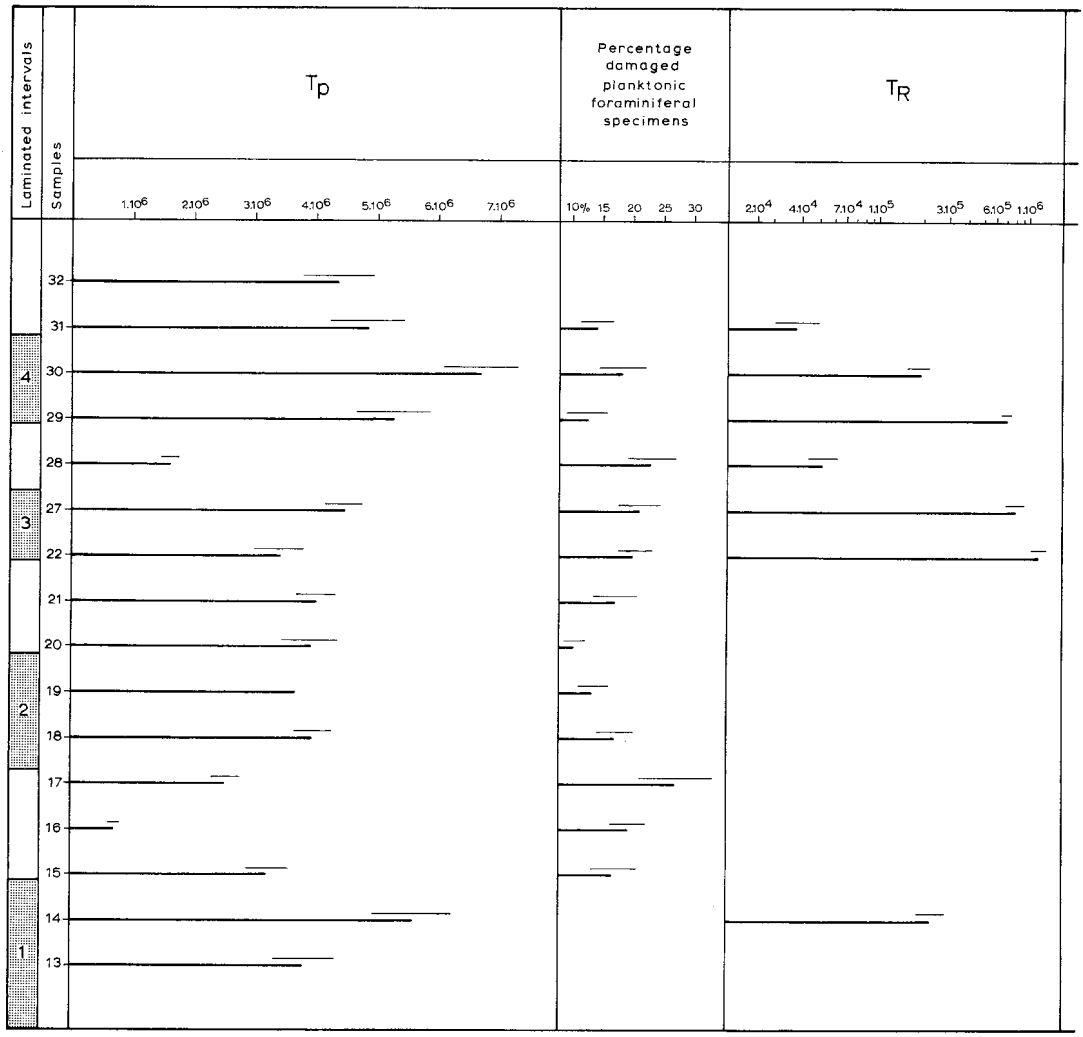
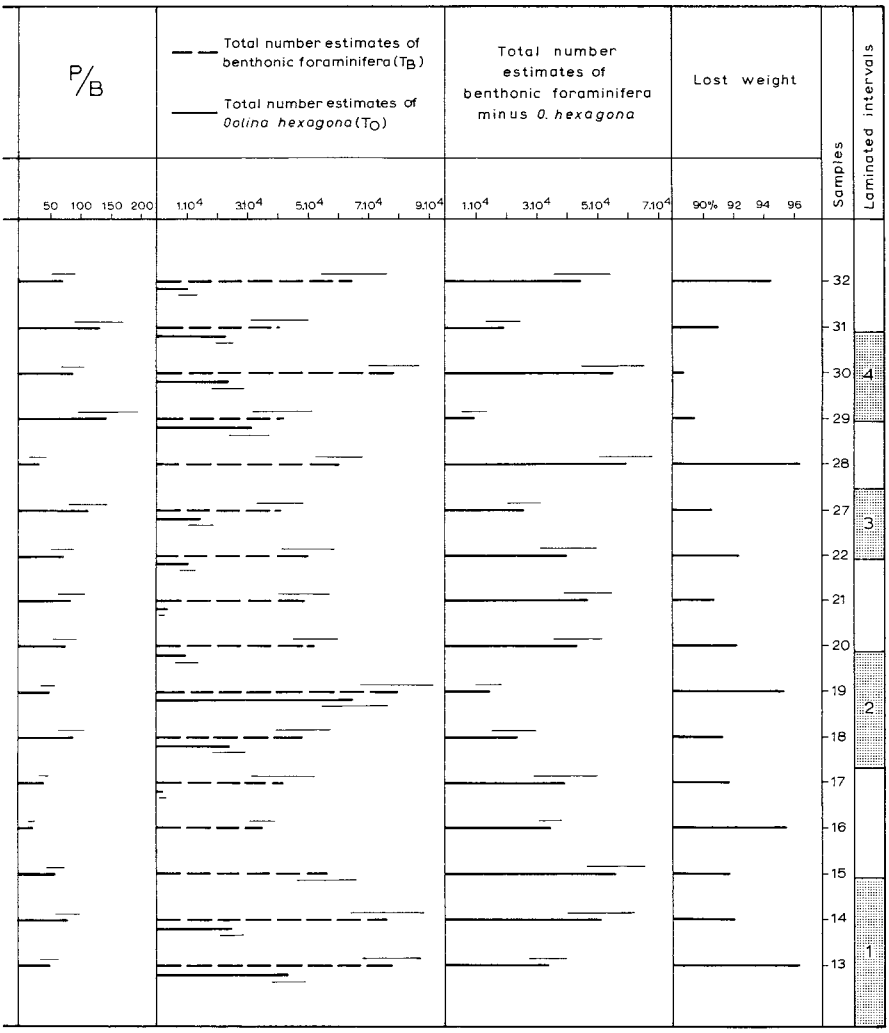


Fig. 5 Graphic summary of total number estimates of foraminifera and radiolaria per 100 gr. dry weight of sediment, P/B ratios, percentage of damaged planktonic foraminiferal specimens, and lost weight percentages. For each value the 68% confidence interval is plotted.

ates is rather unsatisfactory. It is remarkable that in 15 of the 17 comparisons in figure 6, the replicate counts give the higher estimates. It is emphasized, however, that the author's increasing experience in recognizing small-sized benthonic forams may have contributed to part of the differences; expecially the small-sized and generally distorted specimens of



O. hexagona may have been frequently overlooked in the original counts.

One cannot imagine that such an explanation can account for the 7 out of 8 cases in which the second total number estimate of planktonic forams seems to be the higher one. The deviation from the expected random pattern is on the verge of significance. Not understood personal factors may have added to the observed maximum deviation of 50% in the total number

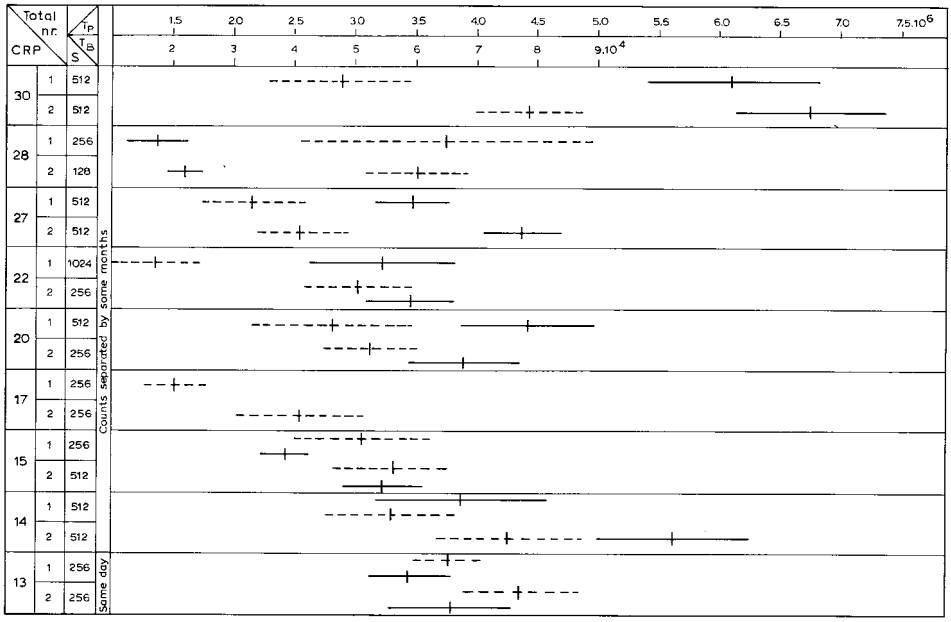


Fig. 6 Repeated total number estimates. The results of planktonic foraminifera (Tp) are represented by solid lines; dashed lines refer to total number estimates of benthonic foraminifera (T_B). For each value the 68% confidence interval is plotted.

estimates. If one considers the remarkable conclusion that the author must have overlooked a fairly high number of small-sized *Globorotalia scitula subscitula* (p. 204) at 40x magnification, it can be postulated that growing experience in recognizing small "particles" as forams in the course of the investigation caused the time-dependent increase in the total number estimates (made at 40x).

The results of the percentage estimates (procedure 3) are graphically represented in figure 7. The species can be ranked according to average frequency in three groups. The first group contains *G. quinqueloba* and *G. glutinata,* with average percentages of more than 30; in the second group *G. falconensis, G. apertura, G. nepenthes, N. acostaensis, G. obliquus,* and *G. scitula subscitula* have frequencies of about 2 to 10%. The third group includes the very rare species *G. margaritae, G. trilobus,* and *O. universa* for which the average percentage estimate is less than 1.

The percentage estimates of the species in the third group were based on the number of specimens of each species per 45 fields; those of all other species are derived from 9 (exceptionally 13) field counts. If a species was

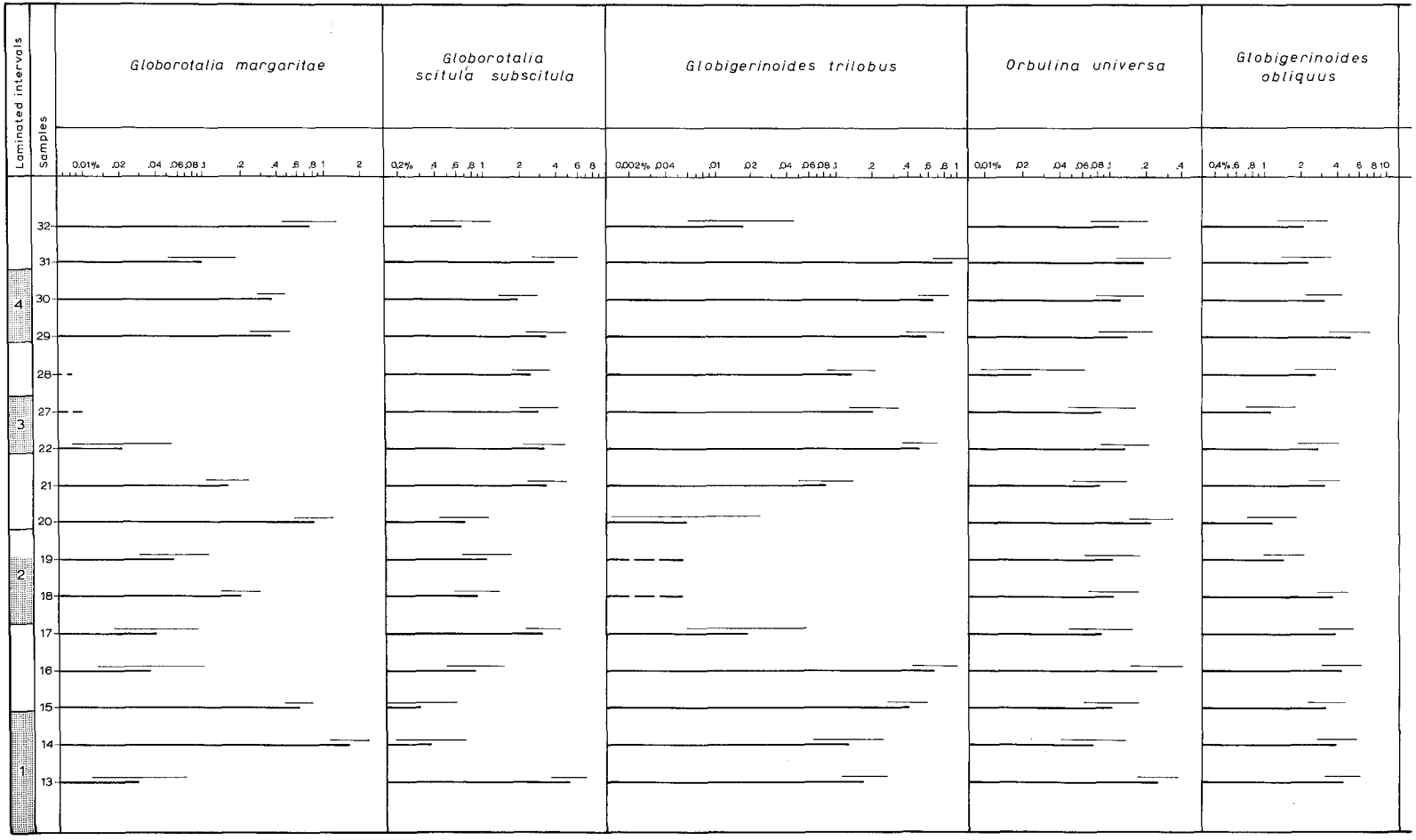
not observed on 45 fields, the percentage is considered to be less than the value obtained if K = 1.

The inaccuracy range of the obtained values is known to depend on the size of the statistical errors induced by the estimated density and the number K. Errors other than the statistical errors and including those from ill-understood personal factors may have added to an unknown extent to the inaccuracy in the percentage estimates.

Firstly we checked whether the estimated density corresponded to the density counted on 9 fields. In 14 samples (CRP 13, 15, and 17–32) the actually counted number of planktonic forams per 9 field-traverse proved to be within the range of the estimated number (calculated from $M \times (\bar{d} \pm 2\ SE_d)$ see values tabulated below). The result suggests that the estimated density is sufficiently reliable.

sample	actually counted nr.	estimated nr.
32	2899	2538 – 4338
31	2002	1422 – 2394
30	2136	2151 – 3123
29	2214	1620 – 2520
28	2427	1989 – 2997
27	1696	1449 – 2061
22	2272	2142 – 3258
21	3002	2709 – 3609
20	2561	2349 – 3753
19	2684	2295 – 3411
18	2702	2637 – 3573
17	2201	1665 – 2241
15	2199	1998 – 3042
13	2447	2160 – 3744

An additional source of error which may influence the percentage estimates of individual species is the magnification factor. Both *Globorotalia* species provided an example. Percentage estimates of *G. scitula subscitula* are based on 9 field counts, using a magnification of 64x. Because *G. margaritae* is much less frequent, counts were continued for this species over 45 fields at a magnification of 40x. Since juveniles of *G. margaritae* can be easily mistaken for *G. scitula subscitula* we feared incorrect determinations of juvenile *G. margaritae* at this smaller magnitude. In order to achieve correct determinations, all observed specimens of both species from 45 fields of samples CRP 15, 16, 18, 19, 21, 22, and 29 were picked and stored in separate slides. For two of the samples (CRP 21 and 22^{II}) the data sheets are reproduced in table 4.


Laminated intervals
Samples
Globorotalia margaritae
Globorotalia scitula subscitula
Globigerinoides trilobus
Orbulina universa
Globigerinoides obliquus
0.01% .02 .04 .06 .08 .1 .2 .4 .5 .8 1 2
0.2% .4 .5 .8 1 2 4 6 8
0.002% .004 .01 .02 .04 .06 .08 .1 .2 .4 .5 .8 1
0.01% .02 .04 .06 .08 .1 .2 .4
0.4% .6 .8 1 2 4 6 8 10
32
31
30
29
28
27
22
21
20
19
18
17
16
15
14
13
4
3
2
1

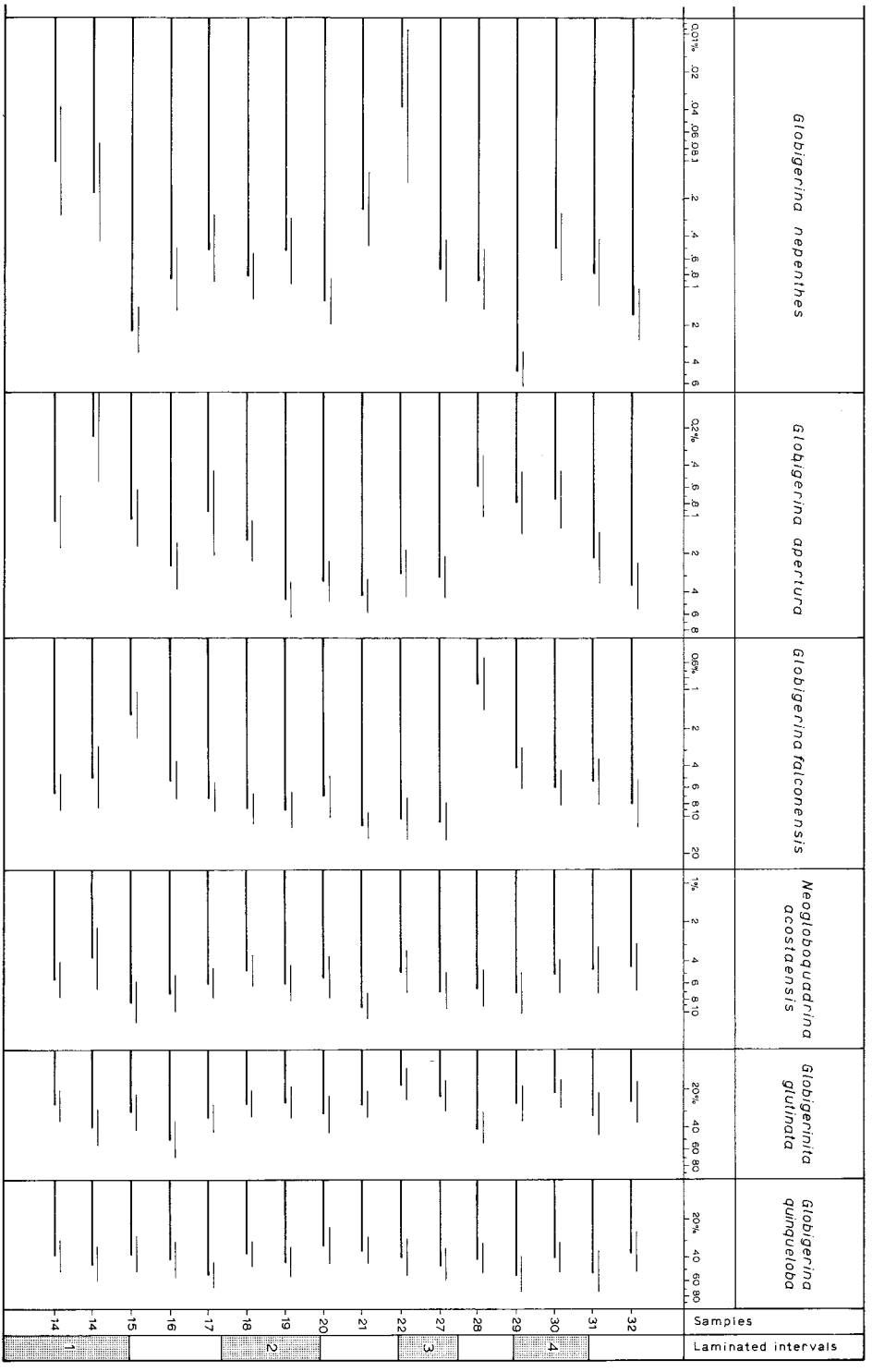
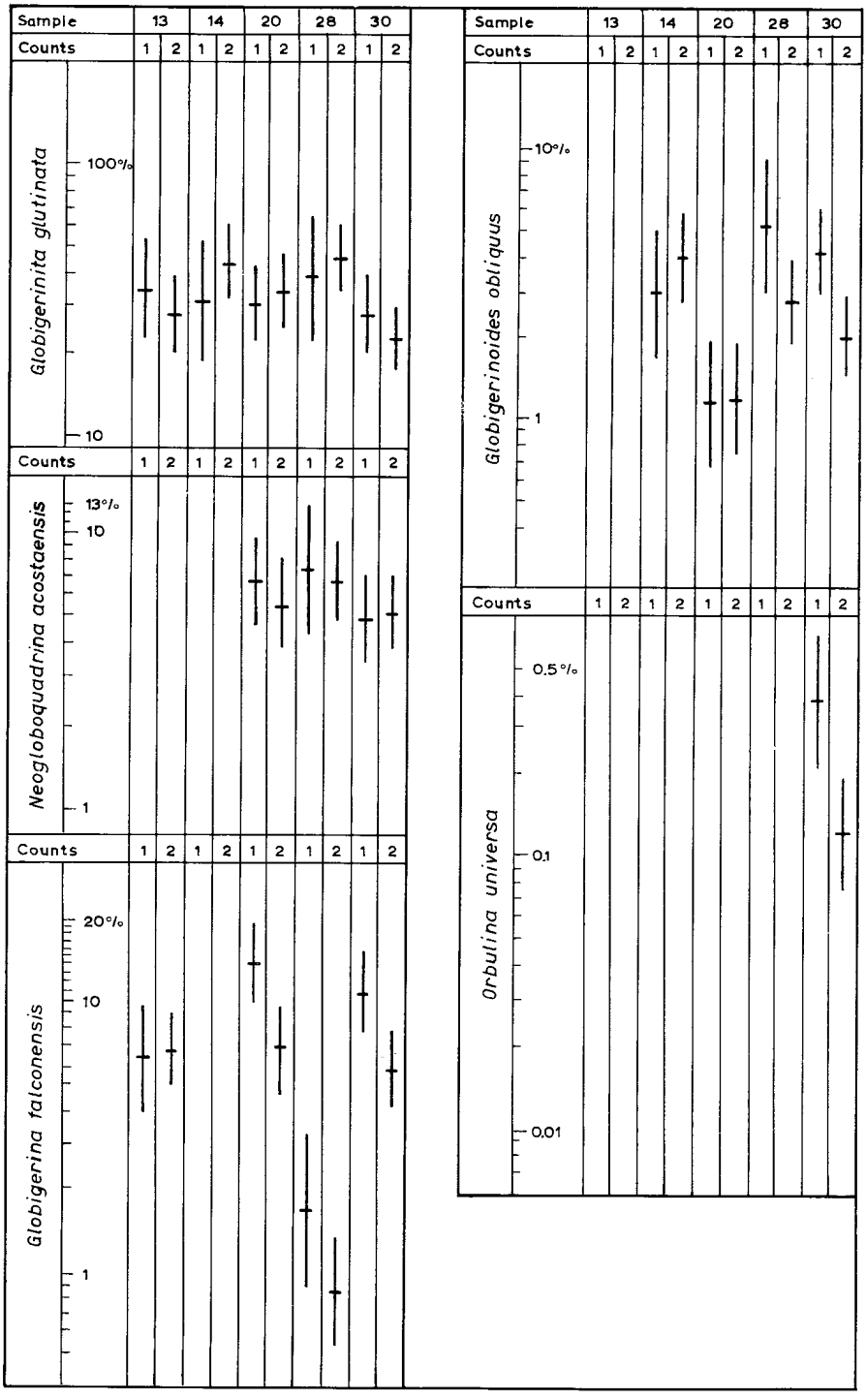


Fig. 7 Frequency patterns of species based on percentage estimates derived from counts per number of fields (procedure 3). For each value the 95% confidence interval is indicated. Percentage estimates are plotted on a logarithmic scale. When a species is absent in 45 fields, its proportion is based on K = 1 and is marked by a dashed bar.


Sample
13
14
20
28
30
Counts
1
2
Globigerinita glutinata
100%
10
Neogloboquadrina acostaensis
13%
10
1
Globigerina falconensis
20%
10
1
Globigerinoides obliquus
10%
1
Orbulina universa
0.5%
0.1
0.01

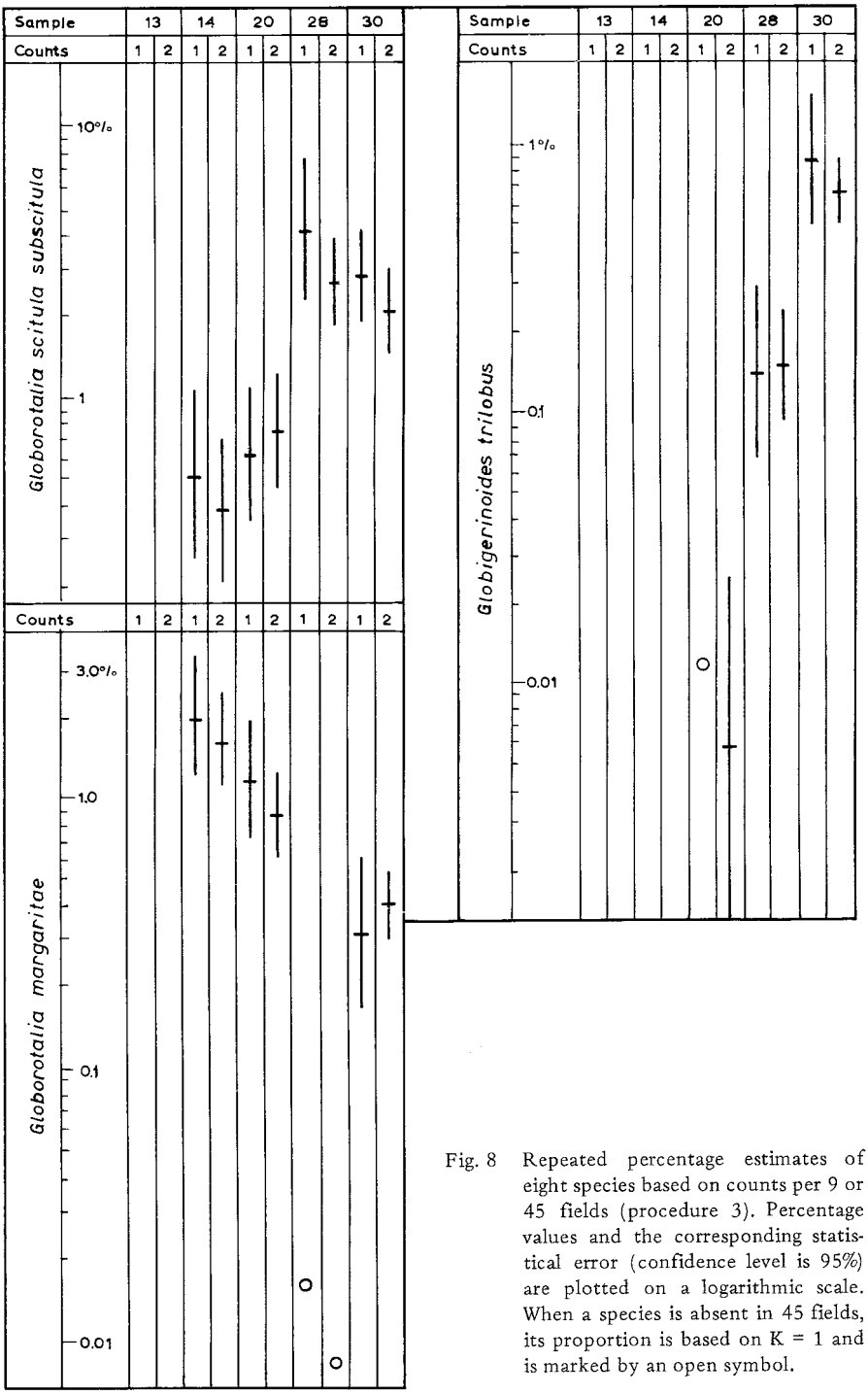


Fig. 8 Repeated percentage estimates of eight species based on counts per 9 or 45 fields (procedure 3). Percentage values and the corresponding statistical error (confidence level is 95%) are plotted on a logarithmic scale. When a species is absent in 45 fields, its proportion is based on K = 1 and is marked by an open symbol.

After identification at 64x the numbers of *G. scitula subscitula* consistently remained far below those expected from the numbers of counted specimens in the 9 fields at 64x. The only explanation seems to be that during the investigation of the 45 fields with a 40x magnification, many of the small-sized *G. scitula subscitula* were simply overlooked. In this case, it is not the investigation of a higher number of fields that gives the more reliable percentage estimates but it is the use of a higher magnification.

As done for the total number estimates, the reproducibility of the percentage estimates of single species was checked through repeated counts.

For this purpose, percentage estimates of some species were repeated for samples CRP 13, 14, 20, 28, and 30. The results are represented in figure 8. Except for sample CRP 13, for which both counts were carried out during the same day, the replicate counts on the other samples were carried out some months after the original counts.

As can be seen from figure 8, the results are generally markedly concurrent. Distinctly different results were obtained in the repeated counts in a few cases only: *G. falconensis* in CRP 20 and 30, and *G. obliquus* and *O. universa* in sample CRP 30. The overall result indicates that the reproducibility of percentage estimates is fairly satisfactory.

The total number estimates and the percentage estimates of the individual species were compared with each other and with both lithology types by application of an R-mode programme. Significant correlation values between these paired categories and their probability level are shown in figure 9. The interpretation of these correlations is given in the final conclusions and in the chapter on paleoenvironmental interpretation.

FINAL CONCLUSIONS

Considerable differences exist between the quantitative composition of the planktonic foraminiferal associations obtained from the counts on the $> 125\ \mu$ fraction and those derived from the counts on the $> 63\ \mu$ fraction (see figs. 1, 2, and 7). In the 200 counts on the $> 125\ \mu$ fraction (procedure 1) *G. falconensis, N. acostaensis,* and *G. obliquus* are the dominant faunal constituents with joint percentages of 50 to 85. In the counts on the $> 63\ \mu$ fraction (procedures 2 and 3) these species are of secondary importance and they are outnumbered by *G. quinqueloba* and *G. glutinata.* The latter two species together make up 50 to 80% of the associations.

Conspicuous differences were also met with in the results of the R-mode programme applied to the data of all three counting procedures. This pro-

Correlations (percentage estimates of species and total number estimates obtained from proc. 3)	pos./ neg.	P	Correlations (percentage values of species obtained from proc. 2; total number estimates derived from proc. 3)	pos./ neg.	P
T_P – P/B ratio	+	< 0.01			
T_P – laminated sediment	+	0.05			
T_O – laminated sediment	+	< 0.01			
T_O – T_B minus *O. hexagona*	–	0.03			
T_R – laminated sediment	+	0.04			
G. glutinata – T_P	–	0.02	*G. glutinata* – T_P	–	< 0.01
G. glutinata – P/B ratio	–	0.05	no correlation		
no correlation			*G. quinqueloba* – T_O	+	< 0.01
no correlation			*G. quinqueloba* – T_P	+	0.05
no correlation			*N. acostaensis* – T_O	–	0.04
no correlation			*N. acostaensis* – laminated sediment	–	< 0.01
no correlation			*G. quinqueloba* – laminated sediment	+	< 0.01
G. falconensis – *G. apertura*	+	< 0.01	*G. falconensis* – *G. apertura*	+	< 0.01
no correlation			*G. trilobus* – *O. universa*	+	< 0.01
G. obliquus – *G. apertura*	–	< 0.01	*G. obliquus* – *G. apertura*	–	< 0.01
no correlation			*G. obliquus* – *G. quinqueloba*	+	0.04
G. glutinata – *G. quinqueloba*	+	0.01	no correlation		
G. margaritae – *G. scitula subscitula*	–	0.02	no correlation		
G. trilobus – T_R	+	0.05	no correlation		

Fig. 9 Results of an R-mode programme applied to the data obtained from counting procedures 2 and 3. For each of the correlations between paired categories the probability level (P) is given.

gramme was used to investigate possible correlations between paired categories. In this way, frequency patterns of species derived from each of the counting procedures were compared both with one another and with the two lithology types. Paired total number estimates and total number estimates with the lithology types were tested likewise. In addition, percentage values of species obtained from the counts of procedures 1 and 2 were compared with the total number estimates of procedure 3.

No coherent fluctuations were recorded for the frequency patterns of species in procedure 1. There were no correlations between percentage values and total number estimates either. In contrast, a series of distinct correlations was recorded for the same paired categories in procedures 2 and 3 (see fig. 9).

The difference in the results obtained from the data of procedure 1 and of procedures 2 and 3 are no doubt caused by the use of different size frac-

tions. Differences in the total series of correlations recorded from the data of procedures 2 and 3, however, are only partly understood.

The presence of a positive correlation between *G. trilobus* and T_R, and of a negative correlation between *G. margaritae* and *G. scitula subscitula* in the counts of procedure 3, and the absence of such significant correlations in the counts of procedure 2, may be explained by the more reliable description of the frequency patterns of these rare species obtained in procedure 3. Noteworthy is the distinct positive correlation between *G. trilobus* and *O. universa* in the counts of procedure 2, whereas no correlation could be calculated for the percentage estimates of both species in procedure 3. A closer inspection of the frequency patterns of both species in procedure 3 shows the patterns to be parallel, except in the case of the sample interval CRP 17–21, in which the frequencies of *G. trilobus* are extremely low; this exception may be responsible for the lack of distinct correlation in the statistical test.

As can be seen in figure 9, completely different results were obtained from the comparison of the frequency patterns of *G. quinqueloba* and of *N. acostaensis* with those of other categories in the counts of procedure 2 and 3. The percentage values of *G. quinqueloba* derived from procedure 2 show positive correlations with the total number estimates of T_O, with T_P and with the laminated type of sediment. Moreover, the proportions of *G. quinqueloba* in procedure 2 show a statistically significant ($P = 0.01$) overall upward decrease. None of these correlations, not even the negative trend, could be confirmed from the percentage estimates of *G. quinqueloba* in procedure 3.

A possible explanation for these different results might be in the fact that, in addition to the binomial error, the percentage estimates of *G. quinqueloba* include the error induced by the estimated density. The percentage estimates of *G. quinqueloba* were based on 9 field counts. As all planktonic forams on this 9 field-traverse were actually counted, the proportions of *G. quinqueloba* can be calculated also from a realistic number, which includes a binomial error only. In this way, a third frequency pattern of *G. quinqueloba* can be made and compared to the other two established from the counts of procedures 2 and 3. As this third pattern is based on total numbers between 1600 and 3000 planktonic forams actually counted, it is considered to be the most reliable one and may serve as a "standard". This third pattern has been calculated for 5 species in 14 samples and is plotted together with the other two frequency patterns in figure 10.

It may be seen in this figure, that two of the three curves of *G. quinqueloba,* i.e. those based on fixed numbers of 600 and of 1600–3000,

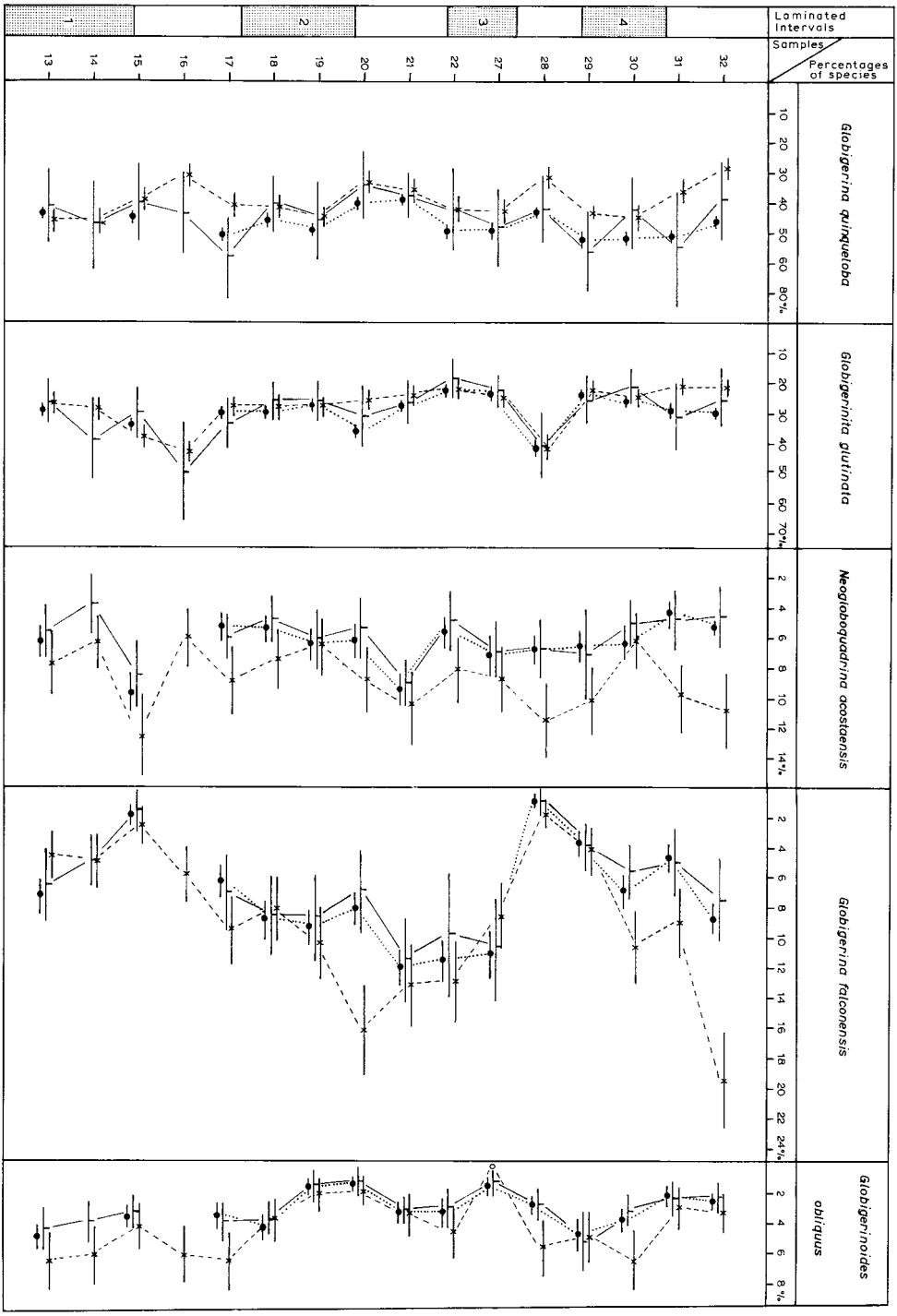


Fig. 10 Frequency patterns of five species based on actually counted and estimated numbers of planktonic foraminifera. Dashed lines are based on fixed number counts of 600 specimens (procedure 2). Dotted lines are based on percentages derived from the actually counted number of specimens per 9 fields (> 1600 and < 3000), whereas solid lines refer to proportions calculated from the estimated number of specimens per 9 fields (procedure 3). For each value the 95% confidence interval is plotted.

respectively, are markedly parallel, whereas the one based on the percentage estimates shows an oscillating pattern relative to the other two. This result may indicate that fluctuations in the frequency pattern of *G. quinqueloba* are less reliably described with procedure 3 than they are with procedure 2. It might be argued that, in addition to statistical errors, irregularities in the density estimates cause procedure 3 to be less reliable for frequent species, i.e. > 5% (see also M. M. Drooger, this volume). If these conclusions are true, the total series of correlations calculated on the basis of procedure 2 between *G. quinqueloba* and various other categories may be considered sufficiently reliable.

The strong positive correlation between *G. quinqueloba* and *G. glutinata,* recorded only in procedure 3, may be artificial on the basis of similar reasoning. As the three curves of *G. glutinata* are fairly concurrent, this correlation may be induced by the random fluctuations in part of the frequency pattern of *G. quinqueloba.*

For *N. acostaensis* the three curves in figure 10 behave differently from those for *G. quinqueloba.* In this case it is the one based on the 600 counts which is out of step. The negative correlations between the relative frequencies of *N. acostaensis* based on the 600 counts and the laminated type of sediment and T_O are absent in the counts of procedure 3 (fig. 9). Relative to both other curves, the curve based on the 600 counts shows two distinct minimum values at the level of laminated sediments (samples CRP 19 and 30). It seems conceivable that these two minimum values in the frequency pattern established for the 600 counts are due to random effects. They may have induced the overall effect of negative correlation between *N. acostaensis* and the lamination.

This example strengthens the impression that at relative frequency values of 4–8% procedure 3 starts to be better than procedure 2 based on the 600 total number counts. All this reasoning does not explain the fact that the percentage estimates of *N. acostaensis* based on the 600 counts are consistently well above those of the other two procedures.

It is noteworthy that the frequency patterns of *G. falconensis* and *G. obliquus* based on the actually counted and the estimated numbers of specimens per 9 fields are just as concurrent as they are for *N. acostaensis.* Notwithstanding the fact that in procedure 2 sampling errors other than the statistical error were negligible, the number of 600 specimens probably was too low to give an equally reliable description of the fluctuations in the frequency patterns of *G. falconensis, G. obliquus,* and *N. acostaensis.*

The preceding examples suffice to make it clear that correlations record-

ed by an R-mode programme should be critically analyzed prior to their incorporation in an attempted interpretation in paleoenvironmental terms.

Attention is drawn to the frequency patterns of *G. falconensis* in the counting procedures 1, 2 and 3. They are more or less parallel, regardless of the size-fraction used (see figs. 1, 2 and 7). This means that fluctuations in this species are independent of the size of the specimens.

The "indeterminable" proportion of the associations in the counts of the $> 63\ \mu$ fraction generally does not exceed 4%, which corresponds well with the percentages obtained from the 200 counts on the $> 125\ \mu$ fraction. This result is surprising, since it was expected that a much higher proportion of the associations in the $> 63\ \mu$ fraction would have to be labelled as "indeterminable" because of the difficulty in recognizing the discriminative features of species in small-sized specimens. The very similar percentages, therefore, must be ascribed to the high proportion of the easily identifiable *G. quinqueloba* in the associations of the $> 63\ \mu$ fraction.

Finally it should be emphasized that for a reliable quantification of species with a frequency of less than 10%, procedure 3 is preferable to procedure 2. Fluctuations in the frequency patterns of more than 10% are thought to be described better in procedure 2, because there the proportions include the binomial error only. In future, the counting load will be considerably less if procedures 2 and 3 are performed on one split. Proportions of high-frequent species can be calculated from a fixed number (not necessarily 600, but possibly less, see fig. 3) to be counted along a cross-arranged traverse. From the density total numbers can be estimated, while the proportions of species with a frequency of less than 1%, and of 1 to 10%, can be estimated from the investigation of 45 and 9 fields, respectively.

PALEOENVIRONMENTAL INTERPRETATION

Fluctuations in the patterns of total number estimates suggest a higher productivity of planktonic forams and radiolaria corresponding to the laminated intervals. Total number estimates of diatoms (Schrader and Gersonde, this volume) show a similar pattern. An increase in the proportions of these groups per unit weight of sediment reduces the proportion of the abiogenic components, and theoretically it is possible that also the calcareous nannoplankton might show a relative decrease. Since, however, the pelite content is distinctly lower in the laminated intervals (Brolsma and Broekman, this volume), calcareous nannoplankton production might have increased as well in a proportion similar to that of the other plankt-

onic organisms (see Schmidt, this volume). The same argument may apply to non-shell building primary producers, such as dinoflagellates, copepods, and euphasiids.

All the reasoning concerning changes of productivity in the higher water layers is in fact based on the observation of a relatively low pelite content in the laminated intervals. If the preservation of original lamination were due to higher rates of sedimentation of abiogenic components, suppressing bioturbation, this would have given the opposite picture. If it is true that the laminated intervals reflect periods of high productivity in the surface water, decay processes of the rapidly accumulating organic material may have resulted in periods of (near-) depletion of dissolved oxygen at or near the sediment-water interface. As a result, the alkalinity of the seawater may have been lowered, which would have enhanced the dissolution of $CaCO_3$. However, the planktonic forams give no clear indications of a higher dissolution degree during deposition of the laminated intervals, as may be inferred from the random pattern in the relative number of damaged planktonic forams throughout the sequence of laminated and non-laminated sediments, and from the absence of well-expressed etching features (see remarks on *Orbulina universa*).

The independent pattern of T_B relative to that of P/B, and the strong positive correlation between T_P and P/B, suggest that the total number of benthonic forams per unit weight of sediment does not account for the observed fluctuations in P/B ratios. The excessive increase in total numbers of *Oolina hexagona*, and the corresponding decrease in benthonic diversity in the laminated intervals may be explained by the greater tolerance of *O. hexagona* to conditions of oxygen deficiency.

The possibility that oxygen depletion at or near the bottom is a consequence of a higher biological productivity in the surface waters suggests an unstable water stratification in the upper part of the water column and a more homogeneous lower part.

Lost weight percentages of the clay-silt fraction are high and amount to 90–96. Since the pelite content is low (Brolsma and Broekman, this volume), it is assumed that the clay-silt fraction consists largely of calcareous nannofossils. If this is true, the Trubi should be classified as a calcareous nannoplankton ooze (at least as far as the non-siliceous intervals are concerned). The extremely high P/B ratios do not necessarily reflect a great depth of deposition; they may as well be regarded as the result of high productivity in the surface waters in a sea of moderate depth.

The overall composition of the planktonic foraminiferal faunas in the Mediterranean Lower Pliocene, in which tropical forms are absent, is very

similar to those reported from the Pleistocene and Recent Mediterranean (e.g. Parker, 1958; Todd, 1958; Reiss, et al., 1971; Cita, et al., 1973; Cifelli, 1974). However, representatives of the genus *Neogloboquadrina* were apparently more abundant in the Early Pliocene than in the Pleistocene and Recent Mediterranean.

The present Mediterranean fauna is composed of a mixture of northern and subtropical forms (e.g. Cifelli, 1974; Cifelli and Benier, 1976). As recently argued by Cifelli (1976b), the absence of tropical forms in the Mediterranean since the beginning of the Pliocene is related to a southward migration of tropical forms on the eastern side of the North Atlantic.

The great resemblance of Recent (predominantly spinose) planktonic foraminiferal faunas on the Atlantic and the Mediterranean sides of the Straits of Gibraltar indicates that the impact of the Gibraltar threshold as a selective filter for the qualitative distribution is negligible (cf. Cifelli, 1974). In opposition to this conclusion, it is worth noting that since the Early Pliocene, the Mediterranean lodged its own phenotypic variants of the *Neogloboquadrina* group and of *Globorotalia scitula* (see Chapter on remarks on the species). Whether the development of these variants resulted from an adaptation to specific Mediterranean water mass properties or whether once introduced into the Mediterranean they lost genetic exchange with their Atlantic relatives, or whether the effect was a combined one cannot be decided.

The few ensuing paleoecological conclusions should be regarded as highly speculative because they are based on the frequency patterns of a few species in 16 samples only.

Except for the sample interval of CRP 17–21, the frequency patterns of *G. trilobus* and *O. universa,* based on the counts of procedure 3, are markedly parallel. If the similarity in the fluctuations results from changes in a combination of ecological parameters that effect both species equally, the abrupt drop in *G. trilobus* numbers in CRP 17–21 probably indicates that the tolerance level to one or more of these parameters is exceeded. It is a matter of speculation which parameter or parameters limit(s) the distribution of *G. trilobus* within this interval. As the optimum distribution of *G. trilobus* is recorded at higher surface water temperatures than that of *O. universa* (e.g. Tolderlund and Bé, 1971; Reiss, et al, 1974), surface temperature may have dropped below the range preferred by *G. trilobus.* If this decrease in water temperature is a consequence of intensified upwelling, the absence of siliceous microfossils and the not so distinct increase in the total numbers of planktonic forams seem to be anomalous. On the other hand, if the fluctuations in the frequency pattern of *O. hexagona* are related to the degree

of oxygen depletion at or near the bottom, its high total numbers within this interval may have been caused by increased productivity in the surface waters. Either the siliceous organisms were dissolved or the higher productivity of non-shell building primary producers was not followed by a bloom in diatoms, radiolaria and planktonic forams.

The frequency patterns of *G. glutinata* and of *G. quinqueloba* lead to some other conclusions.

In the $> 63\ \mu$ fractions the frequency pattern of *G. glutinata* shows two distinct peaks (CRP 16 and CRP 28), which coincide with a marked reduction in the total numbers of planktonic forams. Procedures 2 and 3 both show a negative correlation of *G. glutinata* with total planktonic foram numbers (T_P); a (weak) negative correlation of this species with P/B is shown only in procedure 3. If the assumed increase of overall productivity followed from a better nutrient-supply, *G. glutinata* was evidently not the first to profit, i.e. *G. glutinata* could thrive at lower nutrient-levels than other species.

In contrast, the frequency pattern of *G. quinqueloba,* based on the 600 counts, shows a positive correlation with the laminated intervals, which are considered to reflect periods of higher productivity. If the productivity is related to upwelling, the observed fluctuations in the proportion of *G. quinqueloba* may be determined by the temperature and/or the nutrient level. Consequently the overall upward decrease in the percentage values of *G. quinqueloba* may indicate an overall decrease in the frequency and intensity of upwelling. If the fluctuations in *O. hexagona* follow indirectly from the productivity pattern in the surface water, its overall upward decrease supports this assumption (see also Brolsma, this volume).

Generally, *G. quinqueloba* is regarded as an indicator for cold to cool-temperate water because of its dominance in high latitudes (e.g. Bradshaw, 1959; Parker and Berger, 1971; Tolderlund and Bé, 1971). However, this species has been recorded by Reiss et al. (1974) in the low-fertility, warm waters of the Gulf of Elat, with highest frequencies below 200 metres. The absence of a thermocline in this Gulf suggests that parameters other than temperature are the determinants of the distribution of this species. Reiss et al. suggested that the amount of light is one of the major factors controlling the distribution of planktonic forams. Consequently, reduced light penetration may be the factor common to high latitudes and to the deep waters of the Gulf of Elat which will explain the increased relative frequencies of *G. quinqueloba*. Therefore, the concurrent increase in the frequency of *G. quinqueloba* and the assumed higher productivity for the laminated

intervals may be understood if diminished light penetration was caused by a higher density of photosynthetic organisms in the surface waters. Higher nutrient level and/or lower surface water temperature would then be less important. Recently, Thiede (1975) pointed out that *G. quinqueloba* is one of the species dominating in an association, the distributional area of which coincides with an area of intensive coastal upwelling off West Africa. This might be interpreted as another chain linking upwelling, higher productivity, lower light penetration and high *G. quinqueloba* numbers.

It is tempting to draw paleoenvironmental conclusions from the wealth of refined data we have for the Capo Rossello section. It must be realized however that many of our conclusions may be wrong because it cannot be proved conclusively that the higher relative productivity for certain levels is due to an absolute increase in planktonic production.

REMARKS ON THE SPECIES

Neogloboquadrina acostaensis (Blow)
Pl. 3, figs. 1 –9

This species is a common constituent in the associations with 15–30% in the $> 125\ \mu$ fraction and 5–12% in the $> 63\ \mu$ fraction.

In the Mediterranean Upper Miocene successive assemblages show an increase in relative numbers of *N. humerosa* types. This trend did not continue into the Pliocene. The Pliocene assemblages consist predominantly of small-sized, relatively tightly-coiled and markedly low-spired specimens with less than 5 chambers in the final whorl. Miocene assemblages show a distinct preference for sinistral coiling; during the Latest Miocene coiling shifts to dextral, and it remains dextral during the Pliocene (Zachariasse, 1975; Montenat et al., 1976). The test-surface structure of the early stages shows a regular pattern of pores and discrete tubercles. In the later ontogenetic stages the tubercles coalesce to form undulating ridges around the relatively wide and flat pore areas. Progressive thickening of the wall is associated with an increase of crystal size in the interpore areas. An ultimate stage of wall thickening is indicated by the formation of euhedral crystals, which are radially arranged on the tubercles forming a stellate pattern (see pl. 3, fig. 7; see also: crystalline and microcrystalline types of Poore and Berggren, 1975a; Srinivasan and Kennett, 1976). Recently, Srinivasan and Kennett (1976) have reported a clinal relationship between *N. dutertrei* and *N. pachyderma* from tropical to cool subtropical areas. Similar clines are suggested for the members of the *N. dutertrei* group throughout its strati-

graphic range. This may indicate that most taxa included in this group belong to successive suites of ecophenotypes.

One can imagine that the re-establishment of a continuously open marine communication with the Atlantic at the beginning of the Pliocene caused some degree of morphological similarity between the Mediterranean and North East Atlantic representatives of *Neogloboquadrina.*

Records from the East Atlantic are given by Beckmann (1972, DSDP sites 135, 139–141) and by Berggren (1972, DSDP sites 116, 118–119). Beckmann reports *N. acostaensis* and *N. humerosa* in varying abundance in sites 135 and 139; at lower latitudes (sites 140–141) both species co-occur with *N. pseudopima.* Parker (1974) reports *N. atlantica* from the Lower Pliocene of site 141 and observed a gradual replacement of *N. humerosa* by *N. dutertrei* in the Upper Pliocene. Some samples from the Lower Pliocene of sites 139 and 141, kindly provided by W. A. Berggren, show the representatives of the *Neogloboquadrina* group to be more tightly coiled, lower spired and with fewer chambers at the more northerly site 139. On the average, the Atlantic specimens are larger and have distinctly more inflated chambers than those of the Mediterranean. Coiling is similar. In the Bay of Biscay (DSDP sites 118, 119) representatives of *Neogloboquadrina* have been assigned to *N. atlantica.* In the Upper Miocene of the northern site 116 (Hatton-Rockall Basin) the latter species is associated with *N. acostaensis-humerosa*; it becomes predominant in the Pliocene to be gradually replaced by *N. pachyderma* (Berggren, 1972). Topotype material of *N. atlantica* shows this species to be markedly different from *N. acostaensis* from the Mediterranean Pliocene. *N. atlantica* is of distinctly larger size and shows a looser coiling. Moreover, the spiral side is well elevated, in contrast to the flat to slightly concave spiral side of the Mediterranean representatives of *Neogloboquadrina.* Noteworthy is the difference in coiling direction: *N. atlantica* is predominantly sinistrally coiled, whereas the Mediterranean forms show dextral coiling.

The obvious differences between the North East Atlantic and the Mediterranean Pliocene assemblages suggest that the latter area housed its own phenotypic variants of the *Neogloboquadrina* group.

The occurrence of *N. dutertrei* in plankton tows (Cifelli, 1974) and in subrecent bottom sediments (Parker, 1958; Todd, 1958; Reiss et al., 1971) may indicate a more recent entry of this species into the Mediterranean.

Globigerina falconensis Blow
Pl. 4, figs. 3–6, pl. 5, figs. 1, 4

In our material *G. falconensis* is used for assemblages in which the *G. falconensis* type outnumbers the *G. bulloides* type. In the > 125 μ fraction *G. falconensis* is the dominant faunal constituent. The *G. falconensis* type is distinguishable from the *G. bulloides* type by its protruding apertural lip and the slightly greater radial length of its chambers. Specimens fitting the description of *G. pseudobesa* (Salvatorini, 1966) are included in the *G. bulloides* type.

Because differences between the *falconensis* and *bulloides* forms become indistinct towards the smaller-sized individuals, the *bulloides* forms were not registered separately in the counts of the > 63 μ fraction. In this size fraction *G. falconensis* has a relatively low frequency (1 to 20%). In some samples the majority of the larger-sized specimens have a heavily encrusted test.

Differentiation problems between small-sized, relatively smooth and shiny representatives of *G. falconensis* and non-bullate *G. glutinata* exist in all samples (see pl. 5, figs. 1–4).

The *G. bulloides* type is especially frequent in the recent western Mediterranean and is replaced by the *G. falconensis* type in the eastern part (Cifelli, 1974).

Globigerina apertura Cushman
Pl. 1, figs. 3–7, pl. 2, figs. 8a, b

G. apertura occurs in low percentages in all samples. In the > 125 μ fraction its relative frequency is 4 to 7%; in the > 63 μ fraction it ranges between 0.5 and 8%. Usually this species can easily be recognized by the highly arched aperture and the strongly raised early portion of the test. The apertural rim varies from strongly protruding to nearly absent. The test-surface structure is regularly reticulate. In part of the assemblages, the reticulate structure seems to be followed in later ontogeny by a "smoothed structure", which reduces and conceals the primary surface topography (see pl. 1, figs. 4–7). Such a "smoothed structure" may be considered an ultimate feature owing to the formation of overlapping plates of crystals.

G. apertura became extinct in the Late Pliocene-Early Pleistocene (e.g. Parker, 1973; Poore and Berggren, 1975b). *Globigerina rubescens* (Hofker, 1956) may represent the modern continuation of *G. apertura.*

Globigerina nepenthes Todd
Pl. 1, figs. 1, 2

G. nepenthes is extremely rare, but continuously present in the > 63 μ fraction. Juveniles do not show the characteristic morphology of the fully developed specimens: the aperture is relatively low-arched, and the test is low-spired and distinctly less elongate (see pl. 1, figs. 1a-f). The formation and deterioration of the reticulate wall structure is identical to that in *G. apertura*. The ultimate "smoothed structure", however, is more pronounced in *G. nepenthes* than it is in *G. apertura*. A strongly protruding apertural rim is a very common feature. In immature specimens, however, the apertural margin is only partly bordered by a rim or there is no rim at all (see pl. 1, figs. 1a-f). Indistinct depressions in the rim probably represent pore-pits. If true, the rim results from the backfolded (downfolded?) margin of the primary membrane (see pl. 1, figs. 2a, b).

Occasional, small-sized forms may be confused with non-bullate specimens of *G. glutinata*. Overlap in morphology between *G. nepenthes* and *G. apertura* may give yet another determination problem for some of the larger-sized specimens.

The range of *G. nepenthes* extends up into the Early Pliocene (e.g. Parker, 1973; Poore and Berggren, 1975b; Cita, 1976).

Globigerina quinqueloba Natland
Pl. 6, figs. 1–6

In the > 63 μ fraction this species is the prevailing faunal constituent with frequencies of 30 to 55%. Because of its small size, *G. quinqueloba* occurs in much lower percentages in the > 125 μ fraction (less than 5).

This species varies considerably in the number of chambers in the final whorl, in the shape of the final chamber and in the test-surface structure. Normally, it possesses 4 to 5 chambers in the final whorl, but some specimens contain up to 7 relatively high and narrow chambers. The last chamber frequently extends downward and covers the umbilicus partly or entirely. Most of the specimens have thin walls with a finely hispid surface. Progressive test thickening finally leads to a considerable crystalline thickening of the interpore areas. Contrary to forms with a hispid surface, encrusted forms show a rapid reduction in the number of pores towards earlier chambers; some of the pores remain open, whereas others become covered by euhedral calcite rhombs. In addition, the sutures become less depressed and the periphery less lobulate (see pl. 6, figs. 3–6).

The variation observed in our assemblages more or less covers the range

of differences reported by Cifelli and Smith (1970) between *G. quinqueloba* s.s. (Natland, 1938) and *G. quinqueloba egelida* (Cifelli and Smith, 1970). The thick-shelled forms with low test porosity are identical to forms recorded as *Globigerina clarkei* by Rögl and Bolli (1973). Recently, Boltovskoy (1977) emphasized the close relationship between *Globigerinita clarkei* and *G. humilis* (Brady, 1884). For reasons of supposed nonspinose wall structure both species are assigned to the genus *Globigerinita*. To judge from his figures it may well be that these specimens (pl. 1, figs. 1–16) can be considered as thick-shelled variants of *G. quinqueloba* rather than as two separate species of the genus *Globigerinita*.

Occasionally, discrimination is difficult between small-sized *N. acostaensis* and compressed specimens of *G. quinqueloba*. The more rapid chamber enlargement in *N. acostaensis* may be used as an additional criterion for distinguishing both species.

Living *G. quinqueloba egelida* is present throughout the Mediterranean (Cifelli, 1974).

Globigerinoides obliquus Bolli
Pl. 2, figs. 1–7, 8c, d

G. obliquus is a common constituent in the faunas, with percentages between 15 and 40 in the $> 125\ \mu$ fraction and less than 8% in the $> 63\ \mu$ fraction.

Variation in the assemblages is mainly in the chamber outline. Forms with all chambers in the final whorl being lateral-obliquely compressed have been separately registered as the *G. extremus* type in procedure 1.

Early stages of *G. obliquus* show a tendency to have a more extra-umbilical aperture and to expose a maximum number of chambers in the final whorl. The test-surface structure of such small forms displays a rather regular pattern of pores and spine bases. In later stages the spine bases become larger and coalesce to form ridges around the relatively flat pore areas. Progressive thickening is associated with the formation of euhedral rhombs. The resultant knobby surface topography, which conceals the earlier reticulate test structure, indicates that the addition of euhedral crystals takes place preferentially at the spine bases (see pl. 2, figs. 2–7). In most of the samples overlap in variation between *G. obliquus* and *G. apertura* causes labelling difficulties for specimens which do not show the supplementary apertural opening (see pl. 2, figs. 8a-d).

G. obliquus became extinct in Plio/Pleistocene transitional time (Parker, 1973; Berggren and Amdurer, 1973; Bizon, pers. comm.).

Globigerinoides trilobus (Reuss)
Pl. 6, fig. 8

The relative frequency of *G. trilobus* in the > 125 μ fraction attains 14%; in the > 63 μ fraction it does not exceed 1%.

Our *G. trilobus* includes forms recorded in the literature as *G. trilobus* (Reuss, 1850) and *G. sacculiferus* (Brady, 1877). Within the assemblages the *G. trilobus* type is consistently dominant over the *G. sacculiferus* type. Throughout the section the specimens are thin-walled.

G. trilobus is a common faunal constituent in the present Mediterranean. The *G. sacculiferus* type, however, seems to be absent today (Cifelli, 1974).

Globigerinita glutinata (Egger)
Pl. 4, figs. 1, 2, pl. 5, figs. 2, 3

G. glutinata attains percentages of 20–50 in the > 63 μ fraction and is usually less than 10% in the > 125 μ fraction.

The assemblages of *G. glutinata* include a varied suite of morphotypes. Variation is mainly found in the height of the test, in the shape of the bulla and in the number of infralaminal openings. Four-chambered, low-spired forms grade into extremely high-spired ones, independent of size (see pl. 4, figs. 1a-h). The high-spired forms are conspecific with *Globigerinita uvula* (Ehrenberg, 1861). The shape of the bulla is highly variable with usually 2 to 4 infralaminal openings. The bulla is absent in most of the specimens, especially in the smaller sized ones. The characteristic test-surface structure consists of numerous, irregularly distributed and extremely small pores with relatively broad protuberances of euhedral rhombs in between (pl. 4, fig. 2). In the absence of adequate criteria for distinguishing between the *G. uvula* type and the *G. glutinata* type, the former is retained in *G. glutinata.*

G. glutinata is ubiquitous within the recent Mediterranean (Cifelli, 1974).

Orbulina universa d'Orbigny
Pl. 7, figs. 4–6

This taxon is continuously present in the Capo Rossello section, but its relative frequency is always less than 1%.

O. universa includes specimens in which the spherical chamber only partially englobes the globigerine form. Such forms closely resemble *O. suturalis* (Bronnimann, 1951). The test-surface structure varies from finely hispid, with small pores and a thin shell to relatively coarsely reticulate, with

large pores and a thick wall. Etching-features were observed in some specimens of CRP 18 from a laminated interval (see pl. 7, figs. 6a, b). Dissected *O. universa* specimens lack an internal globigerine stage; in specimens resembling *O. suturalis* the globigerine form resembles *G. falconensis.*

O. universa is fairly common in the recent Mediterranean (Cifelli, 1974).

Globorotalia margaritae Bolli & Bermudez
Pl. 7, figs. 1a-g, pl. 8, figs. 2a-g

This species is present with frequencies of up to 9% in the > 125 μ fraction and usually with less than 1% in the > 63 μ residues.

Variation mainly concerns the peripheral character and the axial outline. Individuals with a distinct keel display a concavo-convex axial outline, whereas faintly keeled to non-keeled specimens approximate a more biconvex outline. The latter type seems to be more frequent in the non-laminated intervals. Early stages already show the compressed chambers and very sharp periphery. Broad protuberances on the earlier part of the whorl, concentrated in front of the aperture, tend to spread into the direction of growth in the fully developed specimens (see also pl. 8, figs. 2a-g). The assemblages are predominantly sinistrally coiled.

G. margaritae entered the Mediterranean from the Atlantic during the reestablishment of a continuously open marine communication at the beginning of the Pliocene. It is a ubiquitous faunal constituent until its sudden disappearance in the course of the Pliocene. The species probably evolved from *Globorotalia scitula.* In contrast to other Mediterranean species that are also considered to be mesopelagic (*N. acostaensis* and *G. scitula subscitula*), our *G. margaritae* is morphologically remarkably similar to representatives in extra-Mediterranean areas (Atlantic: Parker, 1973, Berggren, 1972; Caribbean: Postuma, 1971; Indo-Pacific: Jenkins and Orr, 1972, Fleisher, 1974).

Globorotalia scitula subscitula Conato
Pl. 7, figs. 2a-g, pl. 8, figs. 1a-g

This species occurs discontinuously in the > 125 μ fraction with percentages of less than 3; its relative frequency in the > 63 μ fraction attains 10%.

On the average the specimens are small and slightly biconvex with a fairly acute, but non-carinate periphery. The test-surface structure is smooth with irregularly distributed small pores. The number of pores rapidly decreases towards the earlier chambers, but their size increases in diameter. Chambers in the penultimate whorl sometimes expose one to three extremely wide

pore pits with a multi-layered structure preferentially located near the spiral or intercameral sutures (see pl. 8, figs. 1a-g). Occasional specimens have irregularly distributed, short and broad protuberances, more or less concentrated around the aperture. Coiling is predominantly dextral.

G. scitula subscitula may be easily confused with small-sized *G. margaritae*. The more pronounced and higher number of protuberances in *G. margaritae,* the compact coiling and high-convex umbilical side in combination with the sinistral coiling may be additional features to distinguish *G. margaritae* from *G. scitula subscitula.*

During the Messinian salinity crisis a suite of species belonging to the *G. scitula* group disappeared. Only one small-sized representative *(G. scitula subscitula)* is found in the Mediterranean Pliocene.

G. scitula from the North East Atlantic Pliocene (DSDP sites 139, 141, 142) shows a similar range of morphological variation as the Mediterranean *G. scitula subscitula* and the same coiling direction preference. On the average the Mediterranean representatives are appreciably smaller, however, and exhibit a lower test porosity. This may indicate that *G. scitula subscitula* should be considered as a Mediterranean phenotypic variant of the Atlantic *G. scitula* rather than as a separate species. Because of its close affinity with *G. scitula*, the Mediterranean form is designated as *G. scitula subscitula.*

The *G. scitula* recorded by Cifelli (1974) from the present Western Mediterranean is identical with *G. scitula subscitula.* The same applies to Quaternary and Pliocene records of *G. scitula* in the Mediterranean by Reiss et al. (1971) and Cita et al. (1973).

Globigerinella siphonifera (d'Orbigny)
Pl. 5, fig. 5

Typical representatives of this species were found only in the $> 125\ \mu$ fraction with extremely low frequencies (less than 1%).

Early stages closely resemble small-sized specimens of *G. falconensis.* For this reason and because of the extremely low frequencies no attempt was made to register this species separately in the $> 63\ \mu$ fraction.

Acknowledgments

The author is indebted to the originator of this project, C. W. Drooger, for his supervision and his constructive remarks on the typescript. Sincere thanks are expressed to M. M. Drooger for his patience and invaluable assistance with the statistical treatment of the data. Thanks are also due to

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Plate 1

Figs. 1a-h — *Globigerina nepenthes* Todd from sample CRP 20. 1a-e: X 228; 1f: X 170; 1g: X 182; 1h: X 137. Growth series beginning with an immature individual showing an intra- to extraumbilical aperture (1a), followed by immature specimens having a low-arched aperture and a low-spired test (1b-f) rather than the characteristic elongate test and high-arched aperture found in adults (1g-h). Note that in immature specimens the apertural margin is only partly bordered by a rim. Consecutive stages of wall thickening can be readily observed: a smooth surface (1a) is followed by a structure showing a rather regular pattern of discrete spine bases (1b-f). Progressive thickening transforms the interpore regions into ridges which form a reticulate pattern (1g-h).

Figs. 2a, b — *G. nepenthes* from sample CRP 20. Subsequent to the formation of a distinct protruding rim a minute, ultimate chamber is formed (2a: X 228). Indistinct depressions on the rim and ultimate chamber probably represent pore pits (2b: X 456). If true, the rim results from the backfolded (downfolded?) margin of the primary membrane.

Figs. 3a-g — Size variation in *Globigerina apertura* Cushman from sample CRP 22. 3a-e: X 170; 3f-g: X 160. A distinct reticulate topography is visible in 3f-g only. The test-surface of the other specimens (3a-e) seems to have the features characteristic of early and ultimate stages of wall thickening: the incipient reticulate structure is slightly smoothened (well-pronounced on the early chambers of 3b).

Figs. 4 – 7 — Stages of wall thickening in *G. apertura.* Spine bases are discrete in 4 (X 912), but have coalesced in 5 (X 912). Increasing growth in crystal size on the interpore region constricts the pore pits (6: X 2280). The "smoothed structure" of overlapping plates of calcite probably represents an ultimate feature of wall thickening rather than post-depositional diagenesis (7: X 2280).

Plate 1

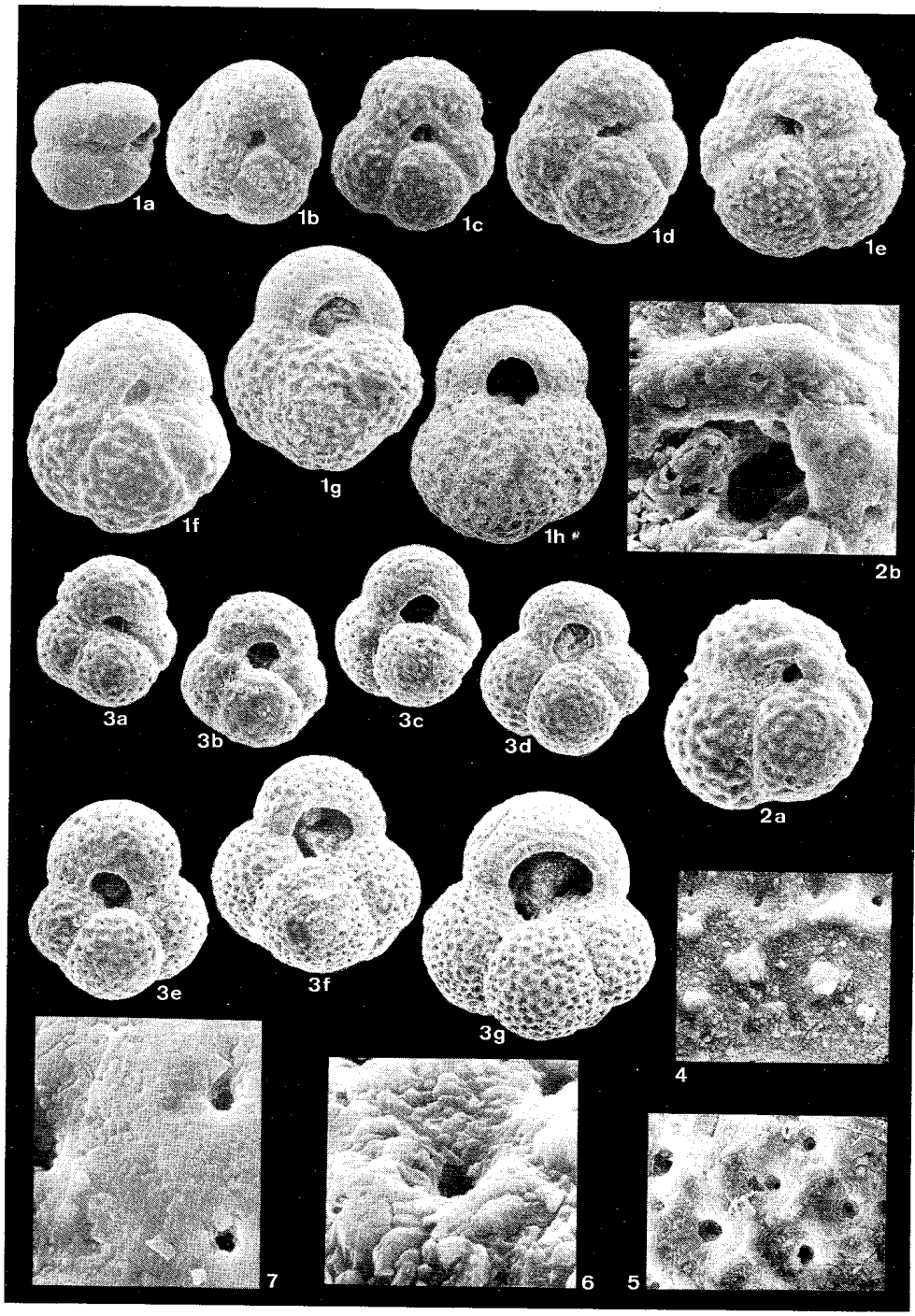


Plate 2

Figs. 1a-f — Immature specimens of *Globigerinoides obliquus* Bolli from sample CRP 22. X 228. In the early stages the aperture has a slightly extraumbilical position.

Figs. 2a-d — Specimens of *G. obliquus* arranged according to progressive wall thickening. X 170.

Figs. 3 – 7 — Details of stages of subsequent wall thickening in *G. obliquus*. 3. final chamber of 1a (X 912) showing discrete spine bases. 4. final chamber of 1f (X 912). Incipient coalescence of spine bases indicated by the formation of terraced ridges. 5. antepenultimate chamber of 2a (X 912). Spine bases have completely coalesced to pronounced interpore ridges. Pore pits are distinct. 6. Antepenultimate chamber of 7b (X 2280). Steeply sided pore pits characteristic of a later stage of wall thickening. Note increase in crystal size relative to 5. 7. An ultimate stage of wall thickening resulting in a knobby topography, which conceals the earlier reticulate structure.

Figs. 8a-d — Example showing difficulties in assigning single specimens to either *G. obliquus* or *G. apertura*. 8a-b: *G. apertura* (X 170); 8c-d: *G. obliquus* (X 170). Discrimination on SEM photographs is mainly based on the slightly higher-arched aperture and smoother topography in 8a-b relative to 8c-d.

Plate 2

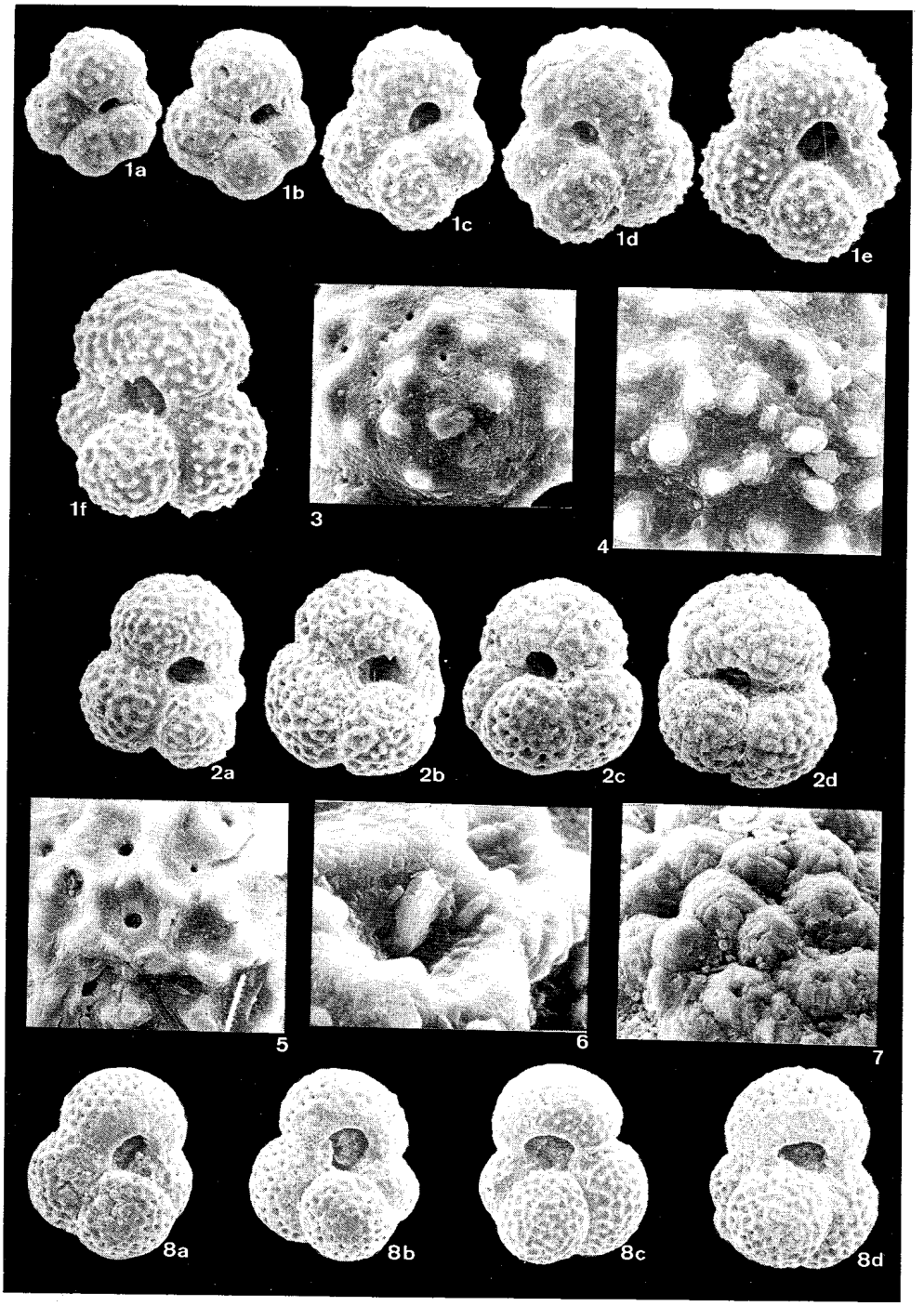


Plate 3

Figs. 1a-j; 8a-9b *Neogloboquadrina acostaensis* (Blow) from sample CRP 13. 1a-j: spiral views. (1a: X 114; 1b-d: X 137; 1e-j: X 170). Growth series showing no distinct differences in gross morphology between immature and adult specimens. Test-surface structures, however, differ greatly. 8a-c: umbilical view (8a: X 137; 8b-d: X 170). 9a-b: axial view (9a: X 137; 9b: X 90).

Figs. 2 – 7 Details of subsequent stages of wall thickening in *N. acostaensis* (X 912). 2. final chamber of 1j showing a relatively smooth surface. Interpore areas already show a few indistinct tubercles. 3. final chamber of 1g. Slightly coalescing tubercles surround future pore-pits. 4. final chamber of 1f. A stage of development slightly more advanced than that of 3. 5. final chamber of 1c. Tubercles coalesced forming nearly complete interpore ridges. 6. steeply sided pore pits. Texture of interpore area is much coarser and more rugged in comparison to that of 5. 7. an ultimate stage of wall thickening is indicated by the formation of euhedral crystals on the interpore areas. Arrangement of crystals on tubercles approaches a stellate pattern (specimens not figured).

Plate 3

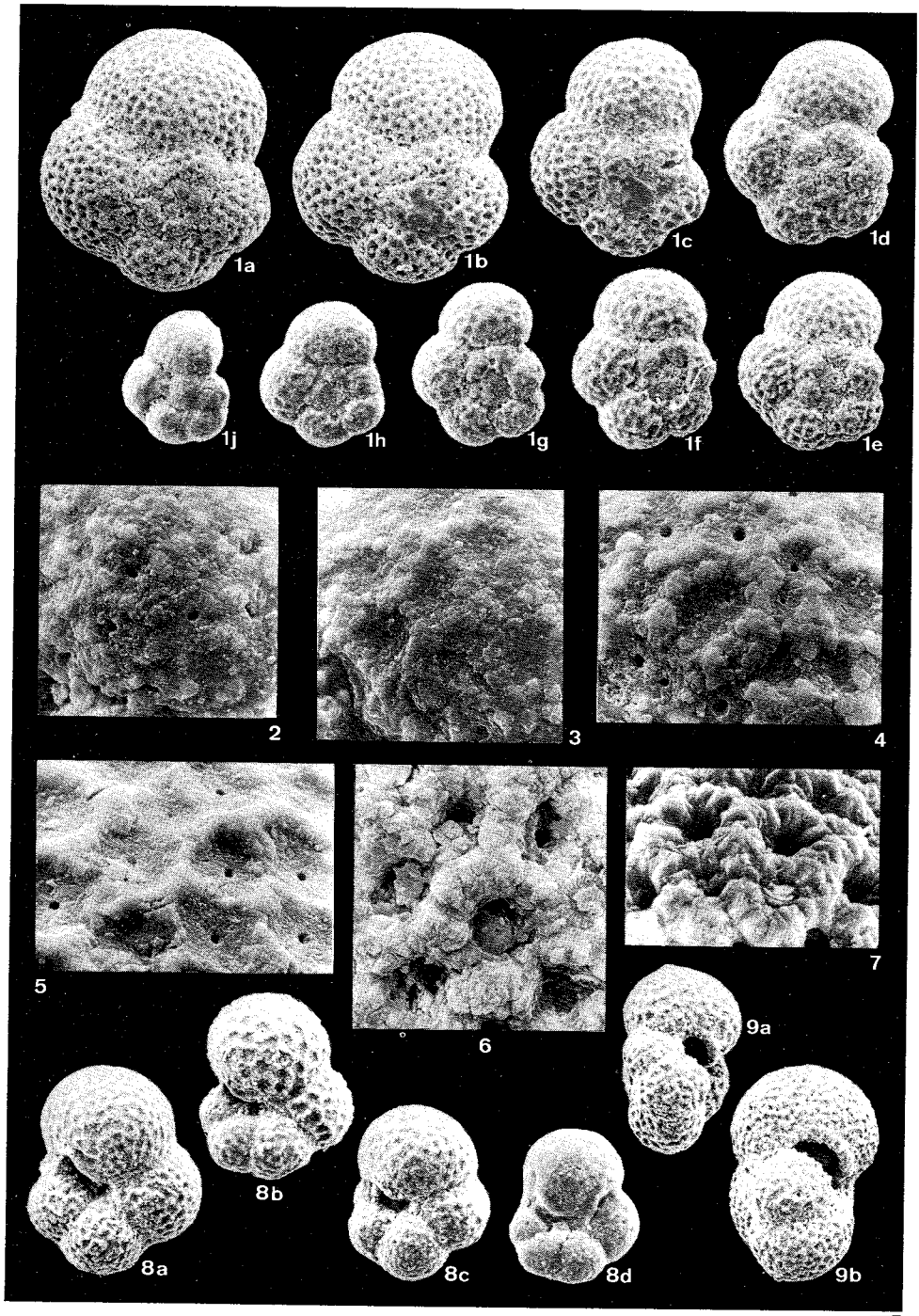


Plate 4

Figs. 1a-h — Variation of *Globigerinita glutinata* (Egger) in the assemblage from sample CRP 13. X 285. Specimens arranged according to increasing height of the test. High-spired forms (1g-h) are identical to *Globigerinita uvula* (Ehrenberg).

Fig. 2 — Test-surface structure of an apertural bulla of *G. glutinata.* X 2280. Extremely small pores and broad protuberances of euhedral rhombs are randomly distributed over the test.

Figs. 3a-f — Variation of *Globigerina falconensis* Blow in the assemblage from sample CRP 27. X 102, except 3a, which is X 80. Specimens 3a-b *G. falconensis*-type; specimens 3e-f *G. bulloides*-type; specimens 3c-d intermediate forms.

Figs. 4 – 6 — Stages of subsequent wall-thickening in *G. falconensis.* An early stage is illustrated in 4 (final chamber of 3f, X 450): spine bases are discrete nodes. As wall thickening proceeds spine bases coalesce to ridges (see 5: antepenultimate chamber of 3f, X 500). 6. antepenultimate chamber of 3b (X 550). Whether the interpore ridges form a reticulate topography (6) or not (5) may be predetermined by the degree in which pores and spine bases are evenly distributed over the test. Relative to the *G. bulloides*-type, a reticulate test topography is observed more frequently in the *G. falconensis*-type.

Plate 4

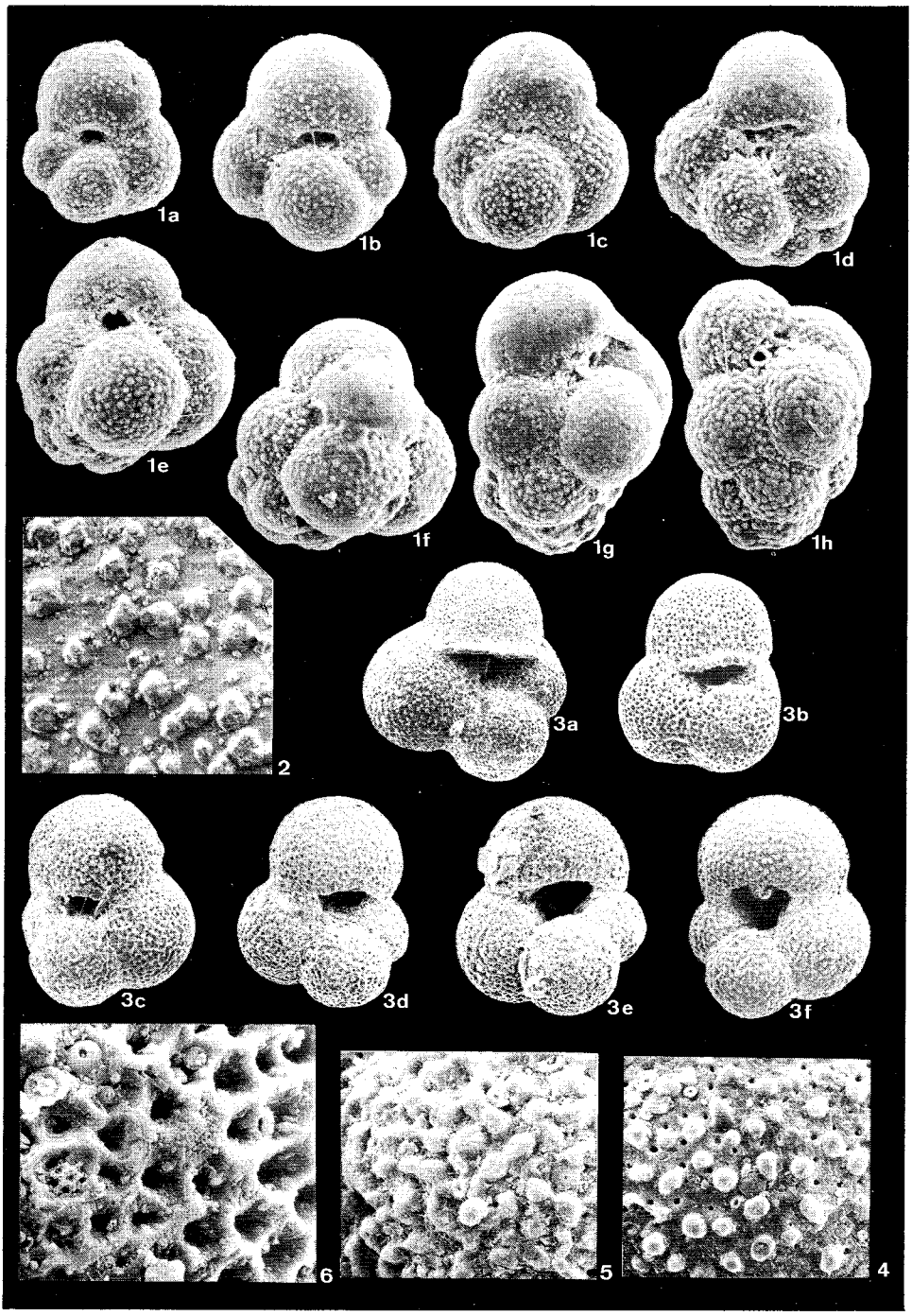


Plate 5

Figs. 1a – 4b Example illustrating differentiation problems between small-sized *Globigerina falconensis* and non-bullate *Globigerinita glutinata* collected from sample CRP 27. When using a normal stereomicroscope, specimens 1–4 (X 137) are morphologically identical. With the scanning microscope, the specimens can be easily identified on the basis of differences in test-surface structures. Test-surface structures of 2a and 3a (see 2b, 3b: X 525; 2c, 3c: X 912) show the characteristic features of *G. glutinata*, i.e., extremely small pores and broad protuberances of calcitic rhombs. Test-surface structures of 1a and 4a (see 1b, 4b: X 525; 1c: X 912) belong to *G. falconensis*, because of the relatively wide pores with spine bases partly coalesced.

Fig. 5 A typical, possibly immature *Globigerinella siphonifera* (d'Orbigny) from sample CRP 13. X 114.

Plate 5

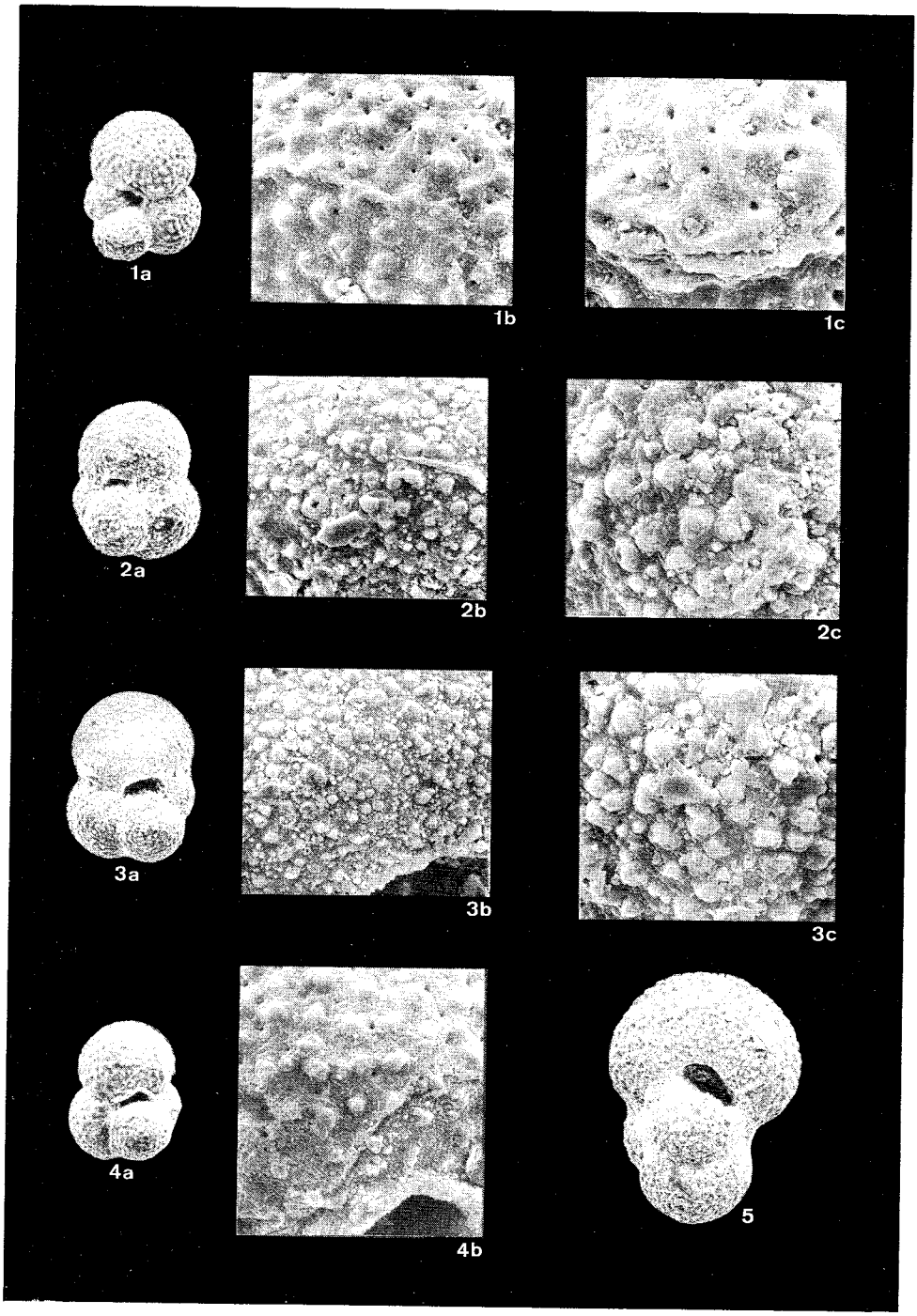


Plate 6

Figs. 1a – 2c — *Globigerina quinqueloba* Natland from sample CRP 13. X 182 (2a X 170). 1a-d: umbilical views. Variation in number of chambers in last whorl, ranging from nearly 6 to 4. 2a-c: spiral views. Generally, the test-surface is finely hispid. In 1a and 2c spine-bases have partly or completely coalesced to ridges.

Figs. 3a-f — Progressive wall thickening in *G. quinqueloba* (umbilical view). 3a-b: X 182; 3c-f: X 170. The finely hispid test surface in 3a becomes gradually smoothened by crystalline thickening of interpore areas (3e-f). Contrary to forms with a hispid test-surface, encrusted forms show a rapid reduction in the number of pores towards earlier chambers and an increase in the diameter of the pore pits.

Figs. 4 – 6 — Close-up views of encrusted specimens of *G. quinqueloba*. 4. fifth chamber of 3d (X 912). At the extreme right, the proximal end of an incised intercameral suture. 5. test-surface structure across the suture between the fourth and fifth chamber of 3f (X 912). 6. final chamber of 3d (X 2280). Note formation of euhedral crystals in interpore areas.

Fig. 7 — *Streptochilus globigerum* (Schwager) from sample CRP 27. X 314.

Fig. 8 — *Globigerinoides trilobus* (Reuss) from sample CRP 30. X 115.

Plate 6

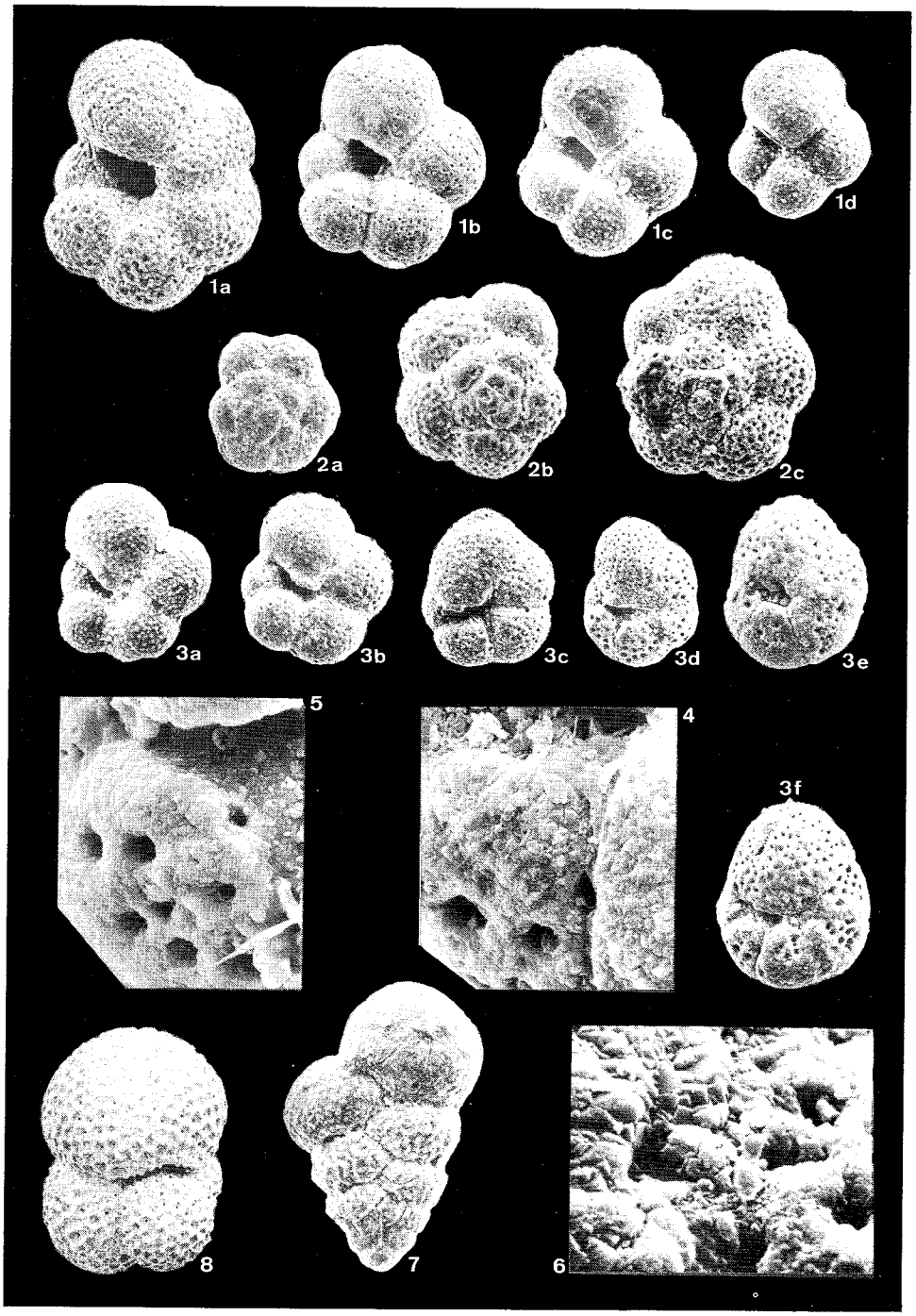


Plate 7

Figs. 1a-g — Growth series of *Globorotalia margaritae* Bolli & Bermudez from sample CRP 13. X 68 (1a X 57). Immature specimens are faintly keeled (1e-f) to non-keeled (1g). Except for specimen 1g, all specimens show broad, partly coalesced, protuberances on the spiral side. Protuberances are mainly concentrated on the spiral and intercameral sutures (1e-d) and on the keel; they tend to spread over the chamber surface in the earlier part of the test.

Fig. 2a-g — Growth series of *Globorotalia scitula subscitula* Conato from sample CRP 13. X 68 (2a-b X 57). Note that protuberances are almost absent. Contrary to *G. margaritae*, the early chambers of the penultimate whorl have the largest pore-pits, which decrease in size in the direction of coiling (see also plate 8).

Figs. 4 – 5 — *Orbulina universa* d'Orbigny from sample CRP 13. X 114. 4. thin-shelled form with a hispid test-surface structure. 5. thick-shelled form showing a reticulate test-surface structure.

Figs. 6a, b — Detail of test topography of *O. universa* from sample CRP 18 showing the characteristic effects of dissolution.

Plate 7

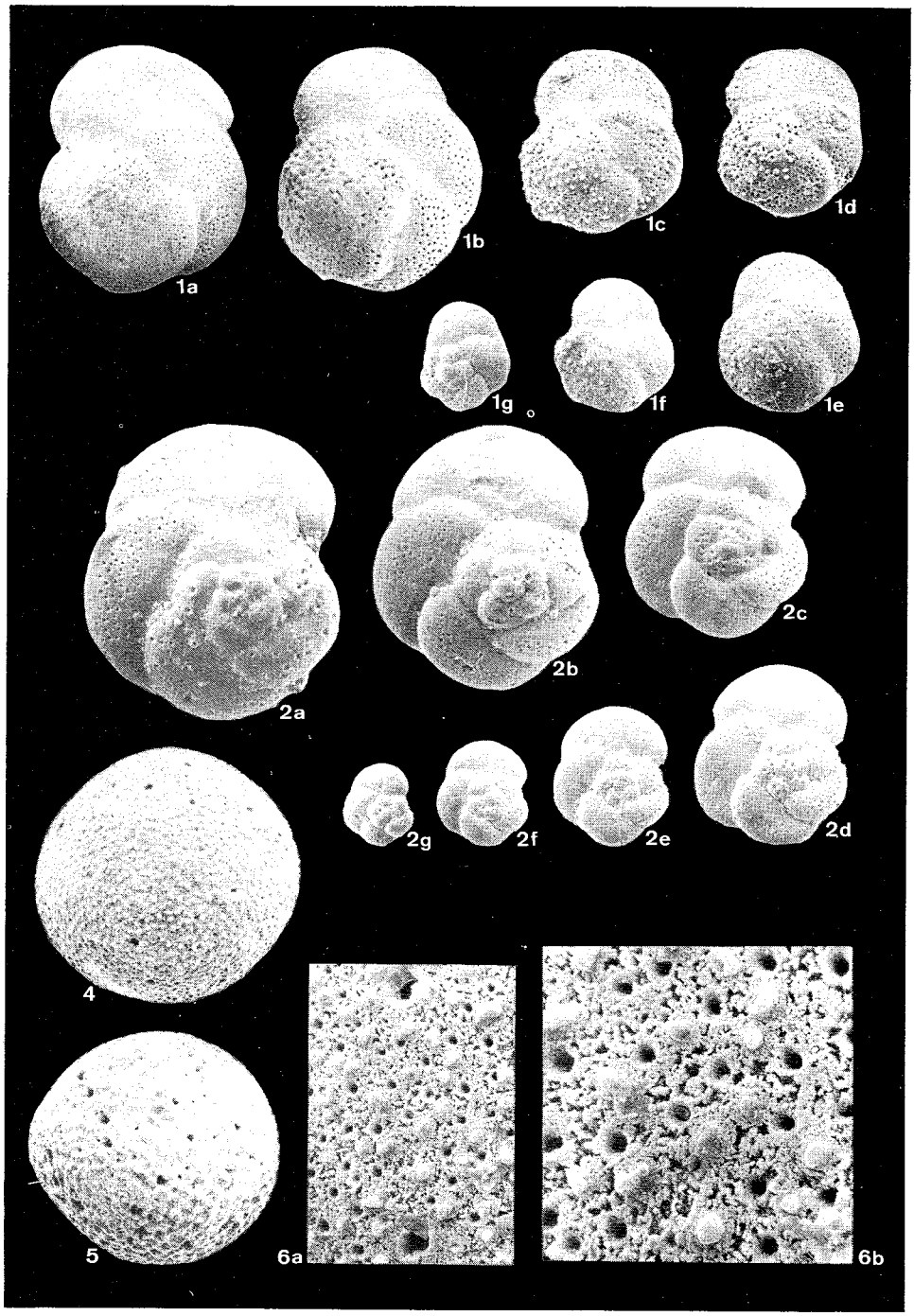
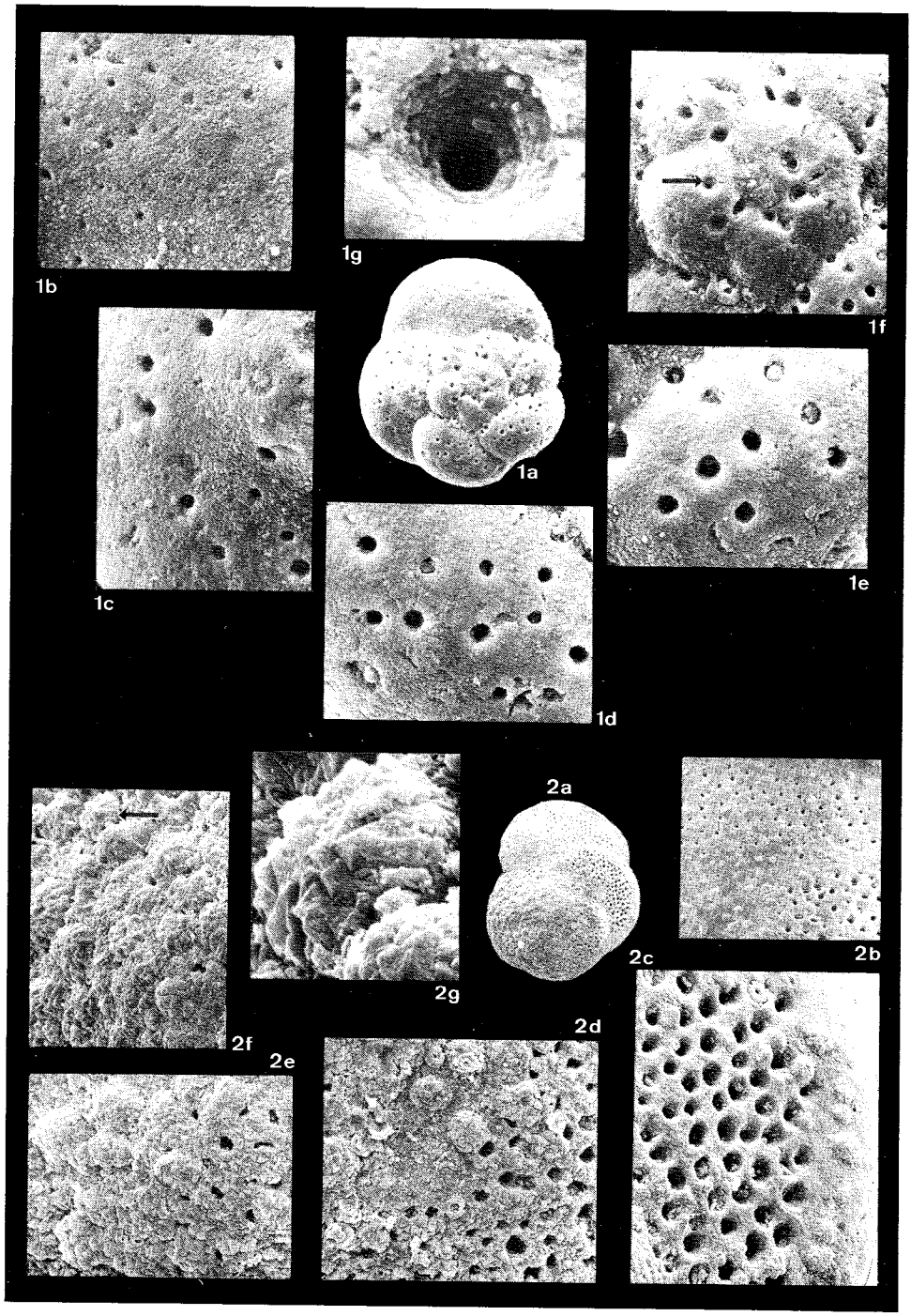


Plate 8

Figs. 1a-g — *Globorotalia scitula subscitula* Conato from sample CRP 13. 1a: spiral view (X 170). 1b-f. Enlarged views of the last four chambers (X 912). Subsequent wall thickening reduces the number of pores in the earlier chambers, while the diameter of the pore-pits increases. Only a few pores remain open in the chambers of the penultimate whorl (1f, X 456). In this early part of the test pore-pits are multilayered (1g, X 4560).

Figs. 2a-g — *Globorotalia margaritae* Bolli & Bermudez from sample CRP 13. 2a: spiral view (X 68). 2b-f: enlarged views of the last five chambers (X 500, 2b X 228). Initially the diameter of pore-pits increases towards earlier chambers (2b-c: ultimate and penultimate chamber, respectively). A few protuberances are mainly concentrated on the proximal ends of the chambers and on the keel. In the earlier part of the test, protuberances spread over the entire chamber surface. With increasing growth of euhedral crystals on the broad protuberances and on the interpore ridges, pore pits become constricted or even closed. In the third chamber growth in crystal size on the interpore areas constricts pore-pits (2d). In the fourth chamber pore pits are strongly constricted (2c). Maximum crystal growth occurs on the fifth and earlier chambers (2f). The arrangement of crystals on protuberances approaches a stellate pattern (2g, X 4560; for location see 2f).

Plate 8



CALCAREOUS NANNOFOSSILS

R. R. SCHMIDT

INTRODUCTION

Calcareous nannoplankton are abundant throughout the eight meter profile of the Lower Pliocene of Capo Rossello.

The purpose of the pilot project was to standardize counting techniques suitable for the quantitative evaluation of calcareous nannoplankton and to consider the various factors that may affect the end result. A quantitative approach demands consistency and a solution to certain problems connected with the preparation, viewing, and counting procedure, the "taxonomic units" to be counted, and a critical look at selective oceanographic and preservation filters which can alter the original species composition. Only then is it plausible to make interpretations concerning paleoecology and/or "accuracy in correlations".

The stratigraphic interval studied (Brolsma and Broekman, this volume) can be assigned to the *Ceratolithus acutus* Zone (Cita and Gartner, 1973; = the *C. amplificus* Zone of earlier authors). This zone is defined as the interval from the entry of *Ceratolithus acutus* to the entry of *Discoaster asymmetricus*. The evolutionary development of the ceratolithids (*Amaurolithus tricorniculatus* via *Ceratolithus acutus* to *C. rugosus*) forms a significant lineage for recognizing the lower zones in the Pliocene. However, the ceratolithids are often very rare in Lower Pliocene samples from the Mediterranean region (Bukry, 1973a; Schmidt, 1973). Only a few *Amaurolithus* specimens were encountered in the 200 counts, but no *Ceratolithus acutus*. The latter species was found in a few samples by scanning at lower magnification for a period of an hour or longer.

Associated criteria for recognizing the *C. acutus* Zone are few. It has been noted in other sections from the Mediterranean region that there is an increase in frequency in thin-rayed *Discoaster surculus* above the Miocene/Pliocene boundary (Schmidt, 1973). For the first time this species is sometimes present in sufficient numbers to enter 200 counts.

PREPARATION, VIEWING, AND COUNTING PROCEDURE

Because of their small size and abundant occurrence in pelagic sediments,

calcareous nannofossils make good subjects for statistical approaches. Pelagic oozes, as represented by the Trubi formation, contain up to 10^{12} specimens per cm^3 (Mohler and Hay, in Hay et al., 1967). A normally prepared slide with well-dispersed coccoliths and discoasters generally contains between 10^5 and 10^6 specimens. Such a large collection can often be scanned rapidly to detect the presence or absence of index species (Hay, 1972).

Samples were made ready for observation by using the smear-slide technique. Approximately 10 grams of each sample were moistened in a small sample bottle with distilled water. The tip of a toothpick was used as a spatula to scrape a small quantity of sediment from a moistened fragment. The small point of sediment was vigorously rubbed on a cover glass until it was completely in suspension and evenly spread on the cover glass. After drying on a hot plate, the cover glass was mounted on a glass slide with Canada balsam. This technique has the advantage that differential settling of the clay-sized particles containing the nannofossils (2–25 μ) is kept to a minimum. The split is nothing but a "scratch" of the total sample in the bottle; it does not have to be representative for the sediment in the bottle. This procedure is different from those used for the other groups of microfossils studied in our project in which a random split is made of a larger "composite" sample.

The smear-slide technique was preferred to a method involving a tiny split of a much larger volume of sediment in suspension for fear of fractionation effects in the latter method (e.g. Mc Intyre and Bé, 1967; Schrader, 1974). With our technique there is much less chance of differential settling and there is no need for a more rigorous standardized procedure. However, a measured pipette method is essential for calculating the total number of nannoplankton per unit weight (or volume).

The method used to view the very small calcareous nannoplankton has a marked effect on the counting results. In general, counting of nannoplankton in the transmission and the scanning electron microscope is suitable only for well-preserved nanno-oozes not obscured by fine debris (Gartner, 1972). Because counting with the light microscope involves an inherent resolution limit most coccoliths of less than 3 μ in diameter are not determinable.

The highest magnification of the Leitz Orthoplan microscope (1250 X) was used for all counts. A template mounted in the ocular, a standard Leitz accessory used to distinguish the photographic field of the automatic camera, defined one field. This field when tested with an objective micrometer appeared to measure 57 μ X 86 μ. A traverse, a multiple of the 57 μ field width, was begun from the same fixed point for each slide (coordinates

10.0 mm and 100.0 mm on the substage calipers). The traverse moves from 100.0 mm in the direction of 118.0 mm until 200 specimens are counted. If necessary, a second traverse was begun at 8.0 or 12.0 of the vertical scale, and begun again at 100.0 mm of the horizontal scale until 200 specimens were found.

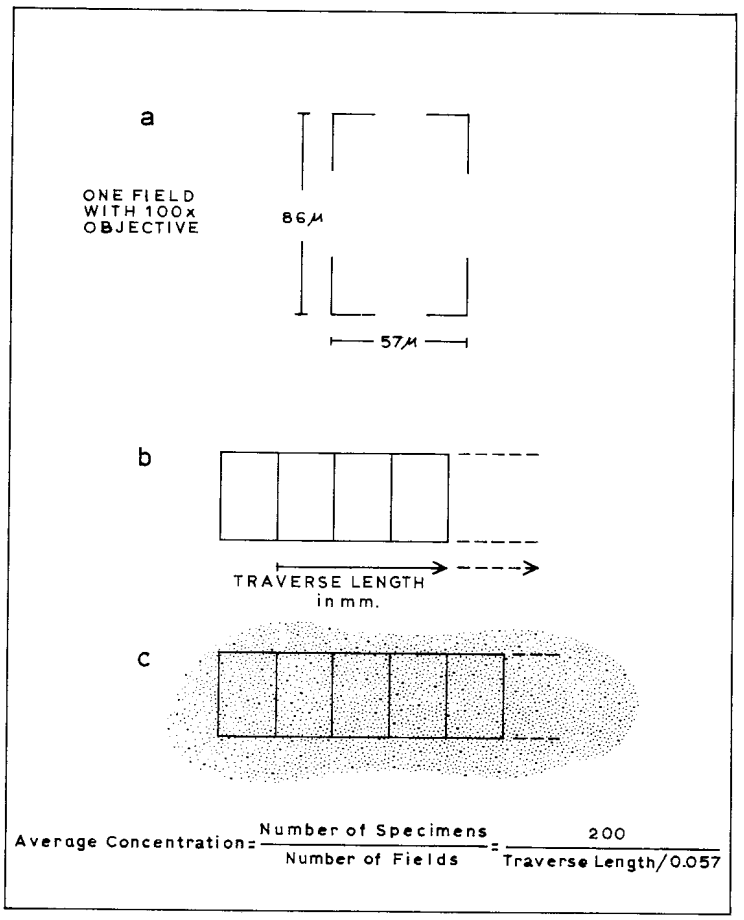


Fig. 1 Counting method illustrated by reference to one field in a template mounted in the Leitz Orthoplan microscope (a). Traverse lengths for all counts are recorded from which an average concentration can be calculated (b, c).

The traverse length in mm was recorded, from which an average concentration can be calculated (fig. 1). By experiment it was found that at this magnification useable concentrations for the Capo Rossello samples varied from 1 to 8 counted specimens per field. The smear-slides used were some-

what thinner than in normal routine investigations to prevent stacking of coccoliths that may obliterate others from the counts. If the concentration was not in this range, or if it contained too many "clusters", a new smear slide was made.

All counts were made with the help of a person who served as counter. In this way, one hand is free to slowly turn the substage caliper while the other hand changes the focus. At the time of this project, we had counted already over 200 samples in this manner; my helper was able to tick-off the species on a work sheet about as fast as I could identify them.

A "half-polarized" light was used routinely for observation, i.e., the analyzer turned towards 45° so that both the species characteristics for discoasters and coccoliths could be seen. When necessary for species determination, full-polarized light also was used by turning the analyzer to 0° in the case of some coccolith species.

TAXONOMIC UNITS COUNTED

Several factors affect the choice of which "taxonomic units" to count. In samples with mixed preservation, such as the short Capo Rossello section, a "lumping approach" was considered advisable. Let us presume, as in the case of the *Cyclococcolithus leptoporus* group, that there are some clear "end members" or varieties that are identifiable. However, there are many specimens that cannot be clearly assigned to one or other of the varieties. These unidentifiable specimens must be assigned to a "variety indeterminate" category, the numbers of which increase inversely with the state of preservation. Poor preservation will obstruct any attempt to single out the types.

Another reason for lumping species is that the specimens occur so rarely that they would not enter the counts consistently unless recognized at the genus level. For example, all species of *Discoaster* are considered as one category in 200 counts. And finally, the paleoecological significance of the relative counts is sufficiently well served at the genus level.

Nine species or genus categories are represented in the 200 counts above the 1% level. *Coccolithus pelagicus* and the *Cyclococcolithus leptoporus* group dominate the counts; these two groups comprise about 75% of the total. The categories of second ranking that generally occur in percentages between 5% and 20% of the total, include the *Helicosphaera carteri* group, *Reticulofenestra pseudoumbilica, Cyclococcolithus rotula* and *Sphenolithus abies.* The categories of *Pontosphaera + Scyphosphaera, Discoaster,* and *Rhabdosphaera procera* generally vary between 1% and 5%.

In addition to the species or genera counted, another category was estimated as "outside counts". Coccoliths, generally less than 3 μ, of not readily identifiable species, were estimated at a factor of 10. So, the counted part of the assemblage forms a subset of the total coccolith population. The relative abundance of small coccoliths is thought to have important consequences for the results of the quantitative study which will be discussed later.

RESULTS OF THE 200-COUNTS

Horizontal variations

One important question to be asked is how much "precision" there is in the relative 200-count method in practice. Horizontal variations were tested by making 10 repeated 200 counts for three different experiments.

The first experiment involves the variation in counts for each species or genus category from one prepared slide taken from sample CRP 39. The data are expressed in histograms (fig. 2a, b) for 200-counts and 100-counts, respectively.

The second experiment involves 200-counts from 10 different slides of the same sample. It is postulated that a sample from non-laminated sediment might be more homogeneous in its distribution of nannoplankton than a sample from a laminated sediment. Counts made from different slides of a non-laminated sample would show less variation in percentages of the counted categories than similar slides from a laminated sample. The results of this experiment on non-laminated sediment (CRP 21, slides 1–10) and on laminated sediment (CRP 22, slides 1–10) are shown as histograms in figures 3 and 4.

The third experiment involves two slides from each of five samples collected laterally along one laminated layer (CRP 22 – CRP 26). Repetitive 200-counts give some measure of the maximum variation to be expected depending upon the chance selection of a "point" sample in one horizontal layer (fig. 5).

The results of the three horizontal experiments are expected to be nested in the same order as presented. Variation in repeated counts from one slide would be less than in counts from different slides of the same sample. Variation in repeated counts based on different slides from a sample of more homogeneous, non-laminated sediment would be less than in similar counts from a sample of laminated sediment. Finally, variation in counts from different slides prepared from lateral samples of the same laminated layer would be the greatest.

Fig. 2a Histograms of the species and genus categories based on 10 successive 200-counts (Experiment 1), along one traverse of the same slide, non-laminated sample CRP 39. (For circled-number coding of genus and species categories, see figure 6).

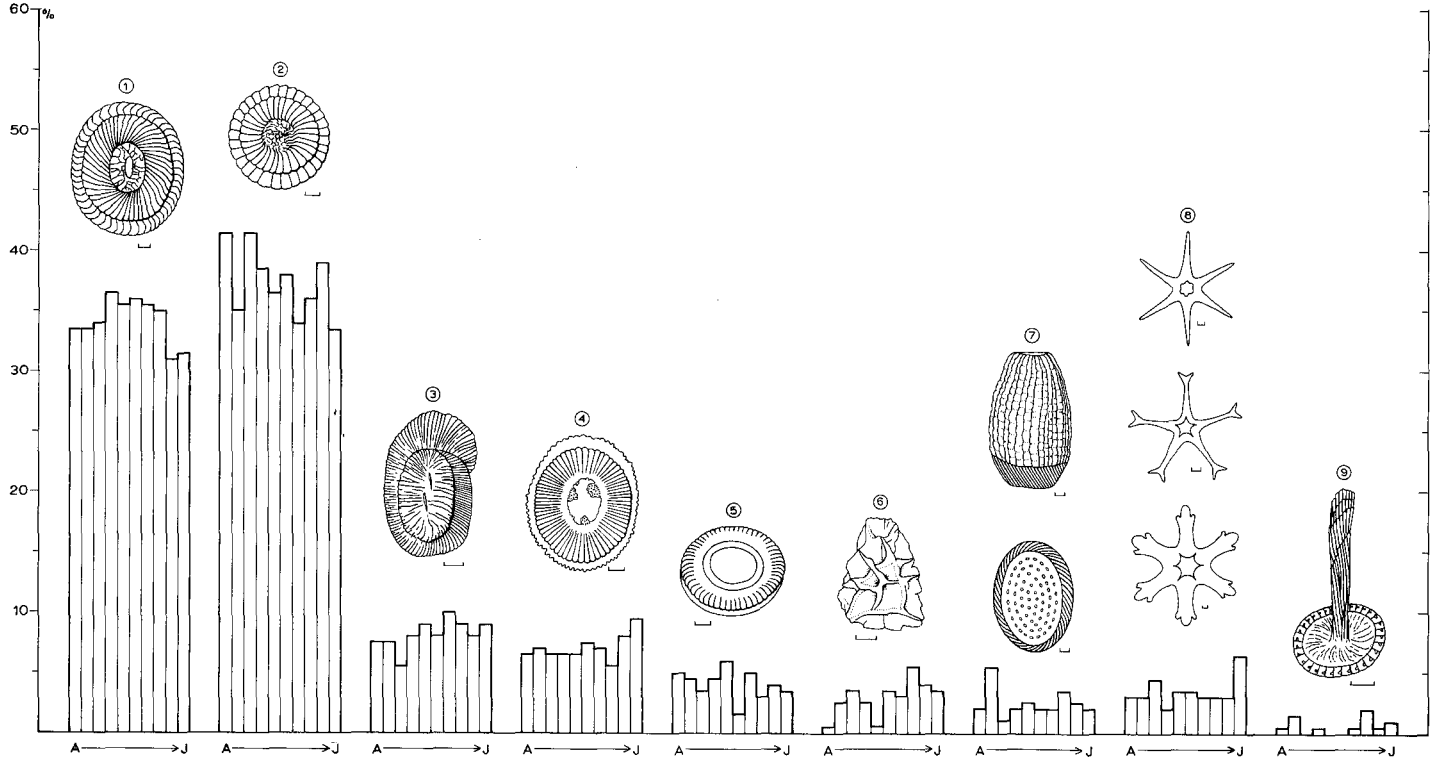
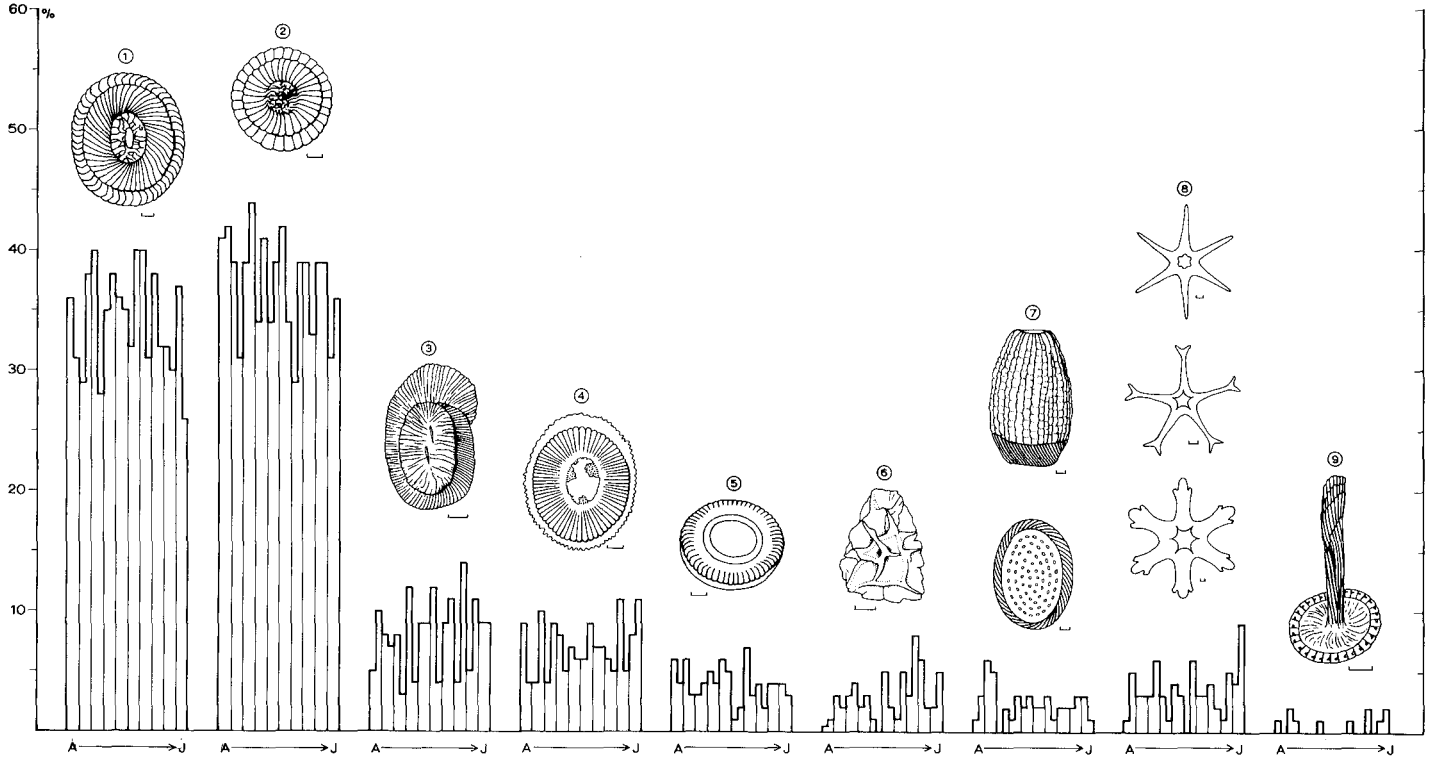


Fig. 2b Histograms of the species and genus categories based on 20 successive 100-counts (Experiment 1), along one traverse of the same slide, non-laminated sample CRP 39. (For circled-number coding of genus and species categories, see figure 6).



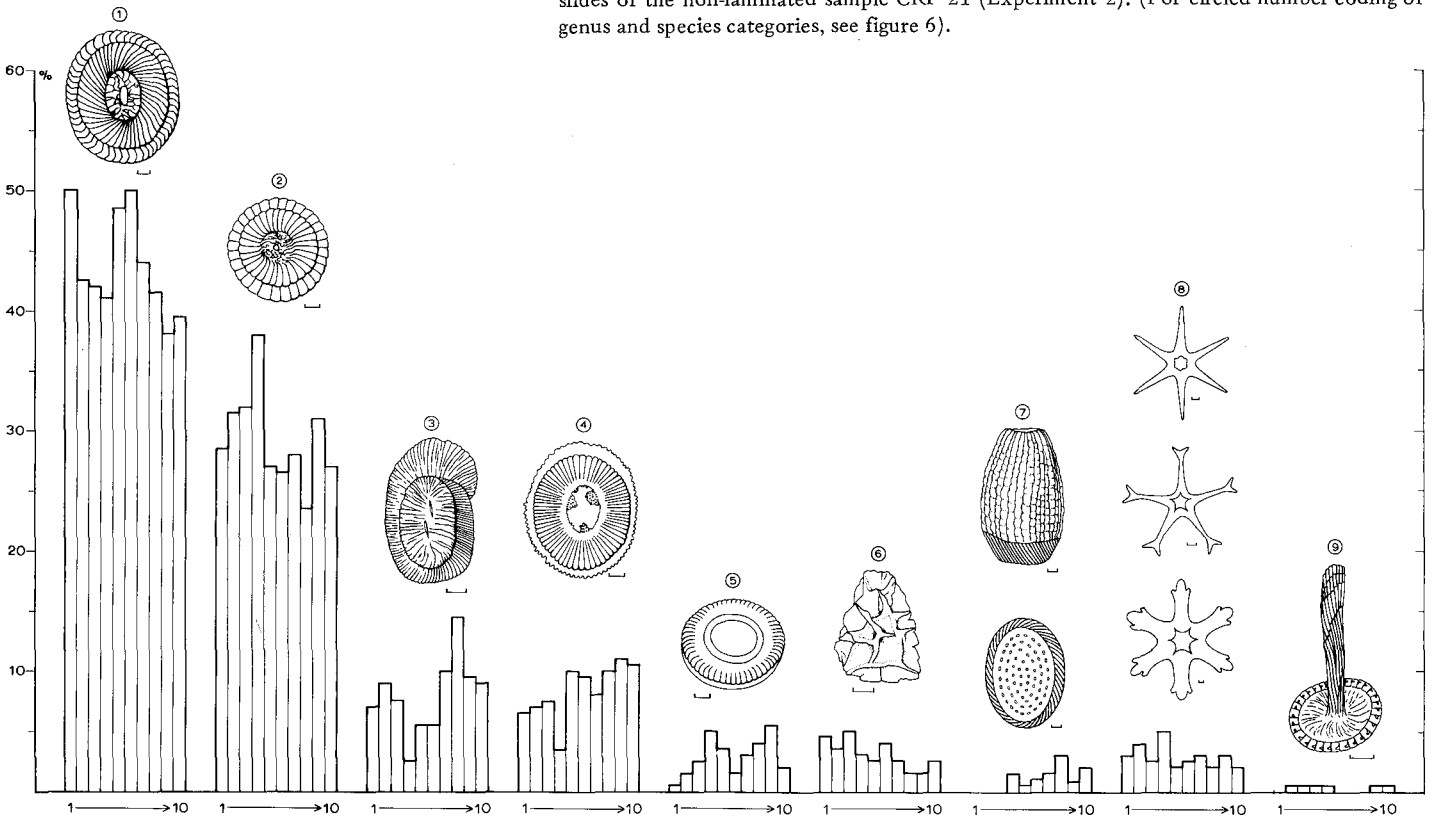


Fig. 3 Histograms of the species and genus categories based on 200-counts of 10 separate smear slides of the non-laminated sample CRP 21 (Experiment 2). (For circled-number coding of genus and species categories, see figure 6).

Fig. 4 Histograms of the species and genus categories based on 200-counts of 10 separate smear slides of the laminated sample CRP 22 (Experiment 2). (For circled-number coding of genus and species categories, see figure 6).

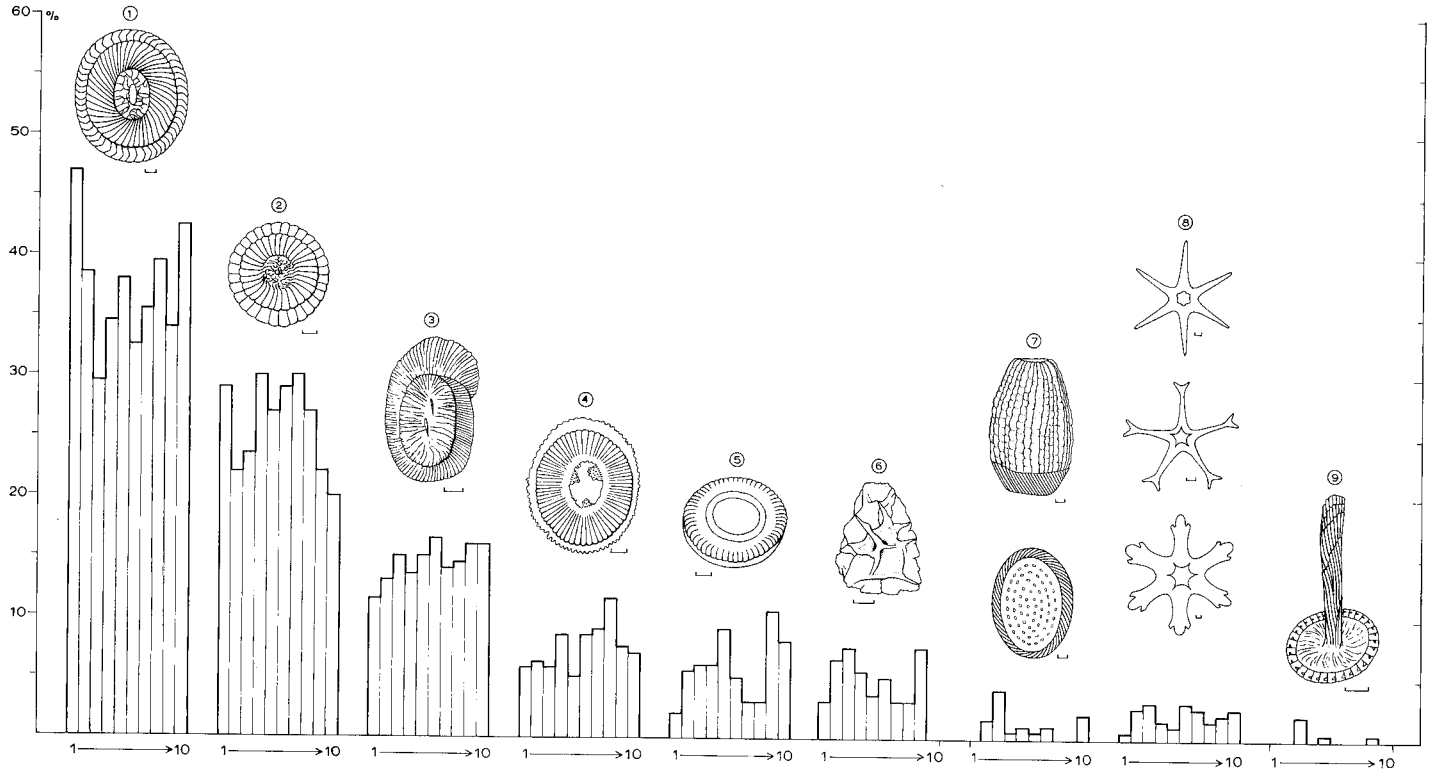
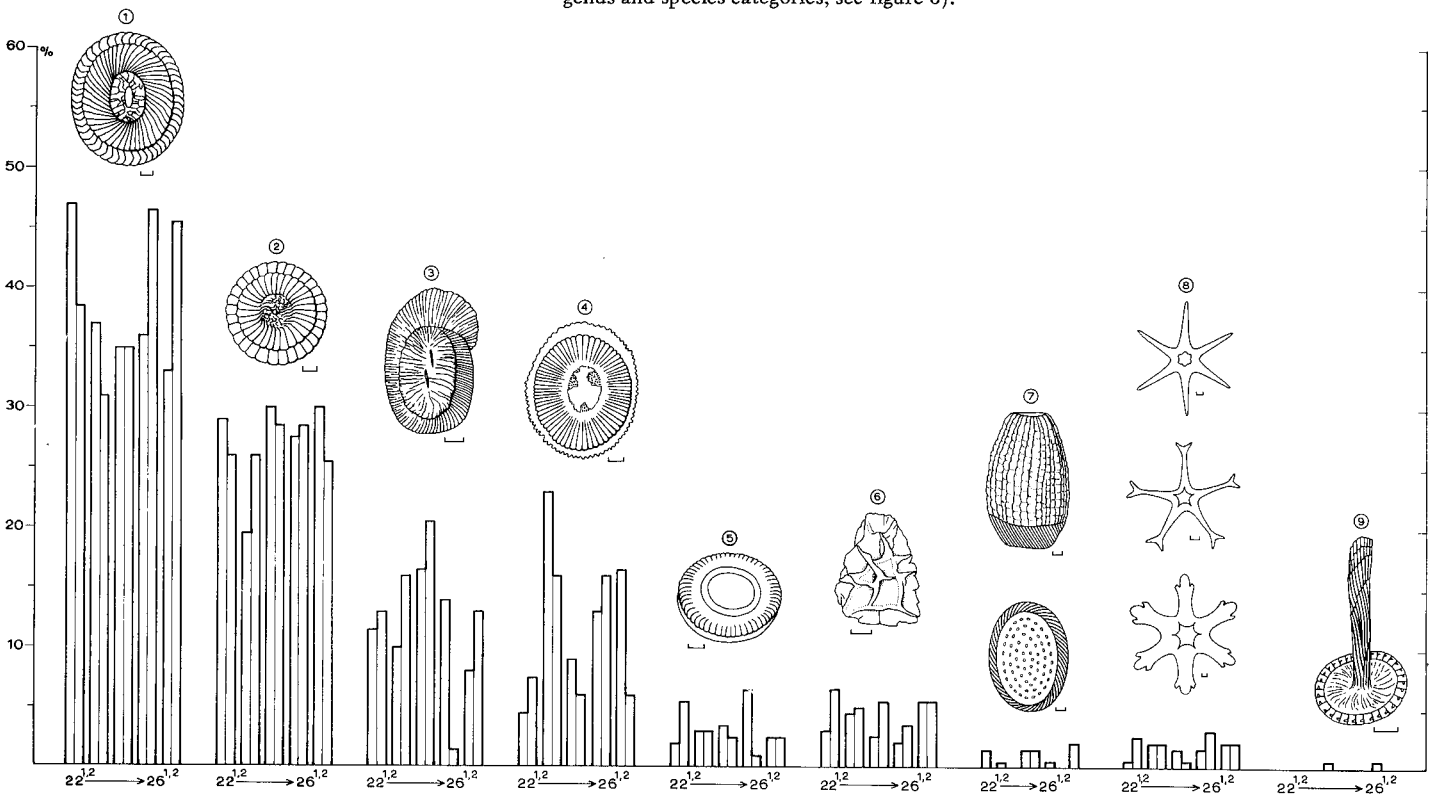


Fig. 5 Histograms of the species and genus categories based on 200-counts of 2 separate smear slides from 5 lateral samples, CRP 22–26 (Experiment 3). (For circled-number coding of genus and species categories, see figure 6).



For each of the 9 species or genus categories in each of the three experiments, a mean value expressed as a percentage and a standard deviation (S.D.) are calculated from the data obtained. A measure of the reliability of these counts in relation to random sampling errors is provided by a comparison with the binomial standard deviation for the 10 × 200 counts and the Chi-square test:

$$\chi^2 \text{ value} = \frac{SD^2 \ 10 \text{ counts}}{SD^2 \ \text{binomial}} \times 9$$

A summation of the χ^2 values for all 9 species or genus categories counted in each experiment serves as a means to compare the variation of the counts in practice to what may be expected in a single population (table 1). If the counts are from one single population, $\Sigma\chi^2$ has a Chi-square disbribution with about 90 degrees of freedom. The value of $\chi^2/90$ indicates the degree of variability. In our case a lower $\Sigma\chi^2$ value indicates less variation than a higher value (see M. M. Drooger, this volume).

In the 10 repeated counts along one traverse on the same slide (experiment 1), the variation in all counted categories is well within that expected for random samples from one population. The $\Sigma\chi^2$ value of 66 is below the critical value of 113, the 95th percentile.

When different slides are prepared and counted (experiment 2), the $\Sigma\chi^2$ value goes beyond the critical value of $P_{99} = 123$. As a whole, the total variability in the species or genus categories of the non-laminated sample seems to be only slightly lower than that for the laminated sample, as may be seen from the values of 129 and 147, respectively.

Repeated counts on different slides along the same laminated layer (experiment 3) show markedly higher variations for some taxa resulting in the high $\Sigma\chi^2$ value of 194.

As reflected in the ever increasing $\Sigma\chi^2$ values, a summation of the variation in counted categories becomes greater in the three successive horizontal experiments. Repeated counts on one slide show a variation in all counted categories within the interval expected for a normal population. It is concluded that a 200-count on one slide is representative for that slide. When different slides from a sample are prepared and counted, the deviations for some species or genus categories are above those expected for random sampling errors. Probably this indicates that each "point" of sediment randomly picked from the sample by the smear-slide technique is not from so homogeneous a sediment that it can be regarded to contain a subsample of one population. When slides are prepared and counted along the same laminated horizon, the variation in some species or genus categories increases

↓ Experiment / Species or genus category →	Statistic	*Coccolithus pelagicus*	*Cyclococcolithus leptoporus* group	*Helicosphaera carteri* group	*Reticulofenestra pseudoumbilica*	*Cyclococcolithus rotula*	*Sphenolithus abies*	*Pontosphaera* + *Scyphosphaera*	*Discoaster*	*Rhabdosphaera procera*		
		1	2	3	4	5	6	7	8	9	$\Sigma\chi^2$	$\sqrt{\Sigma\chi^2/90}$
Experiment 1												
10 counts, same slide	$\bar{p}$ in %	34.2	37.25	8.15	7.05	4.05	2.9	2.35	3.5	0.55		
non-laminated sample	SD	1.86	2.82	1.23	1.09	1.26	1.56	1.18	1.22	0.50		
CRP 39	χ^2	2.8	6.1	3.7	3.3	7.4	14.9	11.0	8.1	8.3	66	0.85
Experiment 2												
10 counts, different slides	$\bar{p}$ in %	43.7	29.25	8.0	8.9	2.9	3.05	1.0	2.9	0.3		
non-laminated sample	SD	4.33	3.99	3.24	3.14	1.61	1.19	1.0	0.97	0.26		
CRP 21	χ^2	13.7	13.8	**25.6**	**22.0**	16.7	8.6	18.4	6.0	4.0	**129**	1.20
10 counts, different slides	$\bar{p}$ in %	37.05	25.95	14.5	7.85	5.8	5.45	1.05	2.0	0.3		
laminated sample	SD	4.99	3.74	1.55	1.70	2.75	2.58	1.23	0.85	0.63		
CRP 22	χ^2	19.2	13.1	3.5	7.2	**25.0**	**23.1**	**26.3**	6.6	**23.4**	**147**	1.28
Experiment 3												
10 counts, 2 different slides	$\bar{p}$ in %	38.45	26.65	12.45	12.0	3.6	4.6	0.85	1.75	0.1		
5 lateral samples laminated horizon	SD	5.82	3.50	5.18	5.78	1.43	2.02	0.75	0.79	0.21		
CRP 22 to CRP 26	χ^2	**25.8**	11.3	**44.5**	**56.8**	12.2	16.8	12.0	6.5	8.2	**194**	1.47

χ^2 test: critical value P_{95} is 16.9 for 9 degrees of freedom
χ^2 test: critical value P_{99} is 21.7 for 9 degrees of freedom

$\Sigma\chi^2$ value: critical value P_{95} is ~ 113
$\Sigma\chi^2$ value: critical value P_{99} is ~ 123

Table 1. Statistical treatment of the 10 repetitive counts in the various horizontal experiments (1–3). The two indices of variability, to the right, are nested in the order as would be expected (see text).

markedly, indicating a notable horizontal shift in floral composition.

It is also important to analyze which species groups show variations above what might be regarded as acceptable in the various experiments (table 1). Perhaps certain species groups consistently show more variation in the repeated counts than others. When species groups that have χ^2 values above the critical value of 21.7 are considered (table 1, experiments 2 and 3), it can be observed that the highly variable species groups are not always the same.

In counts made from 10 slides of the non-laminated sediment of CRP 21, the *Helicosphaera carteri* group and *Reticulofenestra pseudoumbilica* show abnormally high variation; whereas in similar counts from the laminated CRP 22, several more rarely occurring species groups are most variable in the relative counts.

The highest variations occur in the counts from the 5 lateral samples CRP 22 – CRP 27 (2 slides each) from the laminated layer for the two abnormal species groups of the non-laminated sediment, mentioned above. Those slides in which these two species deviated most from the norm were re-counted to check whether some kind of lapse in counting procedure had occurred the first time round. In all cases, the recounts appeared to be similar to the first counts, thus substantiating the earlier conclusion that 200-counts from one slide are representative for that slide.

Vertical variations

The percentages of the various species groups for the 8-meter Capo Rossello section (CRP 8–45) are shown in figure 6. Included at each sample level are the binomial 95% confidence intervals.

The data for each sample, consisting of the counts of the species groups (1–9), a code for lamination (11) or non-lamination (10), diatom number (12) (Schrader and Gersonde, this volume), and traverse length (13), were analyzed with the computer to test for trends and correlations. The results of these tests with probability levels below 0.10 are shown in table 2 with a sign indicating positive or negative correlation.

Trends and correlations based on relative counts have to be interpreted carefully (Berger, 1971). Negative correlations in a closed system may be the result of "a purely statistical competition for space on a 100% scale", or expressed less eloquently, as one species group increases, another group or a combination of others must decrease.

A consideration of causal relationships between the correlations from one section alone is of dubious value. If the same correlations occur consistently in different sections, a cause and effect sequence of events may become

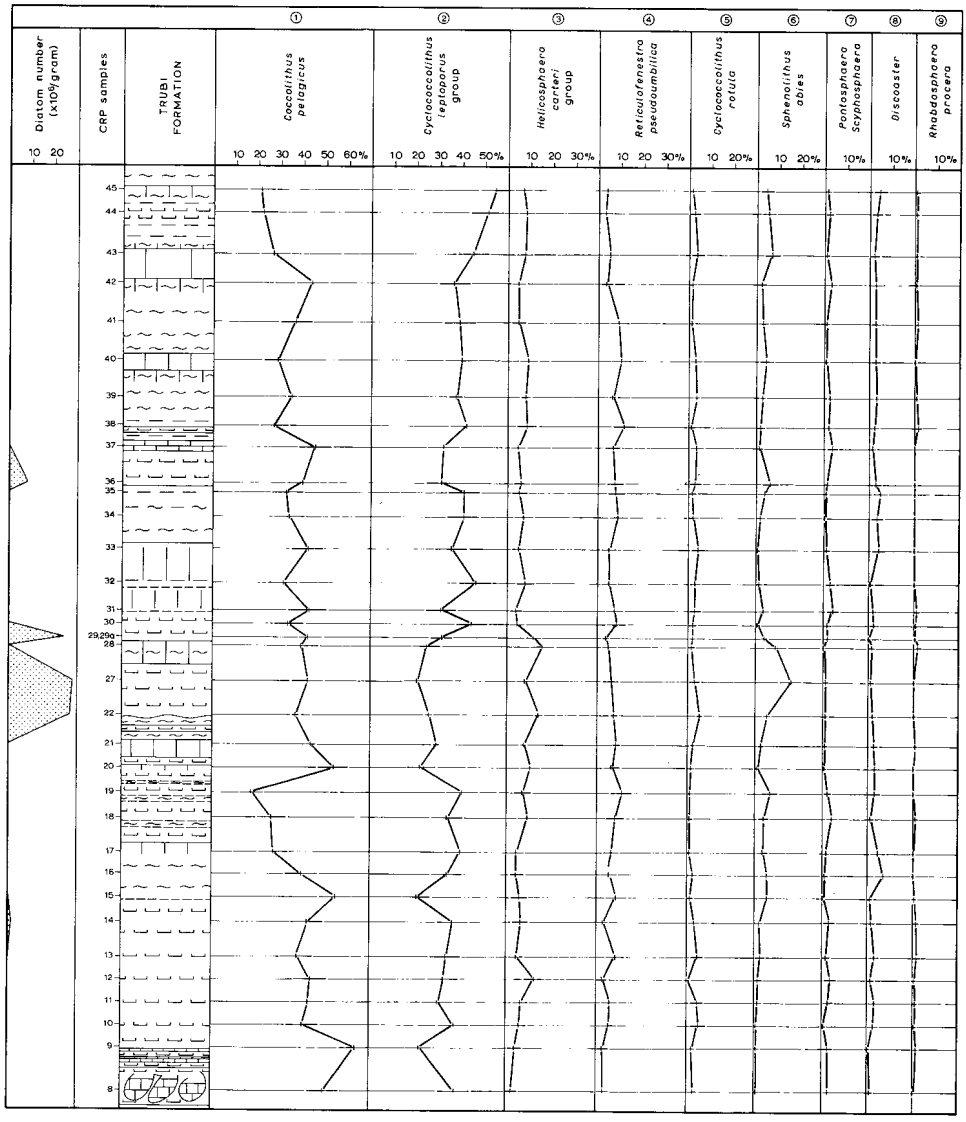


Fig. 6 Vertical distribution of species and genus categories in percentages based on available counts. Bars for each category represent the binomial standard deviation at the 95% confidence level.

Trends				Capo Rossello CRP 8 – CRP 45
1	*Coccolithus pelagicus*			– decrease
2	*Cyclococcolithus leptoporus* group			+ increase
11	lamination			– decrease
Correlations				
11	lamination	– 12	diatom number	+ P ~ 0.02
11	lamination	– 13	traverse length	+ P ~ 0.001
12	diatom number	– 13	traverse length	+ P ~ 0.05
2	*Cyclococcolithus leptoporus* group	– 12	diatom number	– P ~ 0.05
3	*Helicosphaera carteri* group	– 12	diatom number	+ P ~ 0.02
3	*Helicosphaera carteri* group	– 13	traverse length	+ P ~ 0.10
4	*Reticulofenestra pseudoumbilica*	– 13	traverse length	– P ~ 0.05
6	*Sphenolithus*	– 12	diatom number	+ P ~ 0.02
6	*Sphenolithus*	– 13	traverse length	+ P ~ 0.05
8	*Discoaster*	– 11	lamination	– P ~ 0.05
8	*Discoaster*	– 12	diatom number	– P ~ 0.02
8	*Discoaster*	– 13	traverse length	– P ~ 0.05
1	*Coccolithus pelagicus*	– 2	*Cyclococcolithus leptoporus* group	– P ~ 0.10
2	*Cyclococcolithus leptoporus* group	– 8	*Discoaster*	+ P ~ 0.01
3	*Helicosphaera carteri* group	– 6	*Sphenolithus*	+ P ~ 0.10
3	*Helicosphaera carteri* group	– 8	*Discoaster*	– P ~ 0.05
6	*Sphenolithus*	– 7	*Pontosphaera + Scyphosphaera*	– P ~ 0.10
7	*Pontosphaera + Scyphosphaera*	– 9	*Rhabdosphaera procera*	+ P ~ 0.10
				Probability Level

Table 2. Results of computer analysis to test for trends and correlations with probability levels below 0.10. Trends that increase or decrease stratigraphically upwards and correlations that are positive or negative are indicated with a + or – sign, respectively.

more certain. In fact, the study of other sections is now in progress and represents the next logical step in the "correlation project".

However, some conclusions on the trends and correlations on the 200-count data from Capo Rossello will be attempted, bearing in mind the limitations mentioned by M. M. Drooger. The short section of the Trubi studied shows a decreasing upward trend in the relative proportion of laminated sediment, accompanied by an upward decrease in *Coccolithus pelagicus* and an upward increase in the *Cyclococcolithus leptoporus* group. If *Coccolithus pelagicus* represents a "cold-water" indicator, as in Recent oceans, a general warming trend would be indicated. In none of the other

groups dealt with in this volume can a confirmation of this hypothesis be found.

The diatom number is correlated to lamination, but not all laminated layers have high numbers of diatoms. The traverse length needed to observe 200 nannofossils is correlated positively to lamination and also to diatom number. If the average concentration of clay-sized particles on the smear slides is consistently random, as intended, then the ratio of calcareous nannoplankton to other "foreign" particles is less in the laminated samples and particularly in the laminated samples high in diatom numbers.

The genus *Discoaster* shows a negative relationship to the positively correlated triumvirate of lamination-diatom number-traverse length; it is more common in non-laminated levels. The pair diatom number-traverse length shows a positive correlation to the genus *Sphenolithus* and to the *Helicosphaera carteri* group.

Correlations between species indicate some of the same observations already mentioned. The decreasing and increasing trend in *Coccolithus pelagicus* and the *Cyclococcolithus leptoporus* group is indicated by the negative correlation between the two. The positive correlation between the *Cyclococcolithus leptoporus* group and the genus *Discoaster* is in line with the negative correlation of these two species groups with diatom numbers. A positive correlation of the *Helicosphaera carteri* group and the genus *Sphenolithus* is also reflected in positive correlations of the two with diatom number and traverse length.

LOGARITHMIC PROCEDURES AND ESTIMATES

In the Capo Rossello test section, the important index species are rarely encountered in the 200-counts. For zonal recognition in calcareous nannoplankton biostratigraphy, one tries to determine the presence or absence of a limited number of, frequently rare, index markers. In many sections from the Mediterranean region, the Early Pliocene index species do not occur in sufficient abundance to find even one specimen in 200-counts although most of these species are easily identifiable. If "accuracy in correlation" is to be approached, a method has to be employed that can give a better approximation of the presence or absence of index species. Some kind of logarithmic estimation procedure is necessary to give a more reliable estimate of the frequencies of rarer species which generally do not enter into the 200-counts.

A semi-quantitative method has been applied to calcareous nannoplankton and involves an estimation of frequencies according to a logarithmic succession (after Hay, 1970), expressed in different scales.

(Hay, 1970)	(Gartner, 1972)	(Rissatti, 1973)
100 specimens per field	impractical at 1500 X	too thick
10–100 specimens per field	4	1
1–10 specimens per field	3	0
1 specimen in 1–10 fields	2	–1
1 specimen in 10–100 fields	1	–2

This method is useful for giving a ranking of species abundances over four (or rarely five) orders of magnitude, and does not involve much counting work. The most common species are eliminated first, and so on, until only the rare ones are left.

The main objection to the above method is that it is based on the assumption of constant concentrations of nannoplankton of rather thick preparations. Often it is impossible to prepare a sequence of slides with the same concentration of specimens. The ratio of calcareous nannoplankton to other particles can vary markedly, too. For example, this is the case with our sequence of siliceous and non-siliceous sediments.

An improvement on the technique involves a method of estimating an average concentration per field, with confidence limits, and then applying the suggested logarithmic succession to multiples thereof (see Riedel and Sanfilippo, Zachariasse, and Drooger, this volume).

The limits of the possibilities for logarithmic estimates have been tested for a laminated and a non-laminated sample. In these cases, the number of specimens for a comparable traverse length is known as a result of the repeated count experiments. Thus an average concentration can be calculated per traverse length. Partly because of dilution by siliceous debris, the average concentration in the laminated sample is much less than in the non-laminated sample, as may be seen from the following table:

Laminated sample	Non-laminated sample
Slide CRP 22–2	Slide CRP 39–1
Average concentration	Average concentration
1.33/field (0.057 X 0.086 mm)	6.33/field (0.057 X 0.086 mm)
or 400 per 17.1 mm traverse length	or 2000 per 18.0 mm traverse length

As a result of experience obtained in the 200-counts, we can say that these two average concentrations represent approximate end members in the effective counting of specimens in our slides at 1250 X magnification. In addition, the times needed for the counts and estimates have been taken into consideration.

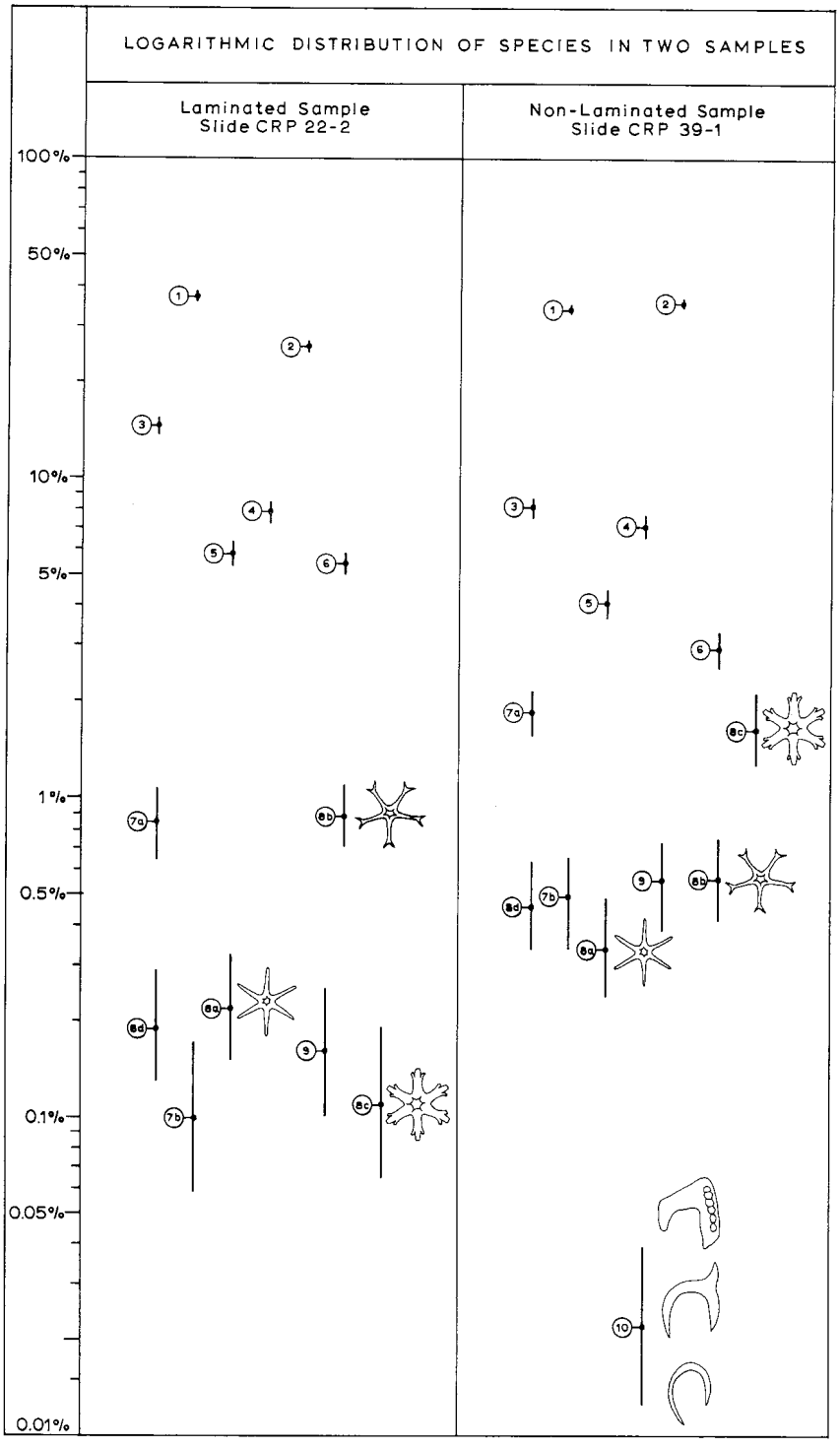
For these two samples, 10 repeated 200-counts have been performed, i.e.

a total of 2000 specimens has been counted. If 10 or more specimens of a species are present in the 2000 total, the species is not considered further in the logarithmic estimates. Amongst the rare species the abundances of individual species of *Discoaster* and *Ceratolithus/Amaurolithus* are considered in particular because of their biostratigraphic importance. In the case of sample CRP 22, specimens of *Rhabdosphaera procera* and *Scyphosphaera,* occurring with less than 10 in the 2000-counts, were also considered in the logarithmic estimates. A non-quantitative examination of the two samples CRP 22 and 39 suggested that the two samples differed in the relative frequency of *Discoaster* not only at the genus level but also at the species level. Specimens of *Discoaster brouweri, Discoaster pentaradiatus, Discoaster surculus,* and *Discoaster* sp. indet. are included in the logarithmic estimates for the two samples.

The logarithmic estimates are based on multiple counts of the standard traverse length so that the frequencies per 10,000 total of specimens can be estimated: for slide CRP 22–2, 25 × 400 specimens at a traverse length of 17.1 mm; and for slide CRP 39–1, 5 × 2000 specimens at a traverse length of 18.0 mm. Parallel traverses between 8.0 mm and 12.0 mm were consecutively searched for the above-mentioned species categories on the assumption that the average concentration remains comparable for each traverse. Distribution tables for each species category per traverse show a consistency in relative numbers comparable to that of actual counts in the repetitive count experiments including a similar random variation component.

The logarithmic frequencies of the species in the two samples are indicated in figure 7, which combines the results from the 10 repetitive 200-counts and the logarithmic estimates. Of particular interest is the added information gained by the logarithmic estimates. The species of *Discoaster* show different relative frequencies in the two samples. In the non-laminated sample CRP 39, *Discoaster surculus* is the most frequent species whereas in the laminated sample CRP 22, *Discoaster pentaradiatus* is clearly most abundant. Although the total number of *Discoaster* is much less in the laminated sample, *Discoaster pentaradiatus* has a similar frequency in the laminated sample and in the non-laminated sample. Most strikingly, *Discoaster surculus* is approximately 10 times less frequent in the laminated sample. *Discoaster brouweri,*

Fig. 7 Logarithmic distribution of species in two slides from a laminated and a non-laminated sample, slides CRP 22–2 and CRP 39–1, respectively. Traverse lengths of 10 repeated 200-counts were used to establish the average concentrations on the slides and the standard error. Vertical bars for each species represent the standard errors at the 68% confidence level (see M. M. Drooger, this volume).


LOGARITHMIC DISTRIBUTION OF SPECIES IN TWO SAMPLES
Laminated Sample
Slide CRP 22-2
Non-Laminated Sample
Slide CRP 39-1
100%
50%
10%
5%
1%
0.5%
0.1%
0.05%
0.01%
1
2
3
4
5
6
7a
7b
8a
8b
8c
8d
9
10

Discoaster sp. indet., *Rhabdosphaera procera* and *Scyphosphaera* seem to be less frequent in the laminated sample.

Species of *Ceratolithus/Amaurolithus,* a lineage most important to the zonation, are extremely rare in all Capo Rossello samples. During routine inspection, sample CRP 39 was found to contain several specimens. In searching traverses to the 50,000 estimate level, 11 specimens were found, including only one specimen of the index species *Ceratolithus acutus.*

SELECTIVE FILTERS

An important factor in interpreting calcareous nannoplankton data involves the effects of various filters operating on an assemblage from the time of its production in the photic zone to its recovery from the sediment. It is essential to have an understanding of the oceanographic factors that alter the living community on its way to the bottom. One needs to know how well the death community (thanatocoenosis) represents the living community (biocoenosis). Post-depositional filters can further alter assemblages and their effect will be incorporated in the counts.

Oceanographic filters

Studies of Recent coccolithophore assemblages indicate that only about one-third of all living species have sufficiently calcified elements to be preserved (e.g. McIntyre and Bé, 1967; Honjo and Okado, 1974). These fossilizable species have various structural potentials which determine their chance for preservation through the water column, at the sediment/water interface, and during post-depositional diagenesis. An important factor is how the tiny coccolith makes its way from the photic zone to the bottom. It is now considered as highly likely that the majority of specimens arrive at the bottom via the "rapid fecal pellet" route (Honjo, 1975, 1976; Roth et al., 1975). Sampling throughout the water column gives a fairly representative picture of the assemblages in the photic zone (Honjo, 1975). This is attributed to the "spilling out" of fresh coccoliths from disintegrating fecal pellets. Since coccoliths are apparently indiscriminately grazed by copepods, and presumably by other zooplankton, fairly representative sample "subsets" reach the bottom.

Alteration of nannoplankton assemblages begins in waters undersaturated in calcium carbonate. The concentration is determined by various oceanographic factors such as temperature, salinity, and circulation patterns. The coccolith lysocline is rather broad in comparison to that for planktonic

foraminifera. Generally changes in composition of coccolith assemblages occur between 3000 and 5000 m (Berger, 1973; Schneidermann, 1973; Roth and Berger, 1975). Even though the assemblages are strongly altered, the calcium carbonate compensation depth for calcareous nannoplankton is still below that for planktonic foraminifera (Hay, 1970; Schneidermann, 1973).

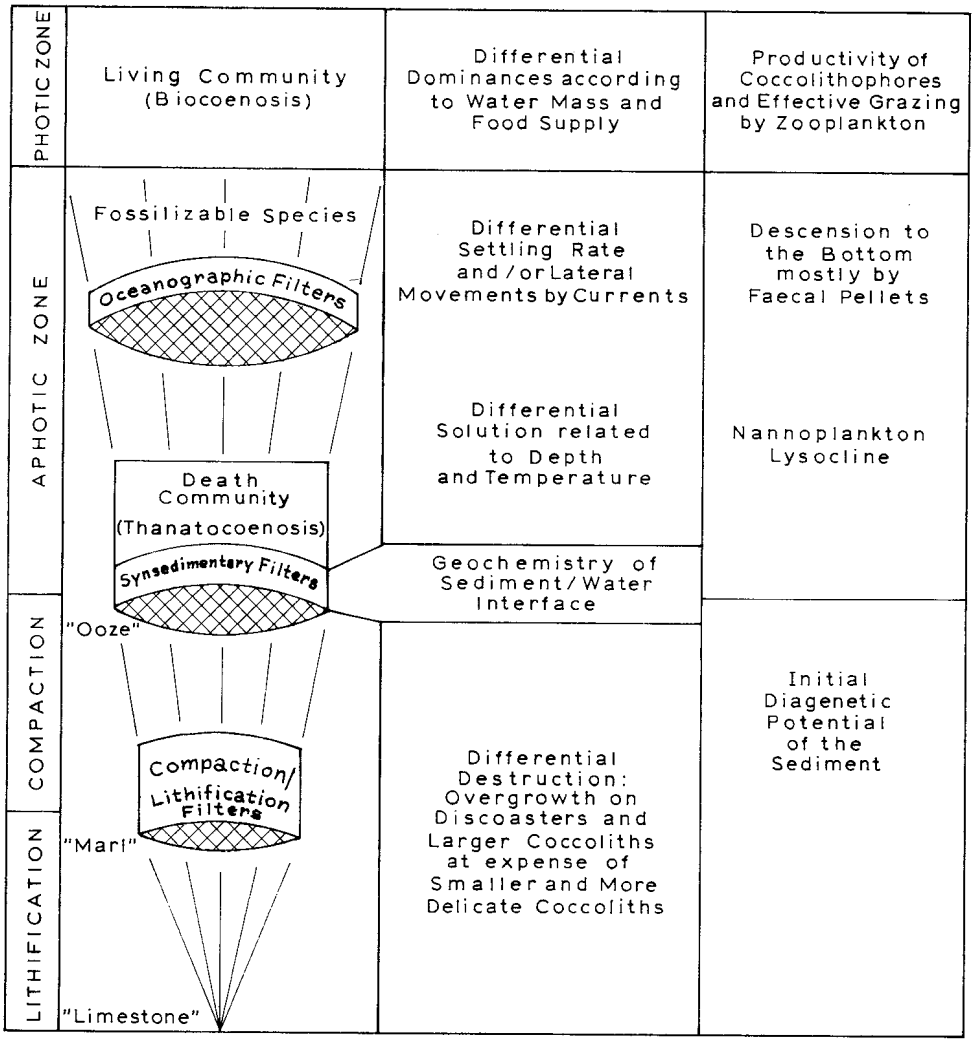


Fig. 8 Schematic diagram illustrating consecutive filters altering original nannoplankton communities, as compiled from various literature sources cited in the text.

Synsedimentary and diagenetic filters

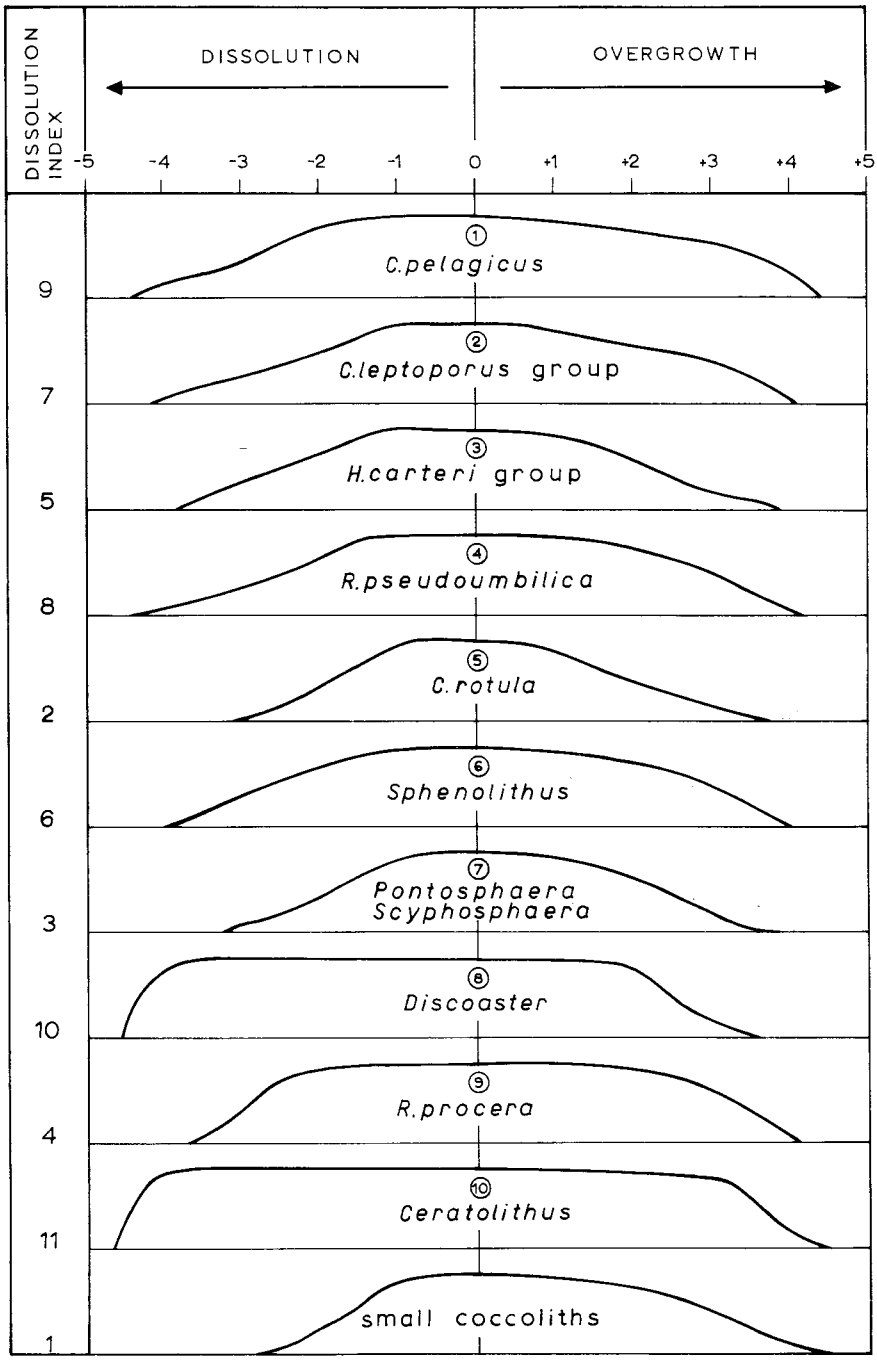
Dissolution of coccoliths is normally accentuated at the sediment/water interface, depending upon various geochemical factors, productivity and sedimentation rate, and the action of burrowers. The fecal pellets of the rapidly arriving supply disintegrate, releasing the coccoliths which are then acted upon by the synsedimentary filters. Further alteration occurs after burial in the compaction/lithification process, the direction of which is pre-determined by the "initial diagenetic potential" in the synsedimentary process, as discussed above (Schlanger and Douglas, 1973). Particularly sediments with a high carbonate content undergo selective solution and reprecipitation in the compaction/lithification process (figure 8). Smaller and more delicate coccoliths are amongst the first particles to become disaggregated to provide the carbonate for precipitation on larger coccoliths and discoasters (Adelseck et al., 1973). As the process continues the discoasters become so overgrown that they cannot be recognized at the species level anymore and only structurally strong coccoliths remain identifiable.

Preservation index

Relative counts can be greatly influenced by preservational factors. Some measure of the state of preservation must be taken into consideration before interpretations can be made. Bukry (1973b) has presented a convenient preservation scale based on many qualitative observations. Each value on the scale has its features of dissolution (0 to −5) or its features of overgrowth (0 to +5). This scale is useful for giving an impression of the total floral assemblage; in detail, overgrowth involves dissolution in the same assemblage.

Figure 9 is an attempt to rank the effects of dissolution and overgrowth on the 11 species categories counted in relation to "identifiability" in the light microscope. The samples analyzed from the Trubi are judged to range from +2 to +3.5 on the overgrowth side of the scale. It has been noted that increasing dissolution removes the more delicate "warm" species, so the assemblage suggests a "colder" aspect than it really has (Schneidermann,

Fig. 9 Estimation of the effects of dissolution and overgrowth on the species or genus categories counted in relation to the "Qualitative Preservation Scale" of Bukry (1973b). On the left side, the "Dissolution Index" gives an approximate ranking in the order of first dissolved to last dissolved (after Roth and Berger, 1975). The height of the strip is an approximation of the relative "identifiability" of the various genus and species categories as dissolution (0 to −5) and overgrowth (0 to +5) increase. The moderately overgrown samples from the 8-meter section of the Trubi range between +2 and +3.5 on the scale presented.


DISSOLUTION INDEX
DISSOLUTION
OVERGROWTH
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
9
7
5
8
2
6
3
10
4
11
1
① C.pelagicus
② C.leptoporus group
③ H.carteri group
④ R.pseudoumbilica
⑤ C.rotula
⑥ Sphenolithus
⑦ Pontosphaera Scyphosphaera
⑧ Discoaster
⑨ R.procera
⑩ Ceratolithus
small coccoliths

1973). In the same vein, it is considered likely that the analyzed section gives a "colder" picture than a better preserved section would show with the same original species composition.

PALEOECOLOGICAL SUMMARY

The section chosen for this study makes possible an experiment between laminated sediments (15 samples) and non-laminated sediments (19 samples). Correlation of species groups that increase or decrease with this change in lithology are not clear in this section. More of a correlation seems evident between siliceous-rich sediments and non-siliceous sediments. If the siliceous-rich sediments represent times of higher productivity, probably times of upwelling, the following changes in the nannoplankton are suggested with this phenomenon: an increase in the *Helicosphaera carteri* group, an increase in the genus *Sphenolithus,* and a decrease in the genus *Discoaster.* In the Pacific Ocean, *Helicosphaera carteri* occurs in greater percentages in gyre margin waters with higher fertility (Roth and Berger, 1975, p. 101). The genera *Discoaster* and *Sphenolithus* are now extinct so that no Recent comparisons can be made. However, *Discoaster* occurs in greater abundance in tropical localities (Bukry, 1973b) and is generally considered a "warm-water" indicator. The above-mentioned suggestion of higher fertility and lower temperature (upwelling?) for the siliceous-rich, laminated sediments may be considered as a working model to be tested in other sections.

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