

Agglutinated Foraminifera from Neritic to Bathyal Facies in the Palaeogene of Spitsbergen and the Barents Sea

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ABSTRACT

Late Palaeocene to Early Eocene foraminiferal assemblages have been analysed from an exploratory well (7119/7-1) drilled in the Tromsø Basin (southwestern Barents Sea) and from two onshore sections, Basilikaelva and Kovalskifjella, exposed in the Central Tertiary Basin of Spitsbergen. The assemblages reveal marked differences in taxonomic composition and diversity, reflecting inner neritic to middle bathyal conditions. Within this depth range, four foraminiferal biofacies (FB) are distinguished:

FB 1 occurs in the Kolthoffberget Member (of the Firkanten Formation, Late Palaeocene) sampled in the Basilikaelva section. The member consists of interbedded shales, siltstones and sandstones deposited in a transitional delta front - prodelta environment, according to current sedimentological interpretation. The foraminiferal assemblages are entirely agglutinated, show extremely low species diversities and strong dominance of *Reticulophragmium arcticum* followed by *Labrospira* aff. *turbida*.

FB 2 is recognised in the Basilika Formation (Late Palaeocene) exposed in the Kovalskifjella section. The formation consists of silty claystones deposited in a prodelta shelf setting. The foraminiferal assemblages show an increased species diversity, and consist mainly of agglutinated taxa with a strongly subordinate calcareous component. The two most abundant species are *R. arcticum* and *L. aff. turbida*. Species of *Verneuilinoides* and *Trochammina* occur in significant numbers while tubular taxa are rare.

FB 3 is found in the Lower Eocene clay interval composing the upper part of the Torsk Formation in well 7119/7-1. It contains entirely agglutinated assemblages with comparatively high diversities. The dominant species are *Recurvoides* aff. *turbinatus* and *Budashevaella multicamerata*, while *Reticulophragmium amplexans* is typical and common in these strata. Tubular forms referred to *Rhizammina* occur locally in significant quantities. The diversity and composition of the assemblages suggest an outer neritic to upper bathyal environment.

FB 4 is developed in Palaeocene claystones comprising the lower part of the Torsk Formation in well 7119/7-1. In this interval the species diversity, as well as the frequency of tubular forms (referred to *Rhizammina*, *Bathysiphon* and *Hyperammina*) attains maximum values. Other common to dominant taxa include *Spiroplectammina spectabilis*, *Haplophragmoides walteri*, *Ammosphaeroidina pseudopauciloculata*, and *Recurvoides* sp. These wholly agglutinated assemblages are interpreted as reflecting upper to middle bathyal conditions.

INTRODUCTION

This paper is part of a long-term project dealing with Palaeocene foraminiferal biostratigraphy and palaeoecology in the southwestern Barents Sea. The assemblages of the area consist of agglutinated taxa, and are attributed to deep water, probably middle bathyal environments (Nagy *et al.*, 1997). The interpretations are partly based on analogies with contemporary assemblages of the Mid-Norwegian

Shelf (Haltenbanken) and the North Sea Basin, which were studied by Gradstein *et al.* (1994) and Gradstein & Bäckström (1996). Further information about palaeobathymetry are obtained from comparisons with Alpine and Carpathian flysch assemblages, as well as from analogies with modern deep water faunas.

In this study, the Palaeogene deep water assemblages of the Barents Sea are quantitatively compared

with their high latitude shallow water equivalents sampled in surface exposures on Spitsbergen. The neritic depositional environments of the latter area, are constrained by published sedimentological interpretations. By combining lithological parameters and faunal data, this paper aims to elucidate the controlling effect of various facies on high latitude, shallow to deep water foraminiferal assemblages.

REGIONAL AND STRATIGRAPHIC SETTINGS

In the Barents Sea region, the main areas of Palaeogene sedimentation are the Central Basin of Spitsbergen and the southwestern part of the Barents Sea (Figure 1). The Central Basin occupies most of middle and southern Spitsbergen, but outliers are preserved also along the western coast at Kongsfjorden and Øyrlandet. In the southwestern Barents Sea, Palaeogene deposits are recorded from the Tromsø, Hammerfest and Bjørnøya basins, from the Stappen High, and from a belt along the continental margin south-west of Bjørnøya. The possible presence of Palaeogene strata in the Sørkapp Basin is mentioned by Nøttvedt *et al.* (1992).

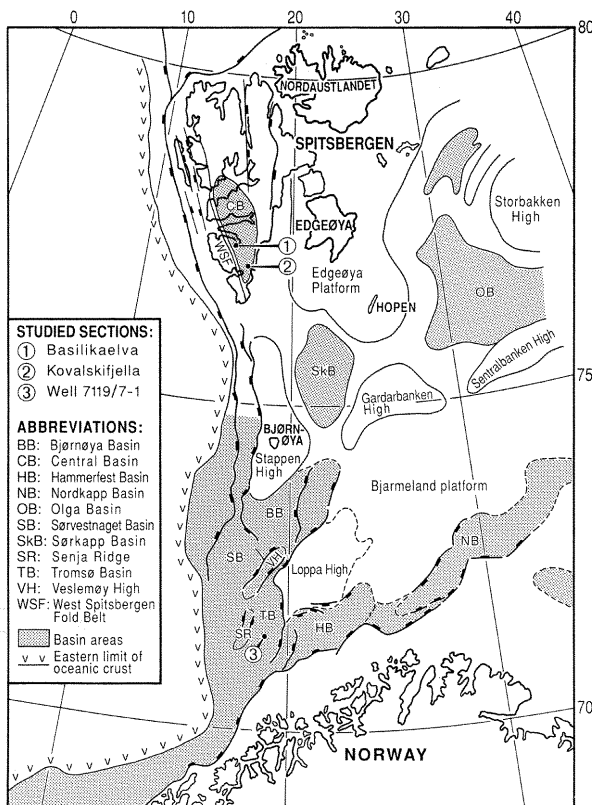


Figure 1. Map of the western Barents Sea with Spitsbergen, showing sedimentary basins, platform areas and highs. The location of the studied sections are also indicated.

In the Western Barents Sea region, Palaeogene sedimentation was controlled by tectonic events along the Greenland-Barents Sea plate boundary. During Late Cretaceous to Early Palaeocene times, local and regional erosion of Cretaceous and older

strata took place along the plate margins. This was followed by a broad subsidence and extensive marine transgression initiating a period of Palaeogene sedimentation. The succession formed during this period consists of mixed fluvio-deltaic and marine clastics on Spitsbergen, and marine shales in the southwestern Barents Sea basins.

In the Central Basin of Spitsbergen, the Palaeocene to Eocene succession of claystones, siltstones and sandstones attains an aggregate thickness of 2000 m, which is subdivided into seven formations (Figure 2). The basal beds of assumed Early Palaeocene age, rest unconformably on Early Cretaceous strata. The main body of the Palaeogene succession was deposited in various shelfal to marginal marine environments; non-marine, coal-bearing strata occur in the lowermost, middle and upper parts. The top of the succession has been truncated by Quaternary erosion, and is probably not younger than Eocene (Manum & Throndsen, 1986).

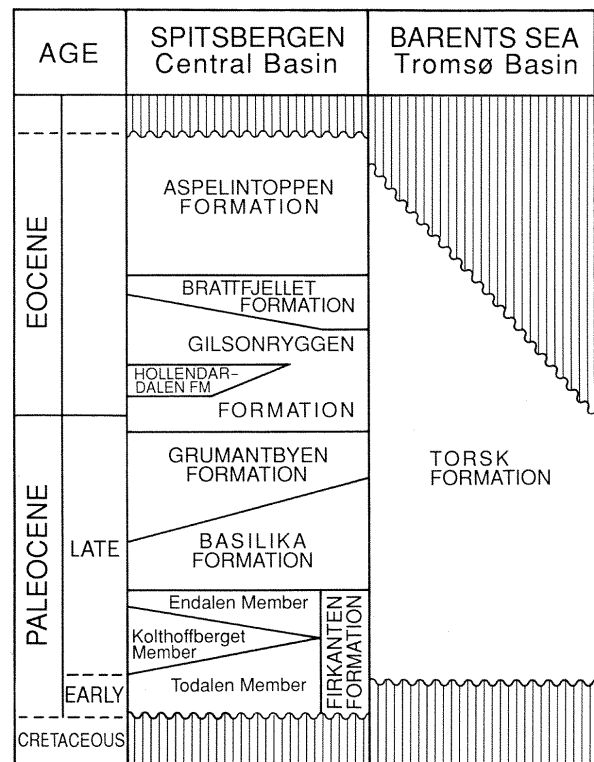


Figure 2. Lithostratigraphic scheme of Palaeogene deposits of Spitsbergen (Central Basin) and the southwestern Barents Sea.

In the Tromsø and Hammerfest Basins, the Palaeogene is composed of marine shales of the Torsk Formation which attain a maximum thickness of 1400 m. Its basal beds are of early to late Palaeocene age, and unconformably overlie Upper Cretaceous strata most commonly of Turonian or Senonian age. The top of the Torsk Formation is cut by an erosional unconformity, and is overlain by Plio-Pleistocene sediments.

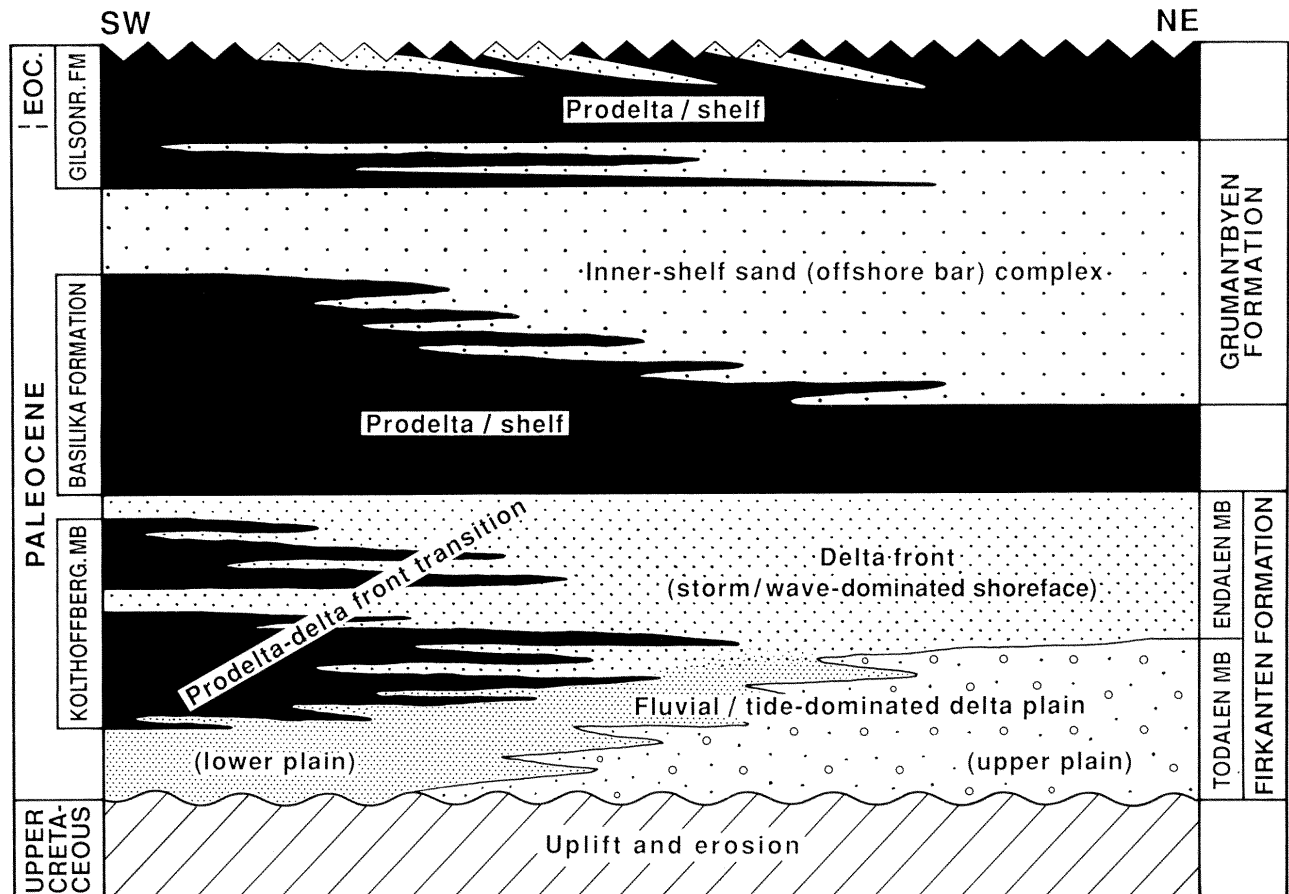


Figure 3. Outline palaeoenvironmental interpretation of the lower formations of the Palaeogene succession in the Central Basin of Spitsbergen. (Based on Steel *et al.*, 1981 and 1985.)

The samples analysed for foraminifera in this study originate from the following strata and localities (Figures 1 & 2): The Kolthoffberget Member of the Firkanten Formation sampled in the Basiliikaelva section exposed in the Central Basin; the Basiliika Formation sampled in the Kovalskifjella section located also in the Central Basin; the Torsk Formation sampled in a commercial exploratory well, nr. 7119/7-1, drilled at a water depth of 238 m in the Tromsø Basin.

In well 7119/7-1, the top and base of the Torsk Formation were penetrated at a depth of 450 m, and 1350 m, respectively. The interval from 620 to 950 m yielded only low numbers of foraminifera, insufficient for quantitative comparisons. Therefore, this part of the formation is omitted from closer treatment. It must be noted here that the interval is strongly tectonised, as indicated by Eidvin *et al.* (1993).

MATERIAL AND METHODS

The foraminiferal samples were collected from fresh surface exposures in the Basiliikaelva and Kovalskifjella sections, while the material from well 7119/7-1 consisted of ditch cuttings. The dry weight of the sediment processed for foraminifera was 100 g in the surface samples, but varied from 40 to 100 g in the cutting samples.

The sediment was disintegrated by means of the kerosene method (Nagy & Johansen, 1991), involving boiling in sodium hydroxide (NaOH). The >125 μm fraction was used for foraminiferal analyses. Tests were hand picked and mounted onto cardboard slides. From samples containing enough foraminifera, ca. 300 specimens were picked, but many samples contained fewer specimens.

The alpha index (Fisher *et al.*, 1943) was used to express species diversity because it facilitates comparison of samples of varying sizes. Dominance is defined as the percentage of the most common species. The abundance is the number of specimens per gram of sediment. For a quantitative discrimination of the various biofacies, a cluster analysis was performed using the program CONISS (Grimm, 1987), facilitating faunal comparison of samples in a stratigraphically fixed succession. To facilitate graphic presentation of the results, only each second sample was included in the cluster analysis from the lower Torsk Formation.

SEDIMENTARY FACIES

Firkanten Formation, Kolthoffberget Member

The Firkanten Formation attains a maximum thickness of 200 m, and is widely exposed along the flanks of the Central Basin of Spitsbergen. In northern and northeastern areas, the Firkanten Formation is

bipartite (Figure 3): the lower Todalen Member consists of shales, siltstones and sandstones with coal seams, and was deposited in wave- and tide-dominated delta plane environments (Steel *et al.*, 1981); the upper Endalen Member consists of sheet sands of delta front and barrier bar origin.

In southern and southwestern reaches of the Central Basin, the delta front sheet sands of the Todalen Member split and are replaced by the finer grained lithologies of the Kolthoffberget Member which approaches 100 m in thickness in distal areas. The main lithologies of the Kolthoffberget are highly bioturbated claystones, siltstones and fine-grained sandstones deposited in transitional environments between delta front and prodelta (Steel *et al.*, 1981). The Kolthoffberget Member shows a cyclicity of repeated coarsening-upward parasequences, where each unit begins in dark silty claystone and ends in organic-rich siltstone, or poorly sorted, very fine-grained sandstone. This cyclicity has probably resulted from recurrent lateral shifting of delta lobes.

In the Basilikaelva section (Figure 4), the Kolthoffberget Member rests on shoreface sandstones (containing numerous *Ophiomorpha* burrows) which form the uppermost part of the Todalen Member. The lower 20 m of the Kolthoffberget Member reveals two coarsening upwards parasequences representing delta front progradations into a prodelta environment. Both parasequences begin with claystone, and the lower one terminates with sandy siltstone at 10 m, whereas the upper one is capped with fine-grained sandstone at 19 m. The calcium carbonate content of the Kolthoffberget Member is low (average 0.4%, range 0.0-1.6%) in accordance with the deltaic nature of its facies. The organic carbon content seems rather high (average 1.4%, range 0.8-1.9%), considering the relatively coarse grain-size of this unit.

Basilika Formation

The Basilika Formation varies in thickness from c. 20 m in the northeastern part of the Central Basin to 300 m in the south and southwest. It is predominantly composed of dark-grey claystones, tending to be siltier and sandier towards the north-east. Thin bentonite beds interpreted as altered volcanic ash (Dypvik & Nagy 1979) characterise the unit. The Basilika claystones are interpreted as prodelta to prodelta shelf deposits, more distal in nature than any of the underlying Palaeocene strata (Steel *et al.*, 1981).

Deposition of the Basilika Formation was initiated by a transgression, which introduced shelfal mud facies directly overlying the delta front Firkanten sandstones (Figure 3). The Basilika claystones are rather homogeneous in the lower and middle part of the formation. In the upper part, the silt and sand content increases upwards, distinct siltstone and sandstone beds appear, and uppermost the finer-grained lithologies are replaced by strongly bioturbated sandstones. The sand-dominated lithologies are referred to the Gromantbyen

Formation, interpreted as a prograding inner shelf (offshore bar) sand complex (Steel *et al.*, 1981).

The 178 m thick package of Basilika claystones sampled in the Kovalskifjella section belongs to the lower and middle, homogeneous part of the formation (Figure 4). The claystones are generally fine-grained through the section, showing an average sand content of 2.4% with a maximum of 7.8% in the lower part and 9.7% in the upper part. The calcium carbonate content averages 0.9% with a maximum of 7.0% in the lower part of the section. The organic carbon content averages 1.2% with little variability (range 1.0-1.5%). Two beds of bentonite, 7 and 25 cm thick, are observed.

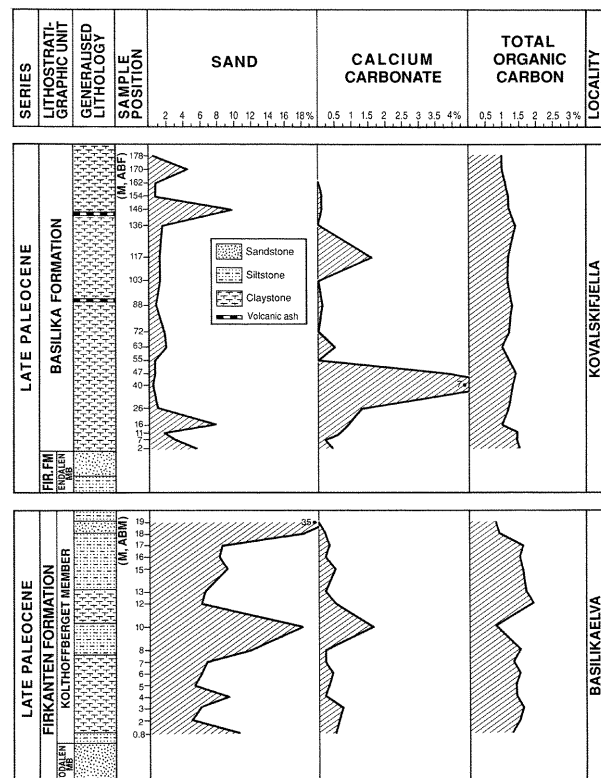


Figure 4. Sedimentary features of the Kolthoffberget Member (Firkanten Formation) sampled at Basilikaelva, and of the Basilika Formation sampled at Kovalskifjella. (ABF=above base of formation.)

Torsk Formation (upper part)

From the upper part of the Torsk Formation in well 7119/7-1, the interval 490-610 m is included in the quantitative faunal analysis. This interval is a homogeneous succession of marine clays, having an average sand content of 3.1% (range 0.4-8.1%) (Figure 5). The calcium carbonate content is low, with an average of 1.2% (range 0.0-5.0%). The organic carbon content is 0.9% on average (range 0.4-1.4%). The age of the interval is Early Eocene based on palynological evidence (K. Johnsen, written comm.).

Torsk Formation (lower part)

The interval of detailed foraminiferal analysis in the lower part of the Torsk Formation starts at 960m and extends to the basal unconformity forming the lower boundary at 1,350 m (Figure 5). Based on palynological evidence, the succession from 620 to 1,320 m is referred to the Late Palaeocene. From 1,320 m and down to the basal unconformity Lower Palaeocene strata are recorded. These rest on Maastrichtian sediments belonging to the Kvitings Formation.

The dominant lithologies of the lower Torsk Formation are light grey and greenish grey claystones with scattered carbonate and silty horizons. The sand content varies around an average of 6.3% and attains a maximum of 37% at 1,270 m (Figure 5). From 990 to 1,260 m, the calcium carbonate content is rather evenly distributed around 1%. Above and below this interval, higher values are present at several distinctive horizons, and probably represent thin limestone/dolomite stringers. The organic carbon content is relatively low and monotonous, averaging 0.8%.

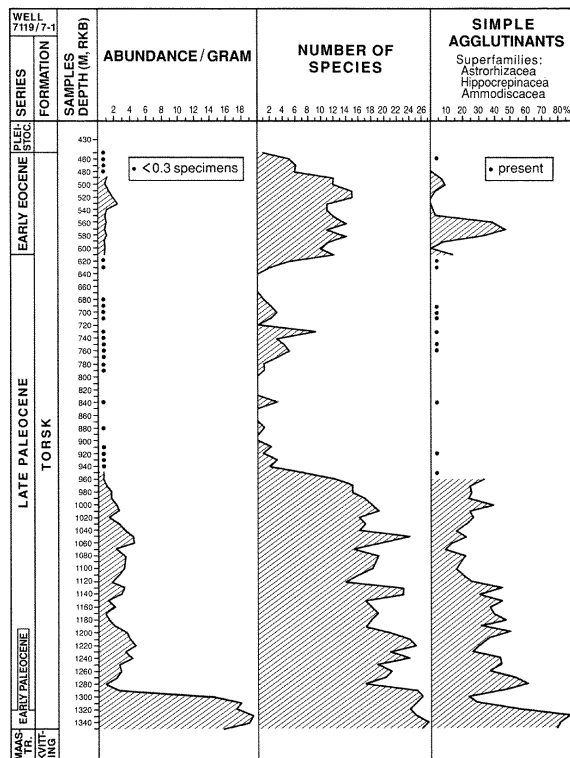


Figure 5. Sedimentary features of the Torsk Formation in Barents Sea well 7119/7-1 located in the Tromsø Basin. (RKB=below rotary kelly bushing.)

FORAMINIFERAL BIOFACIES

Main distributional trends

The four analysed sections reveal marked differences both in major faunal features (Figures 6 to 10), and the distribution of species (Figures 11 to 14). Differences in species composition are displayed by the dendrogram shown in Figure 8. The four faunal units defined are designated as foraminiferal biofacies (FB) 1 to 4, discussed in greater detail on the following pages. The distribution of genera and alpha

diversity in this biofacies model are shown in Figure 9, where it is apparent that the diversity increases with increasing water depth of the environment.

The frequency of deep water taxa and alpha index are positively correlated, and reflect the bathymetric succession of the four facies as shown in Figure 10. For calculating the plots shown in this illustration the following taxa were considered as typical for deep water: *Rhizammina* spp., *Bathysiphon* spp., *Jaculella* sp., *Hyperammina rugosa*, *Hyperammina* sp., *Kalamopsis grzybowskii*, *Psammosphaera fusca*, *P. scruposa*, *Saccammina grzybowskii*, *S. sphaerica*, *S. placenta*, *Glomospira irregularis*, *Repmanina charoides*, *Rzehakina epigona*, *Aschemocella grandis*, *Paratrochamminoides mitratus*, *P. olszewski*, *Eratidus* sp., *Pseudobolivina lagenaria*, *Ammosphaeroidina pseudopauciloculata*, *Ammospheroidina* sp., *Ammomarginulina* sp., *Cystammina* spp., *Spiroplectammina spectabilis*, *Karrerulina conversa*, *K. horrida*, *Caudammina ovula*, and *C. excelsa*.

FB 1. Inner neritic facies: delta front-prodelta

This facies occurs in the Kolthoffberget Member sampled in the Basiliakelva section. It contains exclusively agglutinated foraminifera (Figure 6). The shallow, marginal marine nature of the facies is expressed by extremely low diversity and high dominance: the average alpha index is 1.9 (range 1.0-2.5); the average dominance is 72% (ranges 52-90%). Deep water species occur only in a few samples at very low numbers (Figure 10). The abundance is strongly reduced (average 1.9 specimens in gram sediment), which can be explained by the delta front-prodelta setting, with associated high sedimentation rates.

The dominant species is *Reticulophragmium arcticum*, forming populations of large-sized specimens. Relatively common taxa include *Labrospira turbida* (a typically coarse-grained species), *Crithionina* sp., *Verneulinoides polystrophus*, *Psammosphaera scruposa*, and *P. trinitatisensis*. The assemblages show a very homogeneous composition throughout the analysed interval (Figure 11).

The two robust *Reticulophragmium* species, *R. arcticum* and *R. borealis*, were originally described by Petracca (1972) from the lower part of the Upper Palaeocene of the Beaufort-Mackenzie Basin (Arctic North America). In Spitsbergen, these species compose a plexus of interrelated forms showing a wide range of variation. The quantitatively dominant morphologies, however, most closely resemble *R. arcticum* and therefore, this name is preferred in the present paper.

In the Upper Palaeocene of the Beaufort-Mackenzie Basin, monospecific assemblages of *Reticulophragmium borealis* are typical for shallow water biofacies (McNeil, 1989). In the same basin *Labrospira turbida* is an important marker for delta front facies (Schröder-Adams & McNeil, 1994). Both observations are in accordance with the environmental interpretation put forward here.

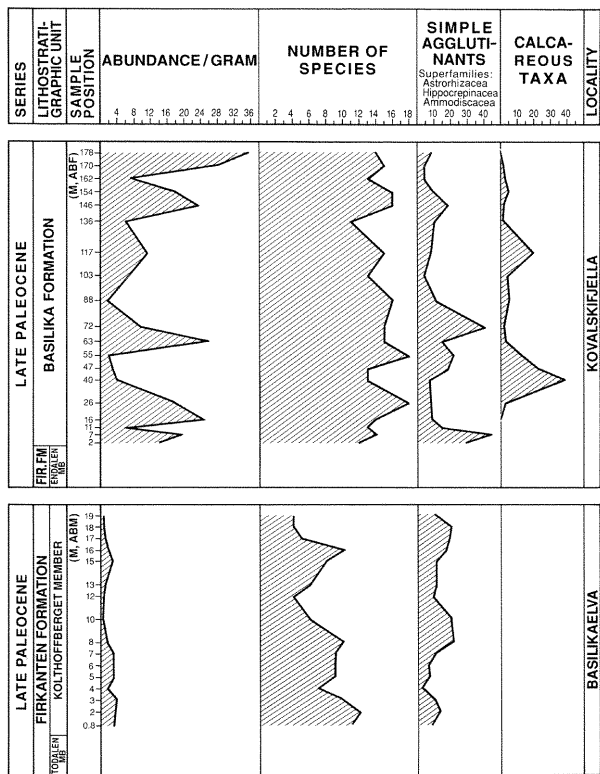


Figure 6. Main faunal parameters of the Kolthoffberget Member (Firkanten Formation) in the Basilikaelva section and of the Basilika Formation, in the Kovalskifjella section. The amount of calcareous taxa is given in percent of total fauna.

FB 2. Middle neritic facies: prodelta-shelf

The assemblages occurring in the prodelta shelf mud complex of the Basilika Formation are essentially agglutinated, but contain also a subordinate calcareous component. In the Kovalskifjella section (Figure 6) the alpha diversity is on average 3.2 (range 2.2-4.2). Calcareous taxa occur in 14 (from a total of 19) samples composing on average 6% (with a maximum of 38%) of the fauna.

The dominant species are *Labrospira* aff. *turbida*, followed by *Reticulophragmium arcticum* (Figure 12). Common species include: *Verneuilioides subeoceanus*, *Trochammina mellariolum*, *Psammosphaera eocenica*, *P. scruposa*, and *Glomospirella* sp. 1. Among the calcareous taxa, *Nonion* aff. *insolitum* and *Eponides* aff. *iojamaensis* are most common.

In the Basilika Formation both the number of species (Figure 6) and the alpha diversity (Figure 9) are higher in comparison to values in the Kolthoffberget Member. The increased diversity and presence of a minor calcareous faunal component suggest that the depositional environment of the Basilika Formation was closer to a normal marine shelf setting than the environment of the Kolthoffberget Member. The significantly more fine-grained nature of the Basilika shales (Figure 4) is also in accordance with a more distal position relative to the deltaic source. The dominance of *Labrospira* aff.

turbida and *Reticulophragmium arcticum* shows similarities in biofacies with strata in the Beaufort-Mackenzie Basin.

Foraminiferal faunas of modern normal marine shelves are dominated by calcareous taxa, and have alpha diversities higher than 5 (Murray, 1973). The marked reduction of these parameters in the Basilika assemblages indicate that the environment was of a restricted type, although the restricting factors are difficult to identify with certainty.

Restricted conditions may be due to the partly isolated nature of the Arctic Ocean in Palaeocene-Eocene times, combined with the effects of local environmental conditions in the sedimentary basin. The development of predominantly agglutinated assemblages and their endemic nature in the Palaeocene-Eocene of the Beaufort-Mackenzie Basin are explained by the absence of deep water marine communication between the Arctic Ocean and other oceanic areas (McNeil, 1990). This restriction seems to have strongly affected the neritic assemblages of the northernmost extensions of the North Atlantic seaway as exemplified by the Basilika Formation on Spitsbergen. In contrast, coeval bathyal assemblages of the southwestern Barents Sea are of cosmopolitan character (Nagy *et al.*, 1997), and consequently, they indicate that the deep water circulation in that area, was in open communication with the world ocean.

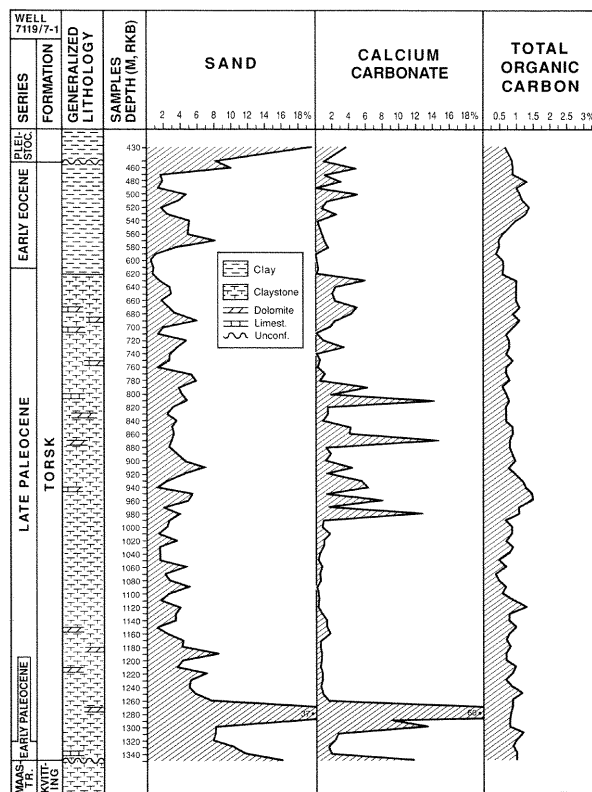


Figure 7. Main faunal parameters of the Torsk Formation in well 7119/7-1.

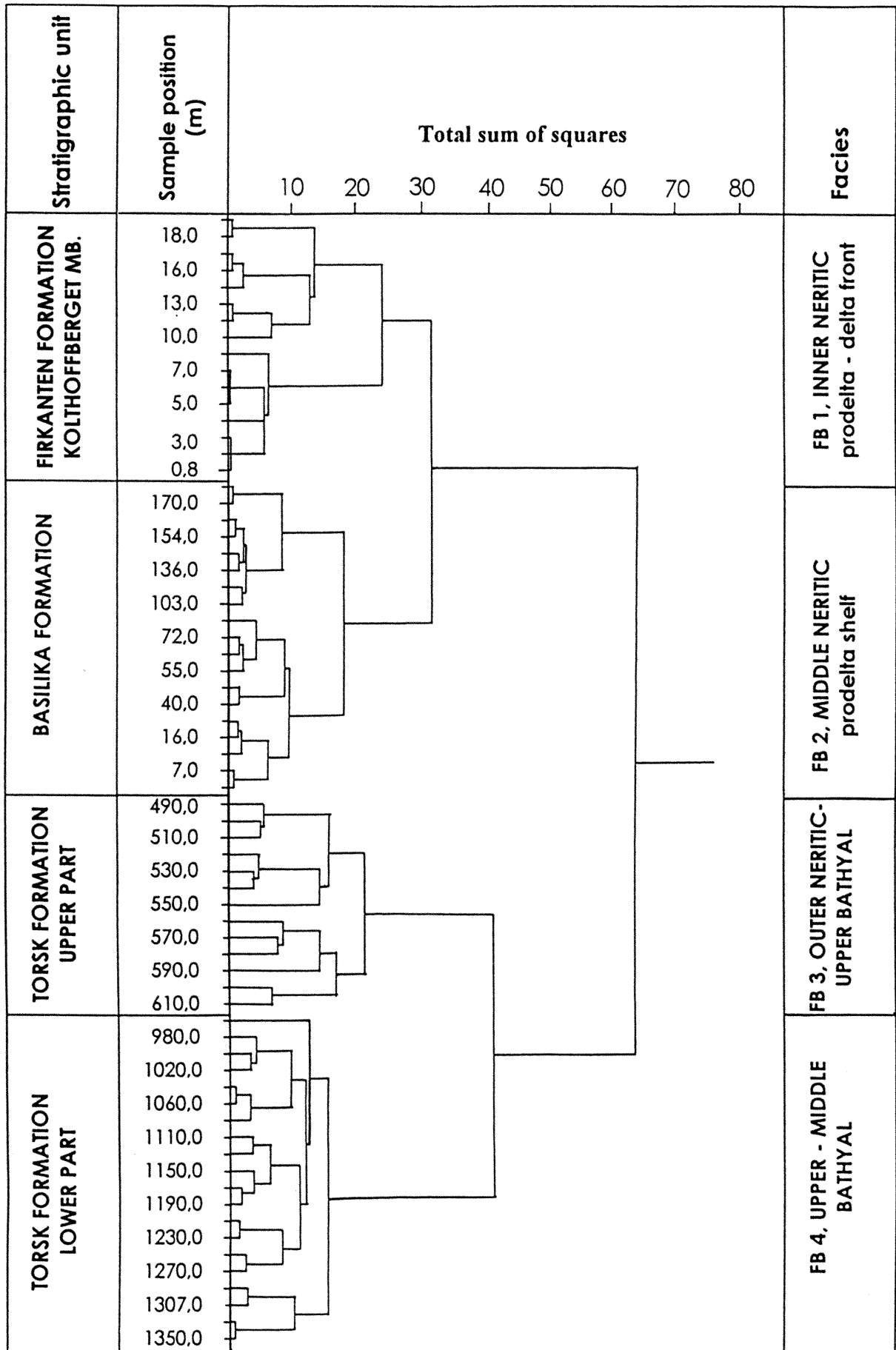


Figure 8. Dendrogram delineating the four foraminiferal biofacies recognised in the study. The data base is the percentage frequency of the species. (Only each second sample is marked by number)

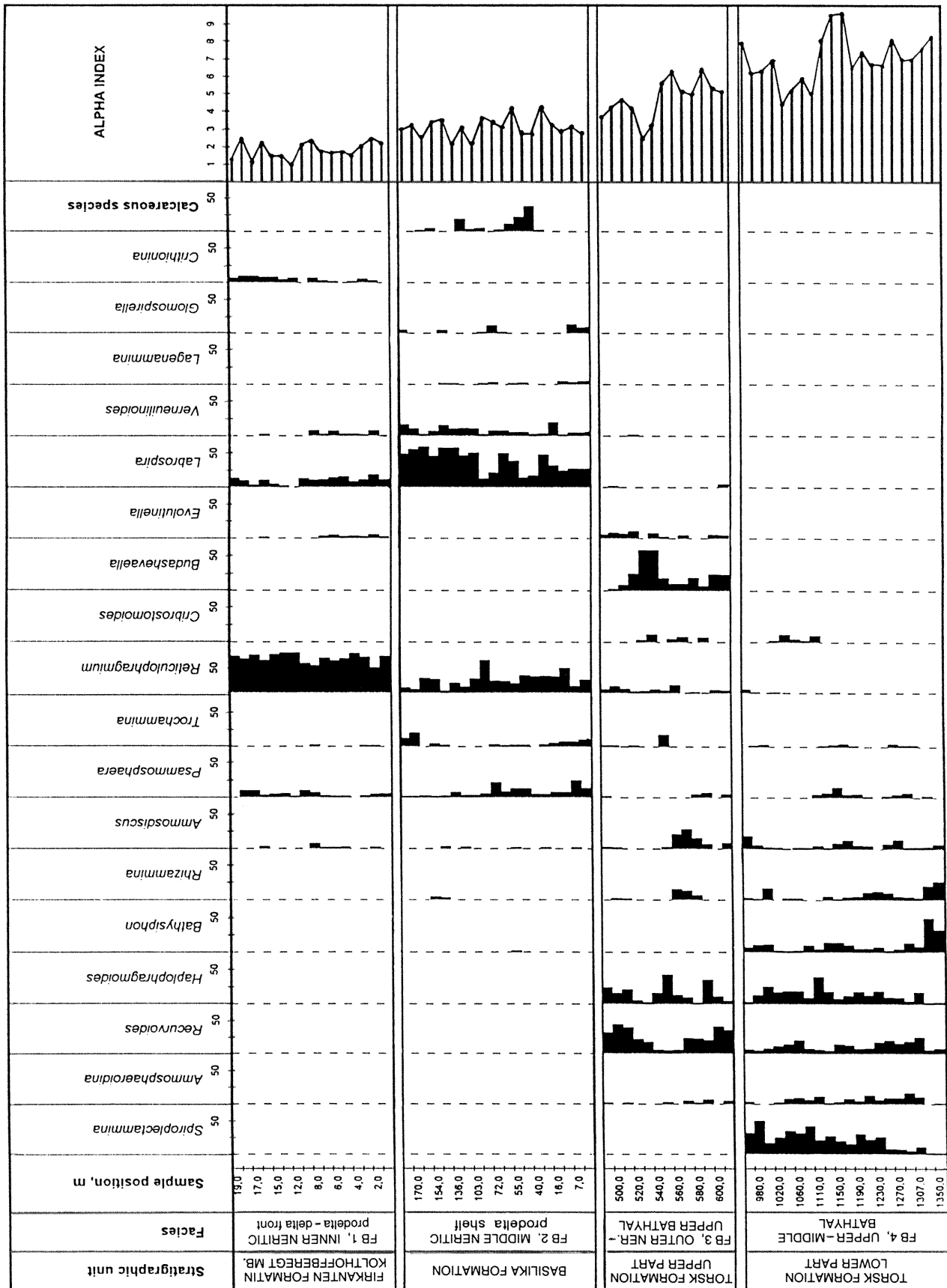


Figure 9. Percentage distribution of common foraminiferal genera and the alpha diversity of the four foraminiferal biofacies (FB) recognized. (Only each second sample is marked by number).

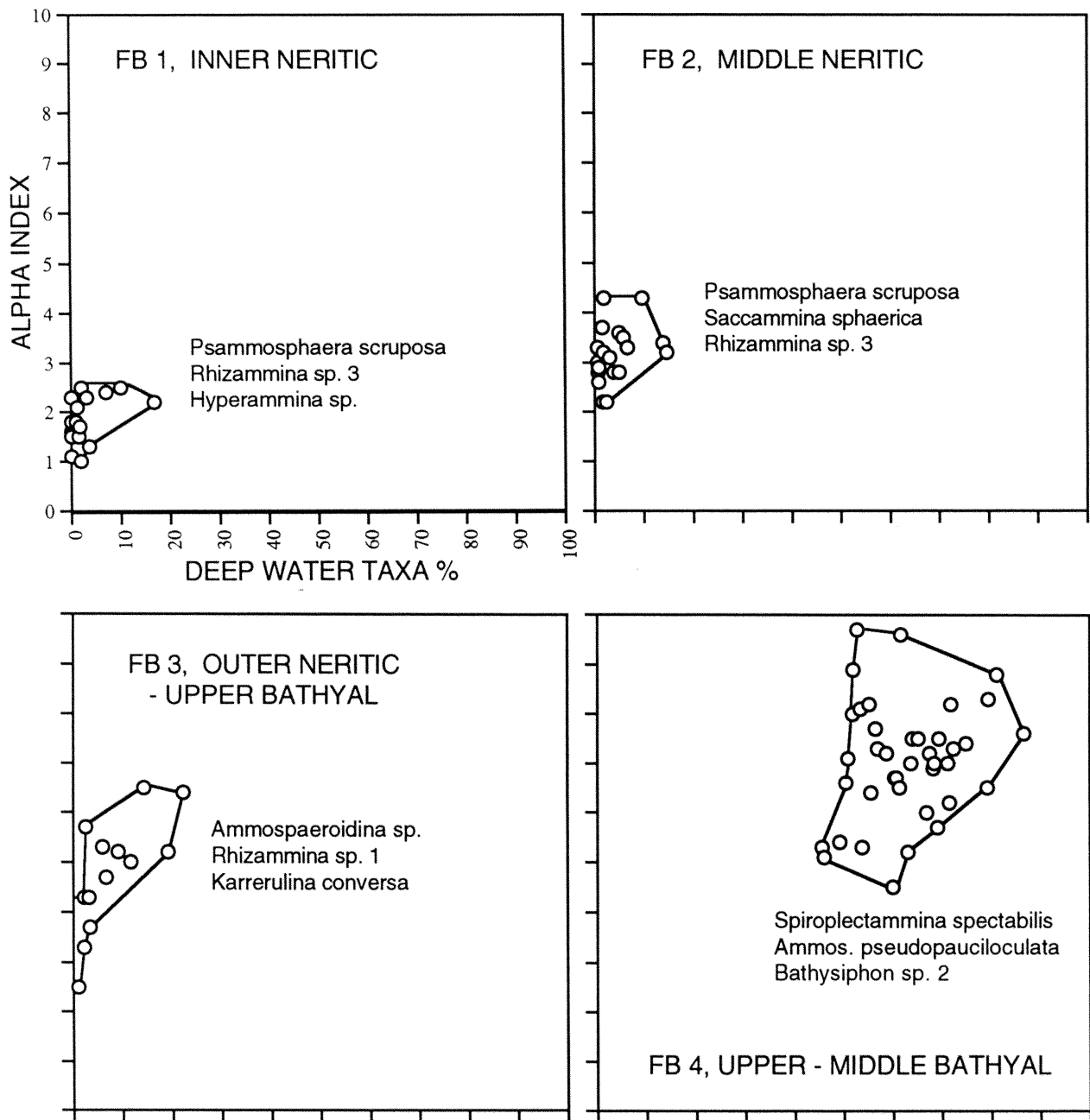


Figure 10. Frequency of deep water taxa plotted against alpha diversity in the four foraminiferal biofacies recognised. In each biofacies the three most common deep-water species are indicated.

FB 3. Outer neritic-upper bathyal facies

The claystones composing the upper part of the Torsk Formation in the 7119/7-1 well contain agglutinated assemblages with moderate levels of abundance and diversity (Figure 7). The alpha diversity is 4.8 on average and varies between 2.5 and 6.5. The dominant species are *Budashevaella multicamerata* and *Recurvoides* aff. *turbinatus*. Common and typical taxa include: *Verneuilinoides* aff. *propinqua*, *Recurvoides contortus* and *Cribrostomoides* aff. *globosus* (Figure 13).

The frequency of deep-water taxa is on average 7.9%, and the group is most abundant in the interval from 590 to 560 m where its proportion varies between 12 and 22%. The most common representa-

tives of this group are *Ammosphaeroidina* sp., *Karrerulina conversa* and *Rhizammina* sp. 1. The expansion of the group, coupled with increased diversity, reflects increased water depth in comparison with the inner and middle neritic facies (Figure 10).

A striking feature of this facies is the high dominance of the recurvoid species *Budashevaella multicamerata* and *Recurvoides* aff. *turbinatus*, which also indicates increased depth. In the Palaeogene of the North Sea and Labrador Shelf, *Recurvoides* is confined to deep water basinal areas, being typical for middle and lower bathyal conditions (Gradstein *et al.*, 1994, Gradstein & Bäckström, 1996).

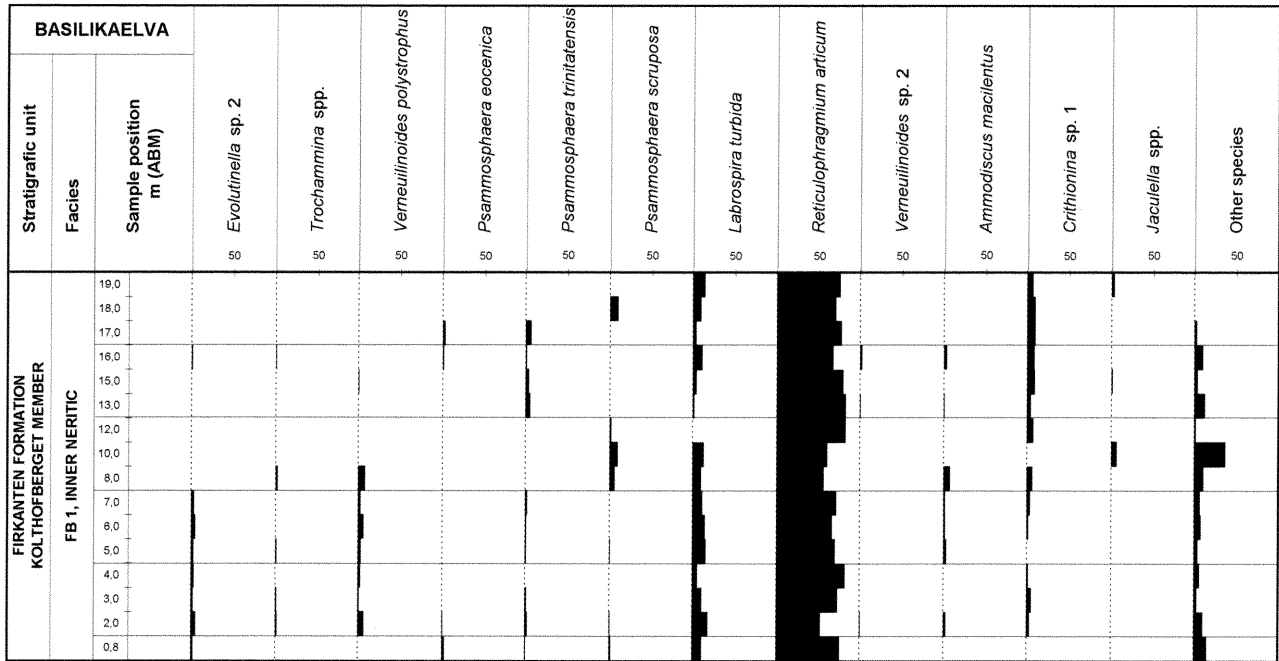


Figure 11. Range chart showing percentage distribution of common foraminiferal taxa in the Kolthoffberget Member (Firkanten Formation) sampled in the Basilikaelva section.

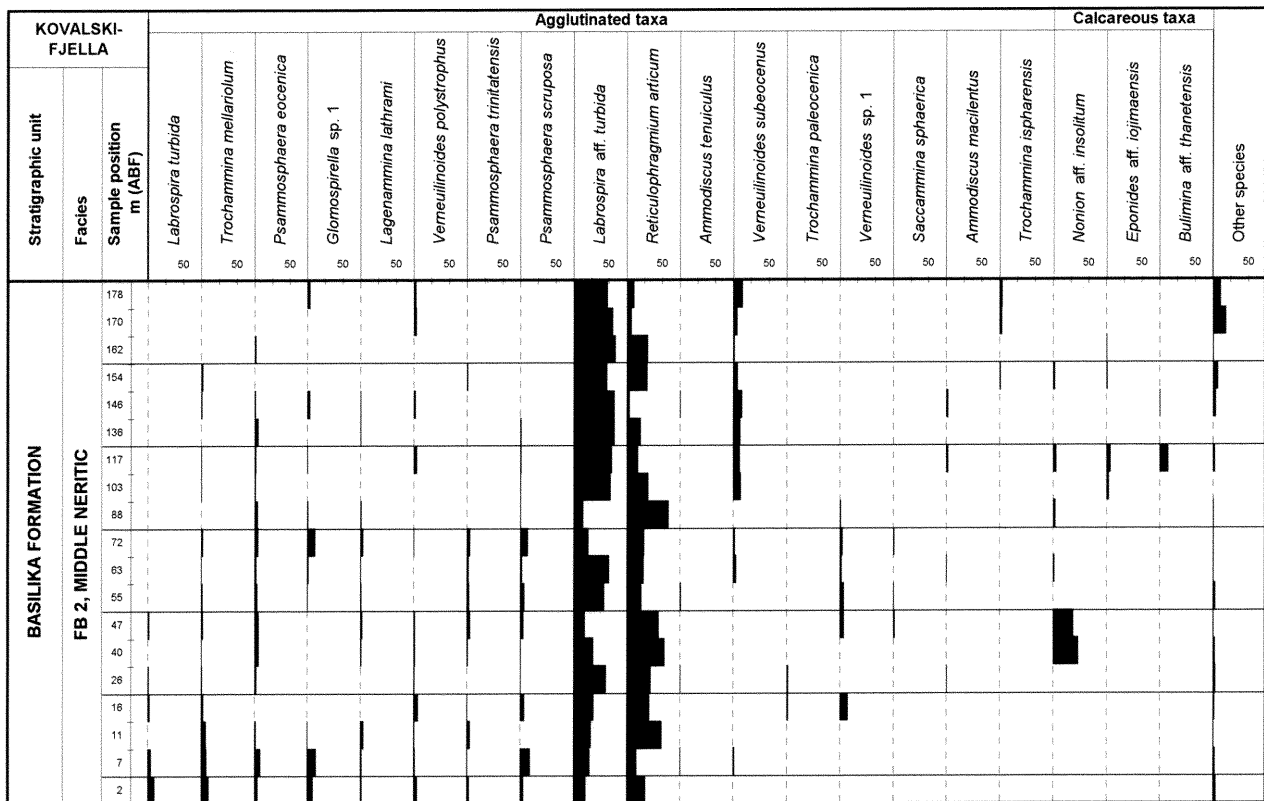


Figure 12. Range chart showing percentage distribution of common foraminiferal taxa in the Basilika Formation sampled in the Kovalskifjella section.

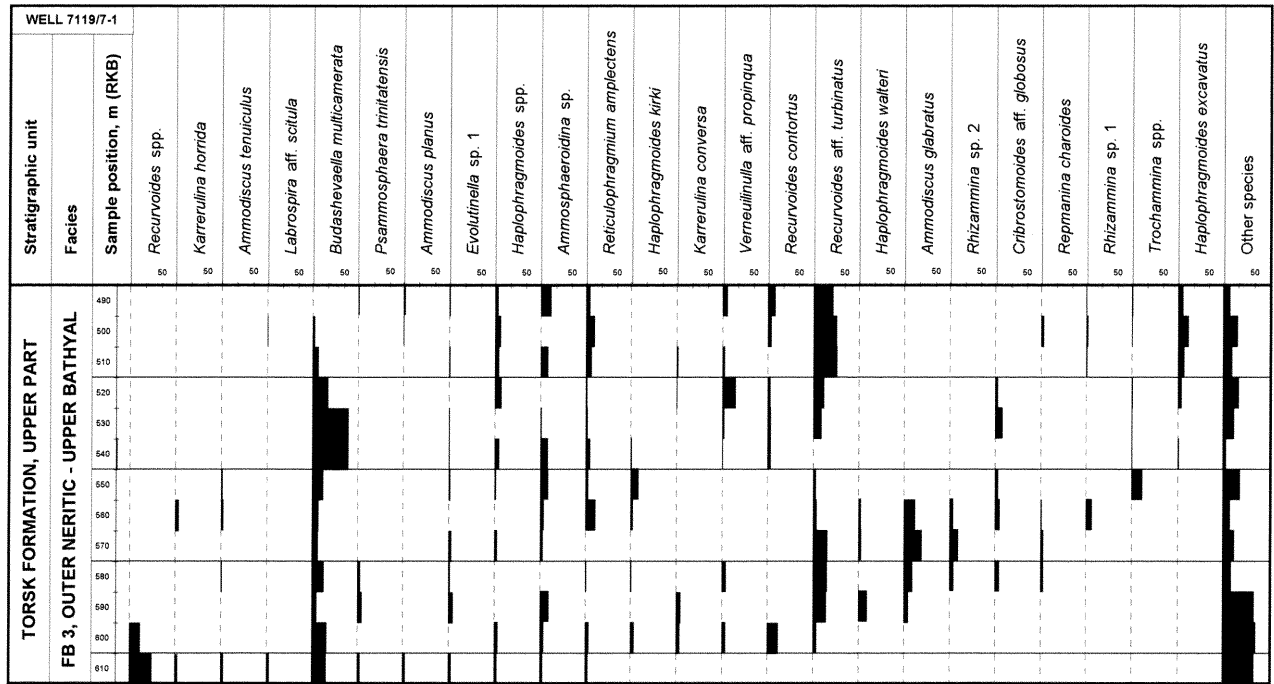


Figure 13. Range chart showing percentage distribution of common foraminiferal taxa in the upper part of the Torsk Formation in well 7119/7-1.

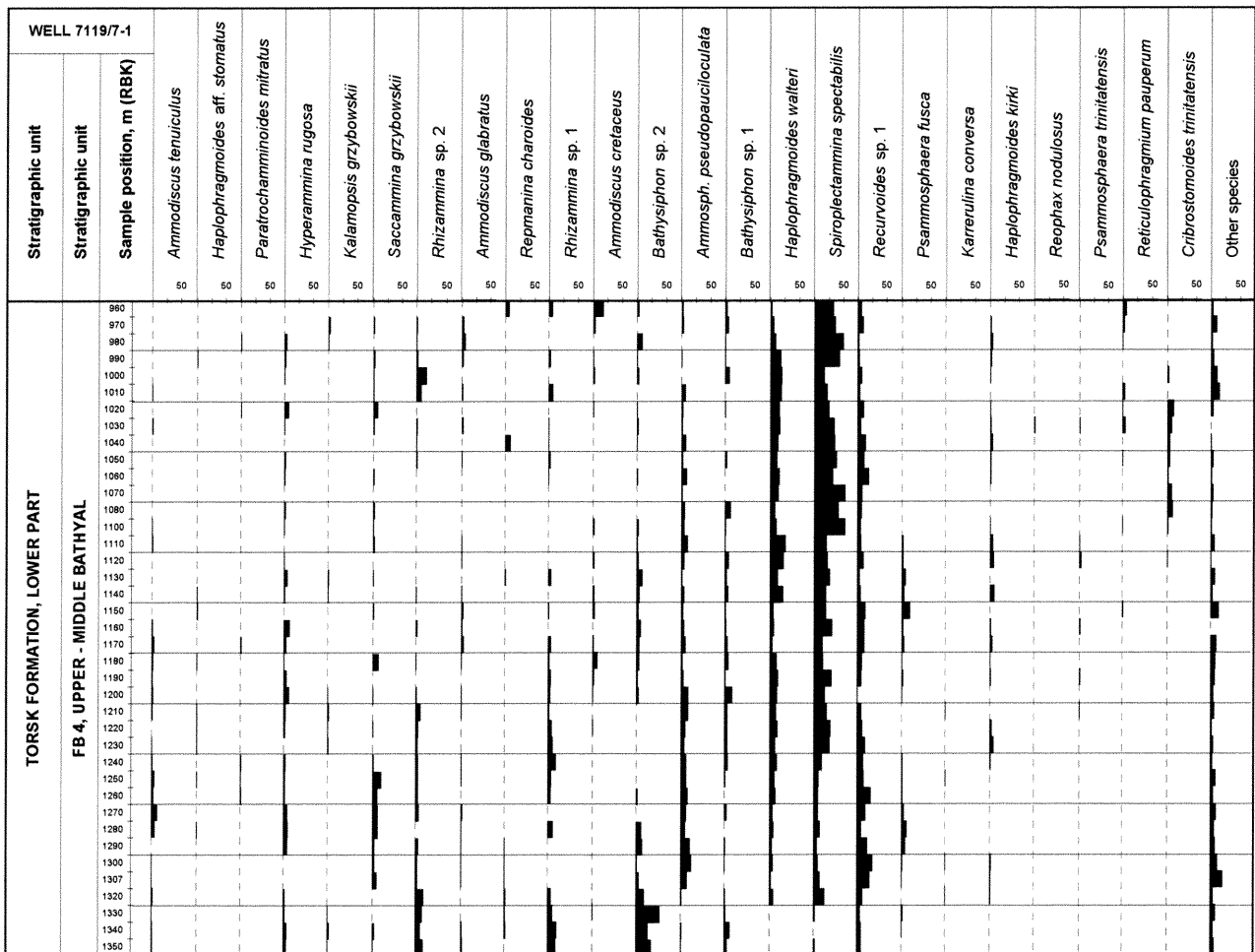


Figure 14. Range chart showing percentage distribution of common foraminiferal taxa in the lower part of the Torsk Formation in well 7119/7-1.

FB 4. Upper-middle bathyal facies

The claystones of the Torsk Formation from 960 to 1350 m contain relatively rich agglutinated assemblages (Figure 7). Alpha diversity values range from 4.5 to 14.6, with a mean of 7.2. The quantitatively most important taxa include: *Bathysiphon* sp. 2, *Spiroplectammina spectabilis*, *Haplophragmoides walteri*, *Recurvoides* sp. 1, and *Ammosphaeroidina pseudopauciloculata*. Tubular species occur commonly, and are referred mostly to *Rhizammina*, *Bathysiphon*, and *Hyperammina* with open nomenclature. The assemblages reveal a marked deep water, "flysch type" aspect, also expressed by the frequency of deep water taxa (Figure 10) attaining an average of 39.2% (range 11.1-60.7%).

A generalised depth distribution model of "flysch type" agglutinated foraminifera in the Upper Palaeocene of the North Sea (Viking Graben) was published by Jones (1988). The 960-1250 m interval of the Torsk Formation shows marked similarities with the upper slope facies of the North Sea by the dominance of *S. spectabilis* associated with common *H. walteri* and *Bathysiphon* sp. 1, a robust species with a thick and fine-grained wall. The lower 1260-1350 m of the Torsk compares best with the middle bathyal facies of the North Sea by being dominated by coarse-grained agglutinants as *Bathysiphon* sp. 2 and *Recurvoides* sp. 1 (Figure 14).

In addition to the dominance of coarse-grained taxa, the lower 1260-1350 m of the Torsk Formation is also typified by a generally increased sand and calcium carbonate content (Figure 5), both attaining here maximum values for the formation. The comparatively coarse grain size suggests increased current activity, or transport by turbidities. The association of relatively high calcium carbonate percentages with deep water agglutinants is also an unexpected combination. The origin of the carbonate may be either sedimentary (transported by currents or turbidites), or diagenetic. The question is difficult to answer based on the present data set and is left undecided.

FACIES DISTRIBUTION OF MORPHOLOGICAL GROUPS

Morphological groups and subgroups for agglutinated foraminifera were set up by Jones & Charnock (1985) on the basis of modern distribution patterns. The morphogroup approach was further adapted for Jurassic foraminifera by Nagy (1992) and Nagy *et al.* (1995), and for Palaeogene foraminifera by Nagy *et al.* (1997).

The relative proportions of agglutinated foraminiferal morphogroups are affected by the dynamic properties of the environment. For example in areas affected by increased bottom current activity, suspension-feeding epifaunal taxa may be at risk, resulting in a community dominated by epifaunal and infaunal opportunists (Kaminski & Schröder, 1987). In more stable deep marine environments the

proportion of infaunal taxa reflects bottom water oxygenation (Kaiho, 1994). Modern agglutinated faunas from dysaerobic deep sea environments are dominated by organically-cemented deep burrowing infaunal taxa (Kaminski *et al.*, 1995).

Simple agglutinants

As defined here, simple agglutinants include the superfamilies Astrorhizacea, Hippocrepinacea and Ammodiscacea, i.e., single-chambered forms and two-chambered taxa (consisting of a proloculus and a large secondary chamber). According to Figures 6 and 7, the group is present in each of the four facies at varying amounts, but is most common in upper to middle bathyal (FB 4) settings.

In the two shallow neritic facies (FB 1 and 2), the most common simple agglutinated species belong to the genus *Psammospaera*. Both fine-grained forms (as *P. trinitatis*) and coarse-grained taxa (as *P. scruposa*) occur in the present material. *Crithionina* is represented by fine-grained species which are restricted to the inner neritic facies. In deep water (FB 3 and 4), tubular taxa are the most common simple agglutinants. Additionally, globular taxa occur in subordinate amounts, including both fine-grained species (as *Saccammina grzybowskii*) and coarse forms (as *Psammospaera fusca*). Ammodiscids occur in low to intermediate quantities in all four facies.

The low diversity assemblages of the two neritic facies (FB 1 and 2) contain tubular forms in very low numbers, and these are restricted to only a few samples (Figure 15). In the outer neritic-upper bathyal facies, the frequency of the tubular group slightly increases with expanding diversity. Maximum values of the tubular group are found in the highly diversified assemblages of the upper-middle bathyal facies. This distribution pattern illustrates that tubular taxa are in general adapted to stable, deep water conditions developing highly diversified faunas, and avoid shelf to marginal marine environments of more or less restricted nature. Apparently, the dynamic nature of the substrate in current-affected areas does not favour the development of the tubular group. A similar pattern was also indicated by Jones & Charnock (1985) in their morphogroup distribution model for Recent agglutinated foraminifera.

Planispiral multichambered taxa

This major group includes both simple-walled and alveolar forms; their frequency is plotted against diversity within the four facies in Figure 16. The inner neritic environments reveal maximum abundances of the planispiral multichambered group (average 83.7%) associated with minimum diversities. At greater depths, represented by the middle neritic and outer neritic-upper bathyal facies, the frequency of this group decreased with increasing diversity. Minimum numbers are found in

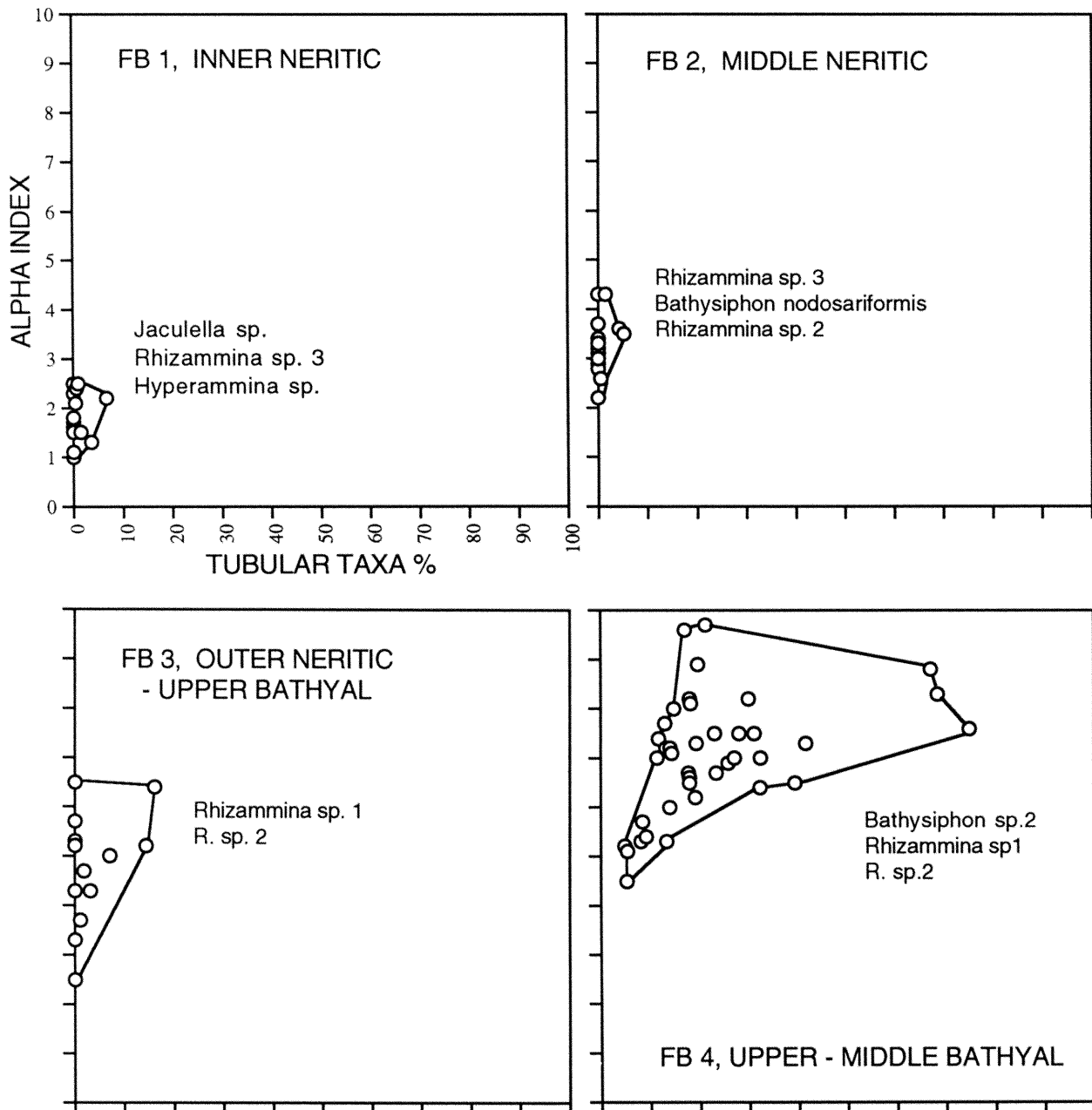


Figure 15. Frequency of tubular taxa plotted against alpha diversity in the four biofacies recognised. Both variables have their maxima in the deepest facies. Two to three of the most common tubular species are indicated in each biofacies.

the upper-middle bathyal facies associated with maximum diversities.

The distribution of the alveolar subgroup (Figure 17) shows essentially the same trend as the main planispiral group in which it forms a quantitatively important proportion. Maximum frequencies are found in the inner neritic zone (average 71.7%) while minimum values occur in the upper-middle bathyal facies where alveolar taxa are absent from a larger number of samples. From these observations it is apparent that the alveolar group, at least in the high latitude Palaeogene, was particularly adapted to restricted, inner shelf environments producing low diversity faunas.

The planispiral "haplophragmoid" test shape seems little specialised, and was adapted to a wide range of habitats including shallow burrowing

infaunal to surficial micro environments. This wide adaptation seems to be particularly favourable in the inner neritic zone (FB 1), where transport of silt and fine sand involves alternating erosion and deposition at a small scale. Consequently, the planispiral taxa dominating here were probably able to be repeatedly exposed from the substrate, and subsequently buried in the sediment.

Elongated serial taxa

The elongated serial group shows lowest percentages in the inner neritic facies (Figure 18). In the middle neritic to upper bathyal facies (FB 2 and 3), its quantity has increased with expanding diversity. Highest values are observed in the upper-middle bathyal facies (average 25.1%)

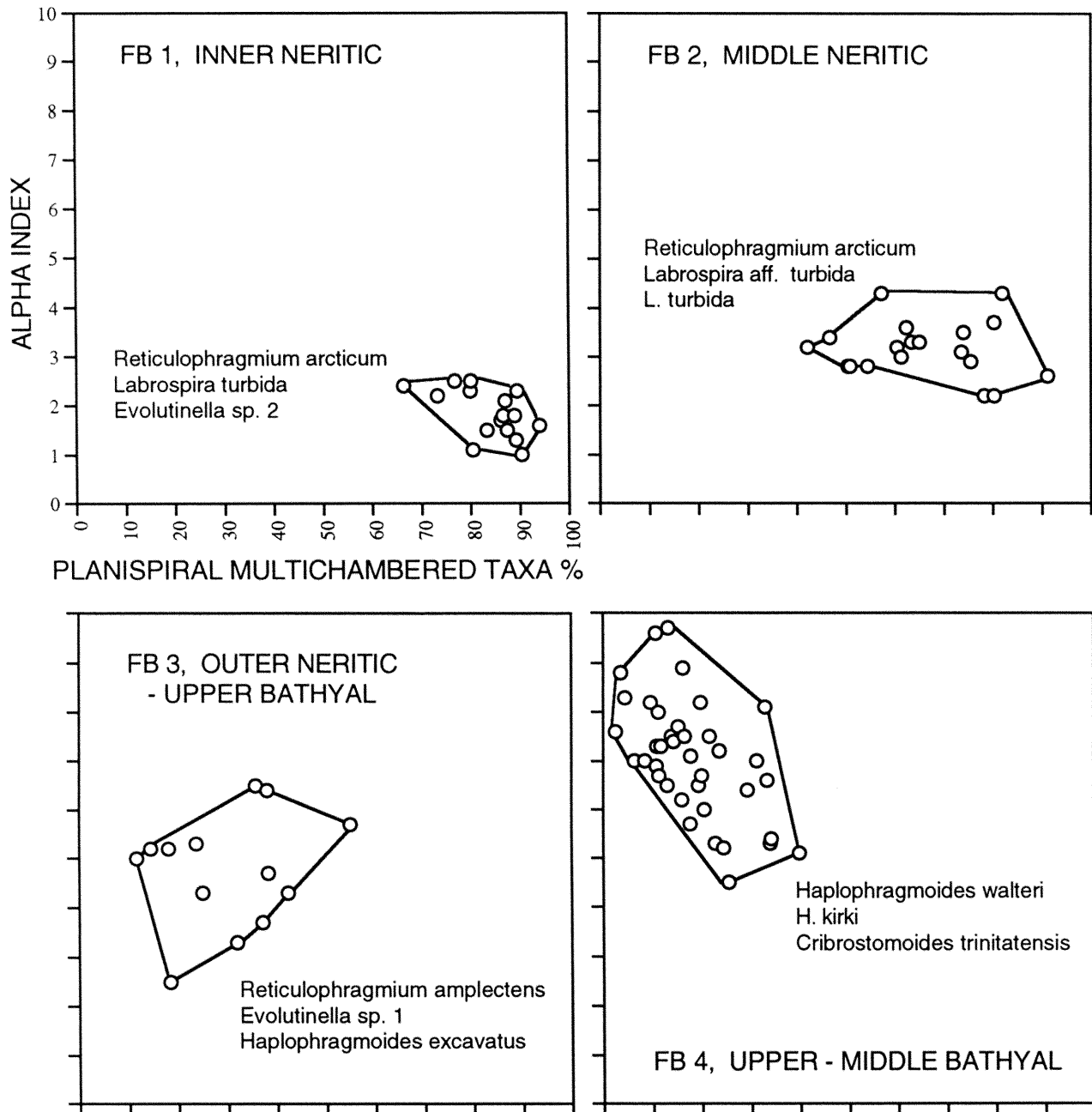


Figure 16. Frequency of planispiral multichambered taxa plotted against alpha diversity in the four biofacies recognised. The three most common planispiral multiserial taxa are indicated in each biofacies.

where the elongated group consists mainly of *Spiroplectammina spectabilis*. According to Jones & Charnock (1985) the modern depth distribution of the elongated infaunal group has an upper maximum in inner shelf areas and a lower maximum in the upper bathyal zone. The main component of the upper maximum in the modern ocean is *Textularia*, a form with calcareous cement. In modern marginal marine, hyposaline environments *Eggerella* is a common form (Murray, 1991). In the lower abundance maximum, organically-cemented "textulariid" taxa and *Reophax* are encountered, particularly in areas with a strong oxygen-minimum zone (Kaminski *et al.*, 1995).

Our material demonstrates that the upper maximum was not developed in Palaeogene high

latitude faunas characterising prodelta shelf to lower delta front facies. The Textularida, a typical low-latitude group, was not observed in these deposits.

The elongated serial test shape is assumed to be adapted to an infaunal, deep burrowing mode of life. The low abundance of this morphogroup in the inner neritic facies in the Spitsbergen Palaeogene may have been caused by the unstable, current or wave affected substrate. The relatively large organiccarbon content of the sediment (Figure 4) suggests ample food supply to the infaunal habitat. This resource was apparently exploited instead by the abundant shallow infaunal to surficial planispiral taxa. However, in the upper-middle.

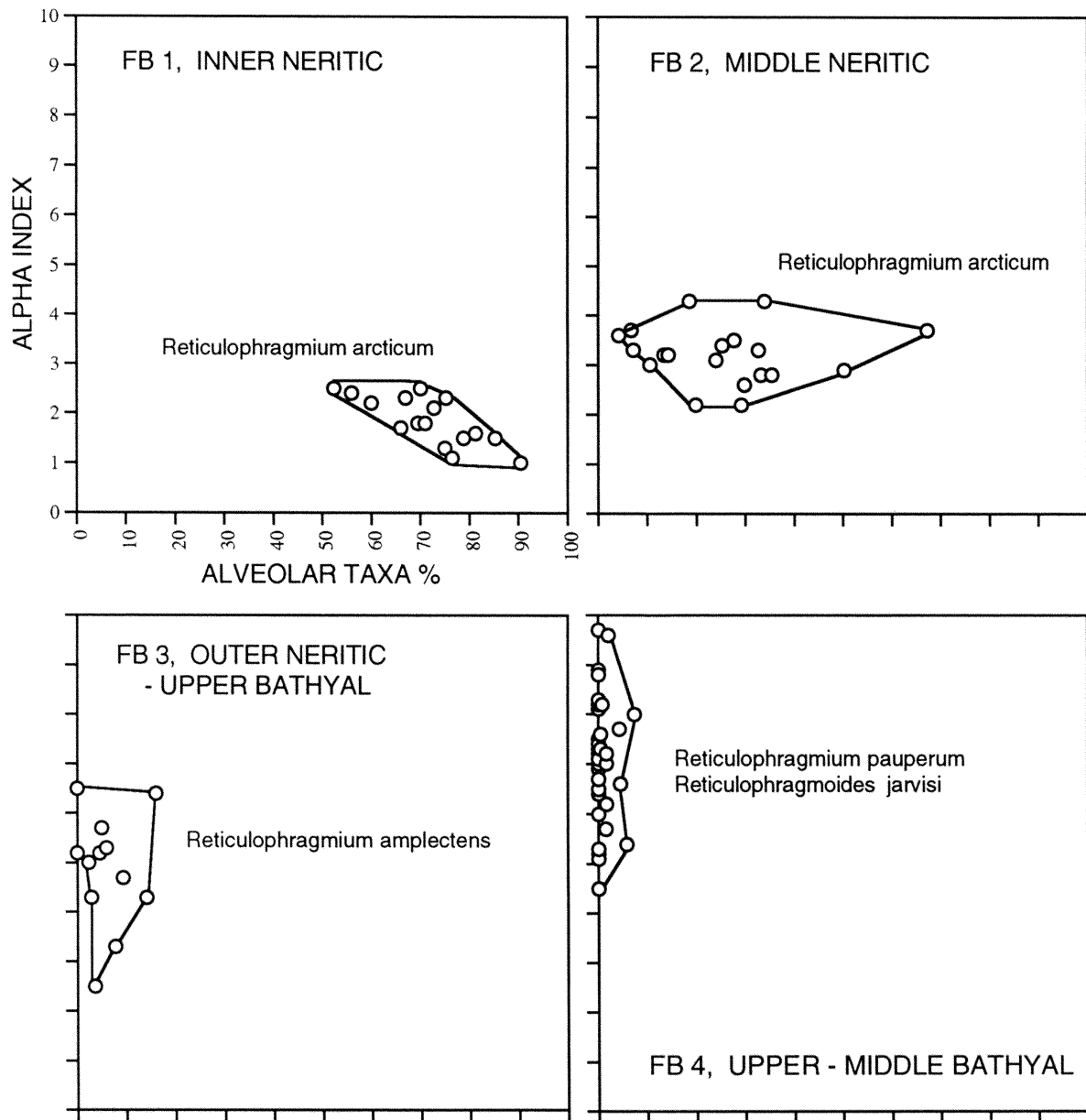


Figure 17. Frequency of alveolar taxa plotted against alpha diversity in the four biofacies recognised. One or two of the most common alveolar taxa are indicated in each biofacies.

bathyal facies, the organic content is also comparatively large (Figure 5), and the the infaunal group (represented mainly by *Spiroplectammina*) is well developed.

Streptospiral multichambered taxa

In the low diversity inner and middle neritic assemblages (FB 1 and 2), streptospiral multichambered taxa are not observed. The group is most abundant in the outer neritic-upper bathyal facies (Figure 19), where its average frequency is 48.4%. In the highly diverse upper-middle bathyal facies the frequency of the group is reduced but still significant (average 18.9%). This distribution pattern suggests that streptospiral multichambered taxa were not well adapted to shelfal and marginal marine conditions, and were affected by restricting factors.

The outer neritic-upper bathyal maximum in streptospiral taxa agrees well with the distribution

pattern observed in Palaeocene sediments of the Labrador Margin (Kaminski, 1987). In this area, *Recurvoides* was one of the dominant genera found in updip wells within the Palaeocene Cartwright Formation, but its relative abundance was observed to decrease in the offshore direction.

CONCLUSIONS

High latitude Palaeogene foraminiferal assemblages are analysed from two onshore sections, located in the Central Basin of Spitsbergen, and from a commercial exploratory well drilled in the Tromsø Basin of the southwestern Barents Sea. A quantitative comparison of the assemblages reveals consistent faunal trends that can be related to palaeobathymetry. Based on these trends a distribution model is devised, which comprises the following foraminiferal biofacies (Figure 20):

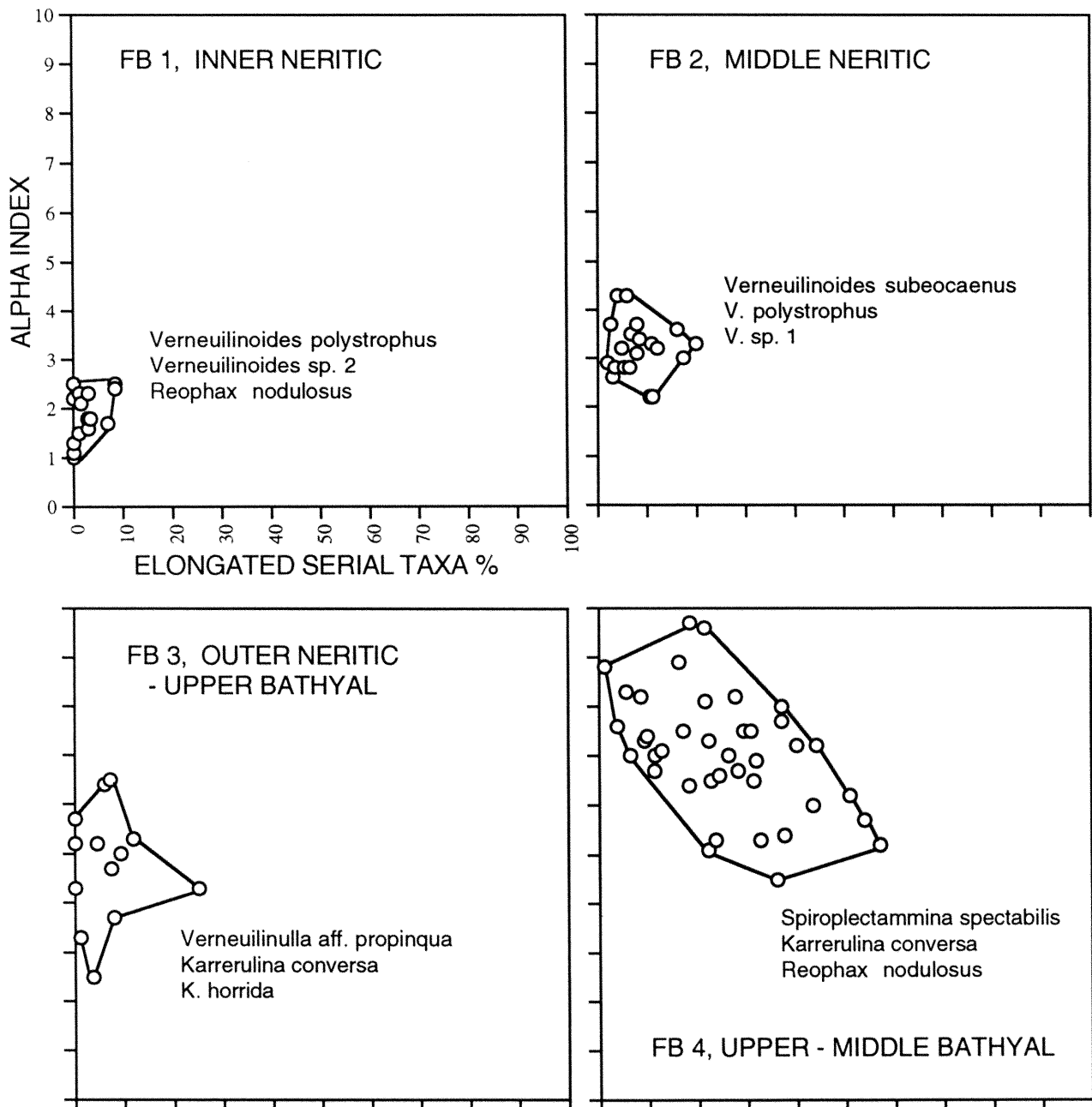


Figure 18. Frequency of elongated serial taxa plotted against alpha diversity in the four biofacies recognised. The three most common elongated serial taxa are indicated in each biofacies.

FB 1. Inner neritic: This facies occurs in the Central Basin where it is developed in the Kolthoffberget Member of the Firkanten Formation. The member was deposited in a transitional, delta front-prodelta environment. High dominance of *Reticulophragmium arcticum* is typical.

FB 2. Middle neritic: The facies is found in the Basilika Formation (Central Basin) which was deposited under delta influenced shelf conditions. This facies is typically dominated by *Labrospira aff. turbida* and *R. arcticum*.

FB 3. Outer neritic-upper bathyal: It is present in the upper Torsk Formation of the Tromsø Basin. The dominant species include *Budashevaella multicamerata*,

Recurvoides aff. turbinatus, *Ammosphaeroidina pseudopauciloculata*, and *Reticulophragmium amplectens*.

FB 4. Upper-middle bathyal: This palaeoenvironment is recognised in the lower Torsk Formation (Tromsø Basin). The assemblages reveal close similarities to deep water "flysch type" faunas of the North Sea and other boreal areas. Dominant species include: *Spiroplectammina spectabilis*, *Haplophragmoides walteri*, *Recurvoides sp. 1*, *Ammosphaeroidina pseudopauciloculata* and *Saccammina grzybowskii*.

The distribution trends of general faunal parameters and major morphological groupings (Figure 21) appear to be useful for distinguishing the various facies. Distribution patterns of these features are summarised in the following:

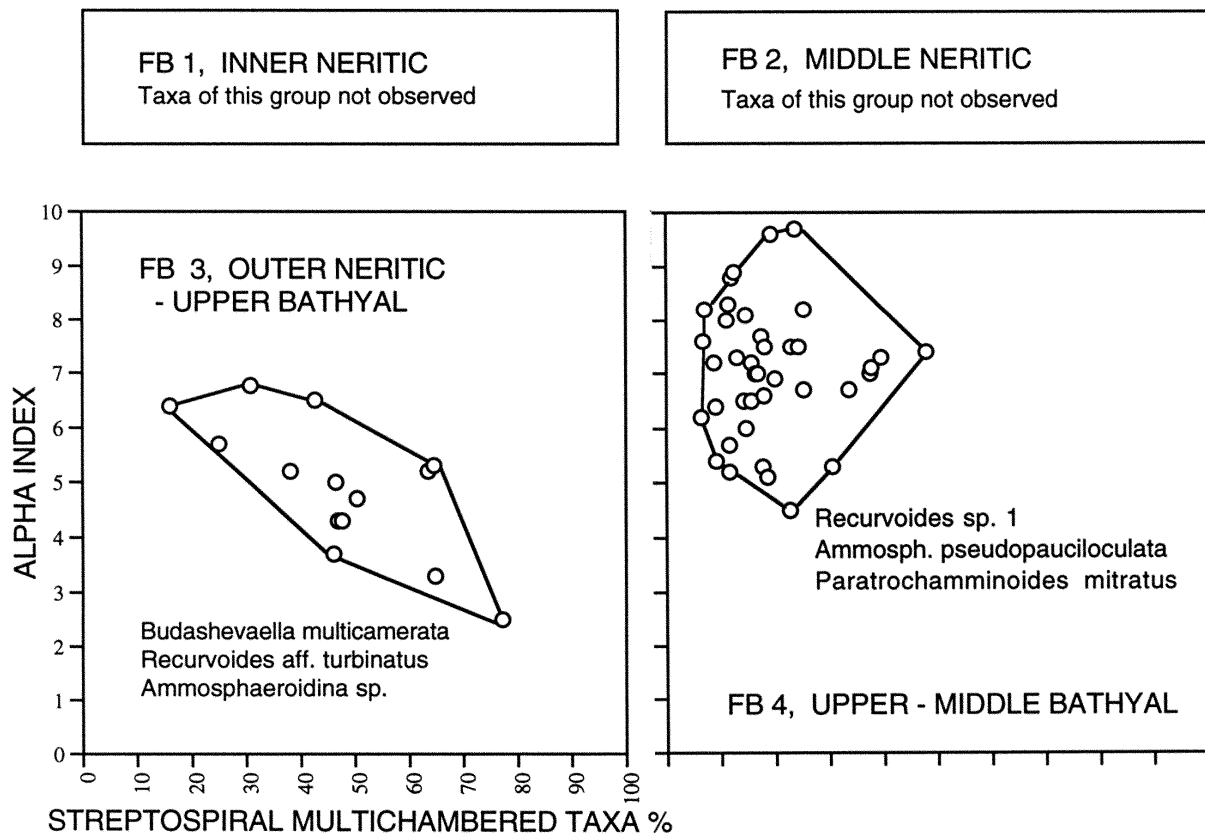


Figure 19. Frequency of streptospiral multichambered taxa plotted against alpha diversity in the two deeper water biofacies. The three most common streptospiral multiserial taxa are indicated in both biofacies

- The species diversity expands with increasing water depth in the biofacies model. Consequently, it is positively correlated with the percentage of deep water taxa.
- Calcareous taxa are restricted to the middle neritic facies where they occur in low numbers.
- Psammosphaerids are the most common simple agglutinants in the two neritic facies (FB 1 and 2).
- Tubular taxa are rare in neritic settings but common in bathyal facies, particularly in FB 4 (Figure 21).
- Alveolar taxa are most abundant in the two shallower neritic facies (FB 1 and 2), and show strongly reduced frequency in deeper environments.
- Streptospiral multichambered taxa are not observed in the inner and middle neritic facies but are particularly abundant in outer neritic-upper bathyal settings.
- Elongated serial taxa are most common in the upper to middle bathyal assemblages.

The inner and middle neritic assemblages of the Central Basin (FB 1 and 2) are of a restricted marine nature as typified by low diversities and virtually entirely agglutinated assemblages. In addition, the taxonomic composition of the faunas reveals pronounced endemism of high latitude character. By

these features, the Spitsbergen assemblages are similar to Palaeocene-Eocene faunas of the Beaufort-Mackenzie Basin (Arctic North America).

The endemic and restricted nature of neritic high latitude faunas in Palaeocene-Eocene times is partly explained by impeded circulation between the Arctic basins and other oceanic regions. This partial isolation lasted until the Early Oligocene, when open deep-water connection became established between the Arctic and North Atlantic basins (Talwani & Eldholm, 1977). In the Beaufort-Mackenzie Basin, the establishment of open communication resulted in the development of calcareous and agglutinated assemblages of North Atlantic and European affinities (McNeil, 1990).

The outer neritic to middle bathyal (FB 3 and 4) assemblages of the Tromsø Basin are of "flysch type" cosmopolitan nature, not affected by high latitude endemism typical of shallower assemblages. These deeper water assemblages reveal close similarities to Palaeogene faunas of Haltenbanken, offshore Mid-Norway, Viking Graben (North Sea), and Alpine and Carpathian flysch occurrences. Thus, the southwestern Barents Sea basins represent the northernmost known extension of bathyal agglutinated facies on the western North Atlantic margin during Palaeocene times. This extension had an open deep water connection with the world ocean.

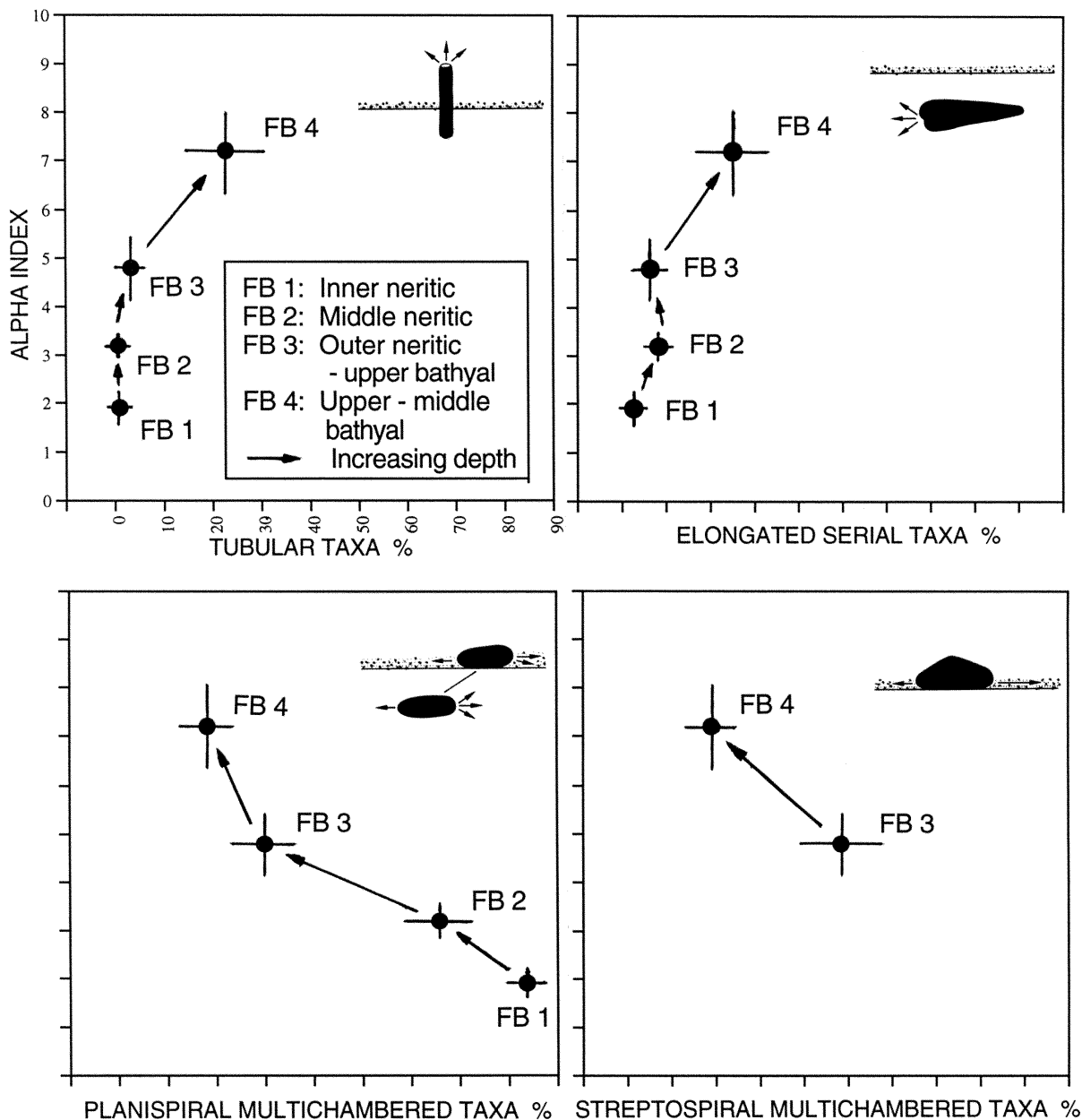


Figure 20. Diagrams summarising the frequency of major morphological groups and diversities in the four biofacies. The dots are average values representing each single facies, with standard deviation.

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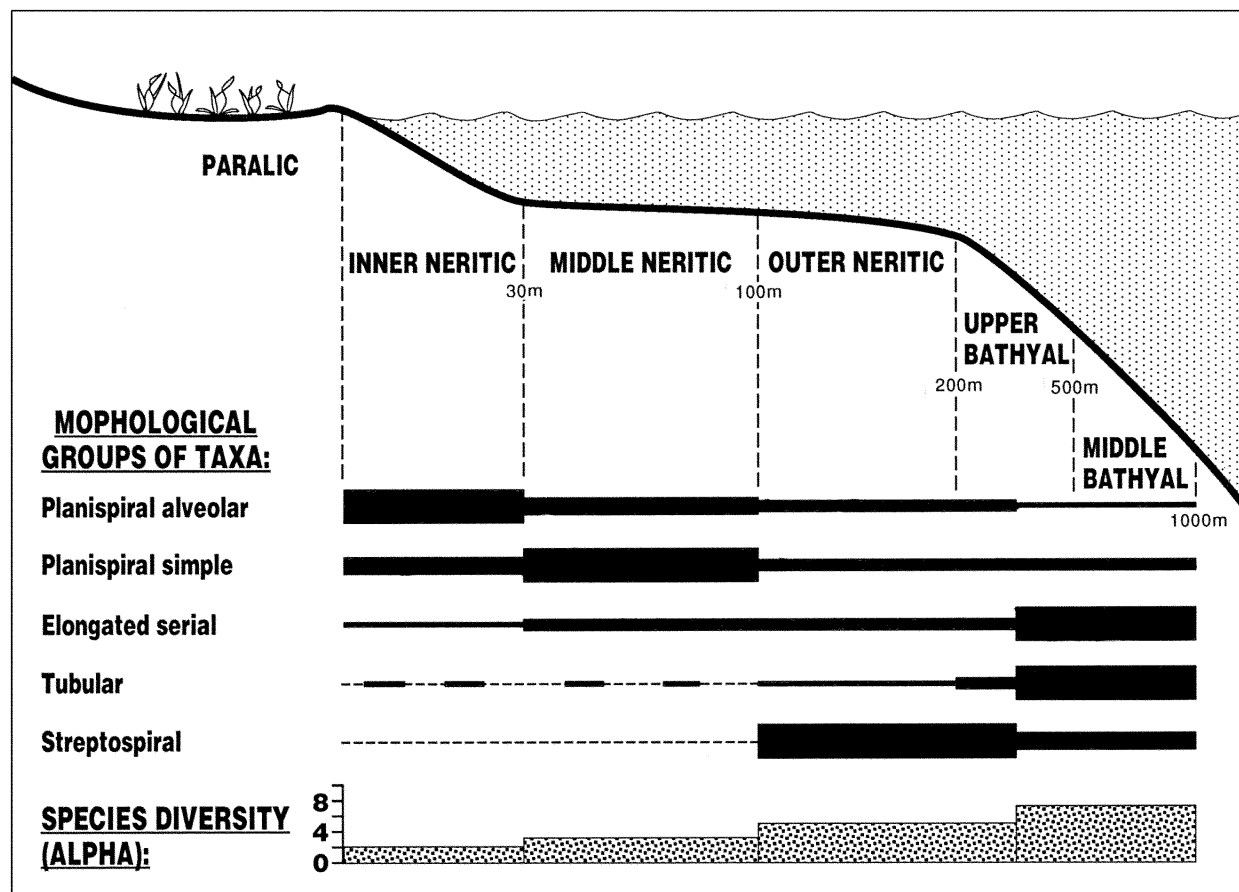


Figure 21. Diagram summarising the palaeobathymetric distribution of foraminiferal groups and species diversities. The model is developed for Palaeogene strata of the Central Basin (Spitsbergen) and the Tromsø Basin (southwestern Barents Sea).

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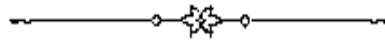


PLATE 1

Samples from Kolthoffberget Member of Firkanten Formation, Basilikaelva section

(RL= reflected light; SEM= scanning electronic micrograph)

- Fig. 1.** *Rhizammina* sp. 3: sample 2.0 m, RL, x65.
- Fig. 2-3.** *Psammosphaera scruposa*: 2. sample 0.8 m, RL, x50; 3. broken specimen, sample 10.0 m, SEM, x60.
- Fig. 4.** *Psammosphaera eocenica*: sample 0.8 m, SEM, x50.
- Fig. 5-6.** *Psammosphaera trinitatensis*: 5. sample 0.8 m, RL, x50; 6. sample 13.0 m, RL, x50.
- Fig. 7.** *Saccammina sphaerica*: sample 10.0 m, SEM, x60.
- Fig. 8-9.** *Crithionina* sp. 1: 8. sample 2.0 m, RL, x50; 9. sample 15.0 m, RL, x50.
- Fig. 10.** *Evolutinella* sp. 2: sample 6.0 m, RL, x60.
- Fig. 11-13.** *Labrospira turbida*: 11. sample 16.0 m, RL, x60; 12. sample 2.0 m, SEM, x60; 13. sample 2.0 m, RL, x60.
- Fig. 14-17.** *Reticulophragmium arcticum*: 14. sample 15.0 m, RL, x60; 15. sample 6.0 m, RL, x60, 16. sample 12.0 m, SEM, x60, 17. sample 4.0, RL, x40.
- Fig. 18-19.** *Verneuilioides polystrophus*: 18. sample 6.0 m, RL, x85; 19. sample 5.0 m, RL, x85.
- Fig. 20.** Pyritised diatom "*Coscinodiscus*": sample 2.0 m, SEM, x90.

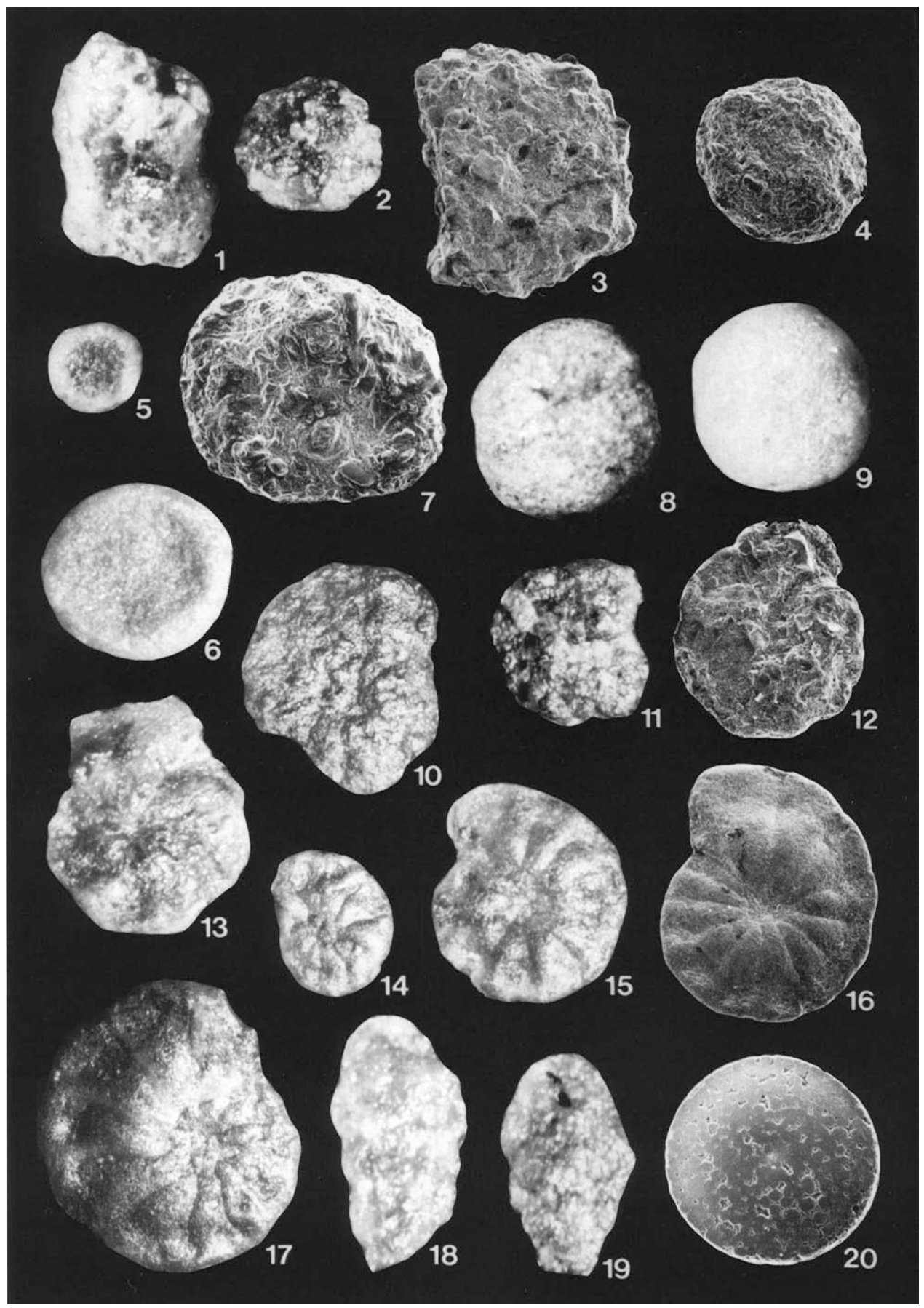


PLATE 2

Samples from Basilika Formation, Kovalskifjella section

(RL= reflected light; SEM = scanning electron micrograph)

- Fig. 1. *Rhizammina* sp. 3: sample 146.0 m, RL, x40
- Fig. 2-3. *Psammosphaera scruposa*: 2. sample 136.0 m, RL, x50; 3. sample 7.0 m, RL, x50.
- Fig. 4-5. *Psammosphaera eocenica*: 4. sample 11.0 m, RL, x50; 5. sample 2.0 m, RL, x50.
- Fig. 6-7. *Psammosphaera trinitatensis*: 6. sample 47.0 m, RL, x50; 7. sample 72.0 m, broken specimen, SEM, x80.
- Fig. 8. *Lagenammina* sp. 1: sample 146.0 m, RL, x85.
- Fig. 9. *Lagenammina lathrami*: sample 72.0 m, RL, x85.
- Fig. 10. *Saccammina sphaerica*: sample 55.0 m, RL, x50.
- Fig. 11-12. *Thurammina* aff. *papillata*: 11. sample 154.0 m, SEM, x70; 12. sample 178.0 m, RL, x85.
- Fig. 13. *Astrammina* sp. 1: sample 2.0 m, RL, x55.
- Fig. 14. *Ammodiscus macilentus*: sample 88.0 m, RL, x70.
- Fig. 15. *Glomospirella* sp. 1: sample 7.0 m, SEM, x80.
- Fig. 16. *Labrospira turbida*: sample 26.0 m, RL, x55.
- Fig. 17. *Labrospira* aff. *turbida*: sample 63.0 m, SEM, x60.
- Fig. 18. *Verneuilinoides polystrophus*: sample 117.0 m, RL, x85.
- Fig. 19. *Verneuilinoides subeocaemus*: sample 103.0 m, SEM, x110.
- Fig. 20-21. *Reticulophragmium arcticum*: 20. sample 26.0 m, RL, x40; 21. sample 11.0 m, RL, X60.
- Fig. 22. *Trochammina ispharensis*: sample 154.0 m, RL, x60.
- Fig. 23. *Trochammina mellariolum*: sample 47.0 m, RL, x60.
- Fig. 24. *Trochammina paleocenica*: sample 26.0 m, RL, x60.
- Fig. 25-26. *Nonion* aff. *insolitum*: 25. sample 47.0 m, RL, x85.; 26. sample 55.0 m, RL, x85.
- Fig. 27. *Nonion* sp. 1: sample 55.0 m, RL, x85.

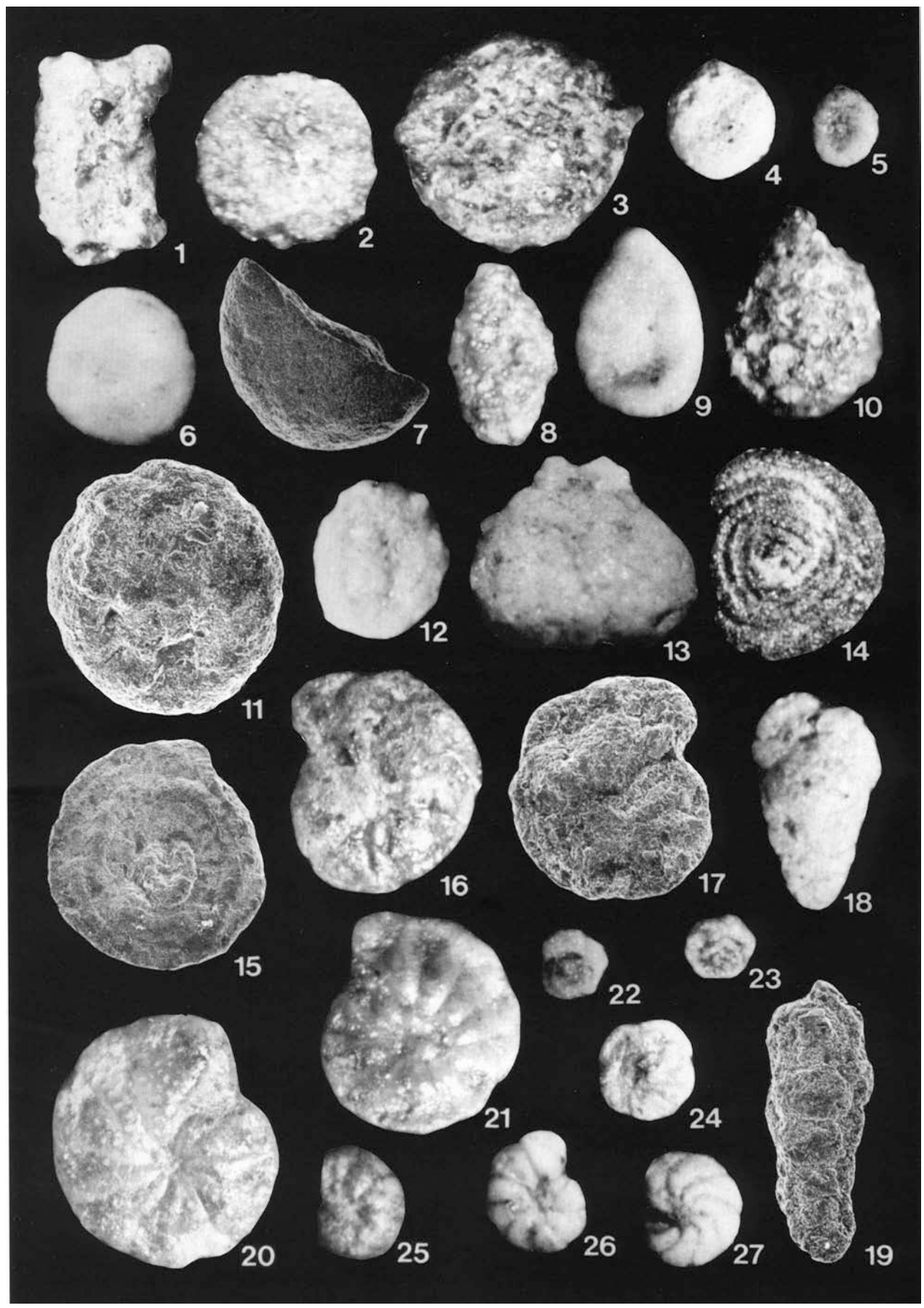


PLATE 3

Samples from upper part of Torsk Formation, Barents Sea,
Well 7119/7-1 (figs. 1-22 and 27-28) and Well 7119/9-1 (figs. 23-26)
(RL= reflected light; SEM = scanning electron micrograph)

- Fig. 1-2.** *Rhizammina* sp. 1: 1. sample 500.0 m, SEM, x65; 2. sample 560.0 m, RL, x70.
- Fig. 3.** *Rhizammina* sp: 2: sample 560.0 m, RL, x65.
- Fig. 4-5.** *Ammodiscus glabratus*: 4. sample 560.0 m, RL, x70; 5. sample 560.0 m, RL, x80.
- Fig. 6.** *Ammodiscus tenuiculus*: sample 550.0 m, RL, x80.
- Fig. 7-8.** *Evolutinella* sp. 1: 7. sample 500.0, RL, x60; 8. sample 510.0 m, RL, x55.
- Fig. 9.** *Haplophragmoides kirki*: sample 600.0 m, RL, x85.
- Fig. 10-11.** *Haplophragmoides excavatus*: 10. sample 520.0 m, RL, x85; 11. sample 490.0 m, RL, x85.
- Fig. 12.** *Haplophragmoides walteri*: sample 590.0 m, SEM, x70.
- Fig. 13.** *Ammosphaeroidina* sp.: sample 540.0 m, SEM, x50.
- Fig. 14.** *Recurvoides* aff. *turbinatus*: sample 520.0 m, RL, x85.
- Fig. 15-17.** *Budashevaella multicamerata*: 15, sample 530.0 m, RL, x85; 16, sample 520.0 m, RL, x85; 17, sample 530.0 m, RL, x85.
- Fig. 18-19.** *Recurvoides contortus*: 18. sample 530.0 m, RL, x85; 19. sample 530.0 m, RL, x85.
- Fig. 20-21.** *Reticulophragmium amplectens*: 20. sample 510.0 m, RL, x60; 21. sample 500.0 m, RL, x60.
- Fig. 22.** *Trochammina* sp.: sample 550.0 m, SEM, x80.
- Fig. 23-24.** *Karrerulina conversa*: 23. sample 710.0 m, RL, x85; 24. sample 710.0 m, RL, x85.
- Fig. 25.** *Karrerulina horrida*: sample 750.0 m, RL, x85.
- Fig. 26.** *Verneuilioides polystrophus*: sample 510.0 m, RL, x85.
- Fig. 27-28.** *Verneuilioides* aff. *polystrophus*: 27, sample 520.0 m, RL, x85; 28, sample 520.0 m, RL, x85.

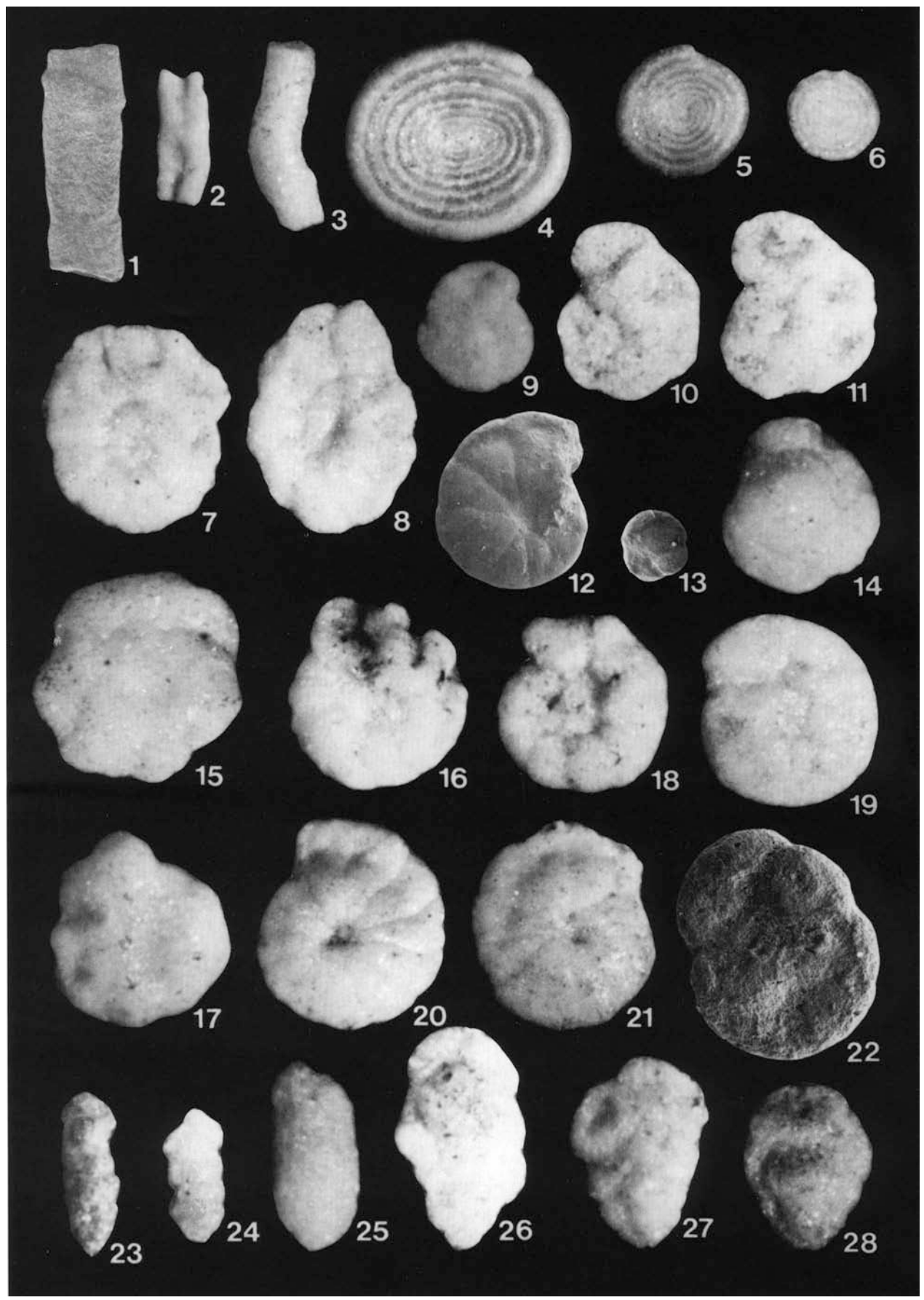


PLATE 4

Samples from lower part of Torsk Formation, Barents Sea, Well 7119/7-1

(RL= reflected light; SEM = scanning electron micrograph)

- Fig. 1.** *Rhizammina* sp.: sample 1250.0 m, RL, x65.
- Fig. 2** *Rhizammina* sp.: sample 1320.0 m, RL, x65.
- Fig. 3-4.** *Bathysiphon microraphidus*: 3. sample 1300.0 m, RL, x65; 4. sample 1150.0 m, RL, x65.
- Fig. 5-6.** *Bathysiphon annulatus*: 5. sample 1340.0 m, RL,x60; 6. sample 1330.0 m, RL, x50.
- Fig. 7-10.** *Bathysiphon* sp. 1: 7. sample 1110.0 m, RL, x55; 8. sample 1110.0 m, RL, x60; 9. sample 1200.0 m, SEM, x60; 10. sample 1230.0 m, RL, x85.
- Fig. 11-12.** *Bathysiphon* sp. 2: 11. sample 1320.0 m, RL, x66; 12. sample 1307.0 m, RL, x65.
- Fig. 13-15.** *Hyperammia rugosa*: 13. sample 1200.0 m, RL, x50; 14. sample 1290.0 m, RL, x40; 15. sample 1290.0 m, SEM, x40.
- Fig. 16-18.** *Kalamopsis grzybowskii*: 16. sample 1340.0 m, SEM, x50; 17. sample 1210.0 m, RL, x70; 18. sample 1330.0 m, RL, x50.
- Fig. 19-20.** *Psammosphaera fusca*: 19. sample 1110.0 m, RL, x35; 20. sample 1290.0 m, RL, x40.
- Fig. 21-23.** *Saccammina grzybowskii*: 21. sample 1270.0 m, RL, x80; 22. sample 1250.0 m, SEM, x80; 23. sample 1250.0 m, RL, x80.
- Fig. 24.** *Saccammina placenta*: sample 1270.0 m, RL, x80.

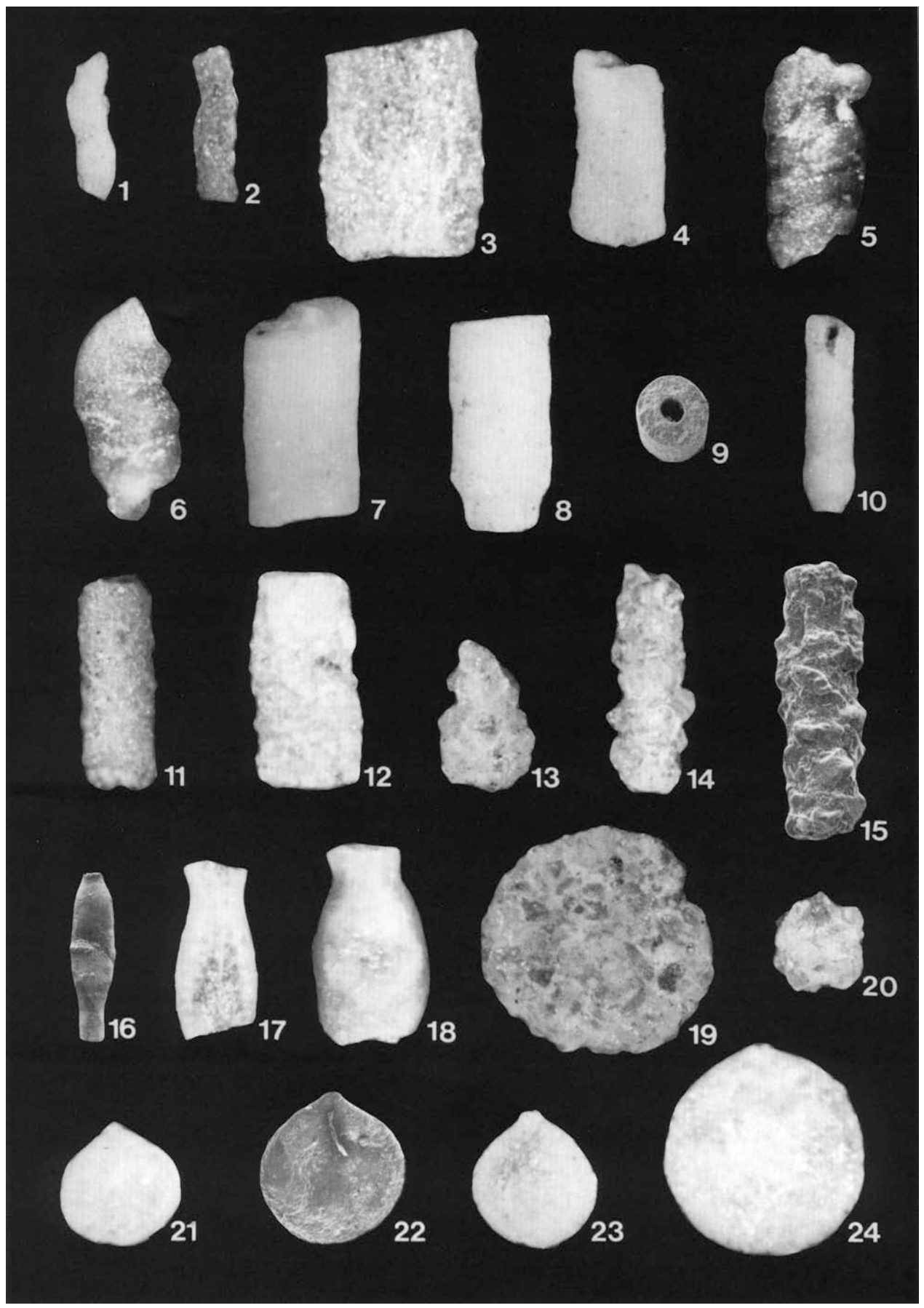


PLATE 5

Samples from lower part of Torsk Formation, Barents Sea, Well 7119/7-1

(RL= reflected light; SEM = scanning electron micrograph)

Fig. 1. *Ammodiscus glabratus*: sample 1270.0 m, SEM, x30.

Fig. 2. *Glomospira gordialis*: sample 1320.0 m, SEM, x65.

Fig. 3. *Repmanina charoides*: samples 1040.0 m, SEM, x65.

Fig. 4. *Rzehakina epigona*: sample 1350.0 m, SEM, x65.

Fig. 5. *Trochamminoides subcoronatus*: sample 1350.0 m, RL, x65.

Fig. 6. *Paratrochamminoides olszewskii*: sample 1290.0 m, SEM, x40.

Fig. 7-8. *Paratrochamminoides mitratus*: 7. sample 1260.0 m, RL, x65; 8. sample 980.0 m, RL, x40.

Fig. 9-12. *Haplophragmoides walteri*: 9. sample 1260.0 m, RL, x85; 10. sample 1110.0 m, SEM, x85; 11. sample 1350.0 m, RL, x85; 12. sample 1060.0 m, SEM, x85.

Fig. 13-14. *Haplophragmoides kirki*: 13. sample 1140.0 m, RL, x85; 14. sample 1230.0 m, RL, x85.

Fig. 15. *Reticulophragmoides jarvisi*: sample 1290.0 m, RL, x85.

Fig. 16. *Haplophragmoides horridus*: sample 1330.0 m, RL, x85.

Fig. 17-18. *Ammosphaeroidina pseudopauciloculata*: 17. sample 1140.0 m, RL, x85; 18. sample 1290.0 m, RL, x85.

Fig. 19-21. *Recurvoides* sp. 1: 19. sample 1340.0 m, RL, x85; 20. sample 1290.0 m, RL, x85; 21. sample 1300.0 m, SEM, x85.

Fig. 22-23. *Spiroplectammina spectabilis*: 22. sample 1100.0 m, RL, x55; 23. sample 1060.0, RL, x65.

