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A PALEOECOLOGICAL MODEL OF LATE PALEOCENE "FLYSCH-TYPE" AGGLUTINATED FORAMINIFERA USING THE PALEOSLOPE TRANSECT APPROACH, VIKING GRABEN, NORTH SEA.

by

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With 5 figures and 2 plates

ZUSAMMENFASSUNG

Agglutinierte Foraminiferen vom Typ der sogenannten „Flyschfaunen“ wurden in einem begrenzten, generell isochronen Zeitschnitt (60,9–62,7 Mill.J.) aus dem unteren Paleozän studiert. Dazu standen sechs Bohrungen aus dem britischen und norwegischen Sektor des Viking Grabens der Nordsee zur Verfügung. Je zwei Bohrungen repräsentieren den oberen Kontinentalabhang (200–500 m), den mittleren Kontinentalabhang (500–1000 m) und den Boden des Beckens (1000–1500 m). Röhrenförmige, astrorhizide Bruchstücke sind in allen Proben mit *Trochammina* dominant, *Haplophragmoides, Spiroplectammina* und *Saccammina* sind deutlich weniger häufig. Neun Arten und 3 Artengruppen zeigen eine deutliche, paläobathymetrische Verteilung. Mittelgroße, grobkörnige Agglutinantier sind relativ häufig in Vergesellschaftungen des oberen Kontinentalabhanges. Faunen des mittleren Abhanges weisen eine relativ große Häufigkeit großer, grobkörniger Formen auf, während die Vergesellschaftungen des Beckens durch kleine, feinkörnig agglutinierte Arten in Vergesellschaftung mit Radiolarien charakterisiert sind. Artendiversität und Vergleichbarkeitswerte sind am Beckenboden durchwegs höher als in Proben des oberen Kontinentalabhanges, während die Werte für den mittleren Kontinentalabhang weit streuen. Verteilungsmuster der „Flyschfaunen“-Assoziationen stimmen mit Rezentbeobachtungen überein und zeigen eine Korrelation von Größe, Grobkörnigkeit des Gehäuses und Diversität zu Bodenenergiebedingungen, Trübeströmungen und Wassertiefe.

ABSTRACT

"Flysch-type" agglutinated foraminifera were studied from a narrow essentially isochronous time slice (60.9-62.7 Ma, Late Paleocene) from six wells in the U.K. and Norwegian Sectors, Viking Graben, North Sea. Two wells each represent upper slope (200-500 m), middle slope (500-1000 m) and basin floor (1000-1500 m) environments.

Tubular-shaped astrorhizid fragments dominate all samples with species of *Trochammina, Haplophragmoides, Spiroplectammina,* and *Saccammina* being conspicuous but less abundant. Nine species and three species groups have distinctive paleobathymetric distributions. Medium-sized, coarse-grained agglutinants are relatively less abundant in upper slope assemblages. Middle slope assemblages contain a greater relative abundance of large-sized, coarse-grained species. Basin floor assemblages are characterized by small, fine-grained agglutinants and a radiolarian species. Species diversity and equitability values are consistently higher in basin floor than upper slope samples; values for middle slope samples fluctuate widely. Distributional patterns of the "flysch-type" assemblages are consistent with recent observations showing a correlation of size, coarseness of test, and diversity patterns with bottom energy conditions, turbidity currents, and water depth.

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INTRODUCTION

Diverse agglutinated foraminiferal assemblages characterized by abundant primitive taxa have been termed "flysch-type" assemblages (FTA) (Gradstein and Berggren 1981). These cosmopolitan assemblages were first described in the late 19th century (Grzybowski 1898); yet, only recently has a generalized paleoecological model accounting for their distribution been widely accepted. Based on various lines of evidence, including geophysical backtracking, taxonomic comparison to modern faunas, and other geological evidence, Gradstein and Berggren (1981) showed that FTAs occur in varying water depths from the shelf edge (200 m) to the abyss (up to 4 km). Depth alone, therefore, is not an overriding factor influencing their occurrence. Rather, many FTAs, such as those in the Paleogene sections of the Labrador and North Sea basins, are intimately associated with restricted basins that were rapidly filled with organic-rich, fine-grained clastic sediments. Presumably, these carbonate-poor conditions hindered the development of a calcareous fauna and promoted the development of FTAs. Because these ecological conditions also promote the preservation of organic matter, FTAs are commonly associated with deep-water petroleum source rocks (Gradstein an Berggren 1981). It would be particularly advantageous to petroleum exploration if further research could move beyond this generalized paleoecological model and determine:

(1) a refined paleobathymetric zonation based on the distribution of "flysch-type" taxa;
(2) a comprehensive biofacies model for deep-sea fans based on the distribution of FTAs.

METHODS

I have used the paleoslope transect approach (Nyong and Olsson 1984) to determine the paleobathymetric distribution of Late Paleocene "flysch-type" taxa in samples from six wells in the Viking Graben, North Sea (figure 1). The position of the Late Paleocene shelf edge (figure 1) is from Heritier *et al.* (1979) and assumed to be 200 m water depth. The 1500 m paleowater depth for the Viking Graben axis (figure 1; axis location after Kirk 1980) was estimated using trignometric techniques outlined in Nyong and Olsson (1984). The 1500 m figure represents an average of determinations obtained using minimum and maximum estimates for the dip gradient of the Late Paleocene continental slope. This paleowater depth estimate is similar to the 1000 m figure cited by Wood (1981) for the Paleogene Central Graben.

Although my results are supported by personal observations in many North Sea wells, the six samples chosen best exemplify the observed faunal trends. Sample quality is unusually high for a paleoslope transect study (figure 2). Five of the six samples are core samples; the other is a well cuttings sample taken directly below a casing shoe so that cavings do not contaminate the sample. All samples are fine-grained clastic mudstones and claystones. Most importantly, the samples are from a narrow time slice based on an in-house palynomorph zonation (60.9-62.7 Ma; approximately equivalent to Zone P3 of Blow (1979); Early Selandian Age; Late Paleocene). All samples were air dried, soaked overnight in kerosene, placed in distilled water until disaggregated, then gently washed over a #200 (75µ) sieve. The foraminiferal residues were air dried and all agglutinated specimens from each sample picked and counted.

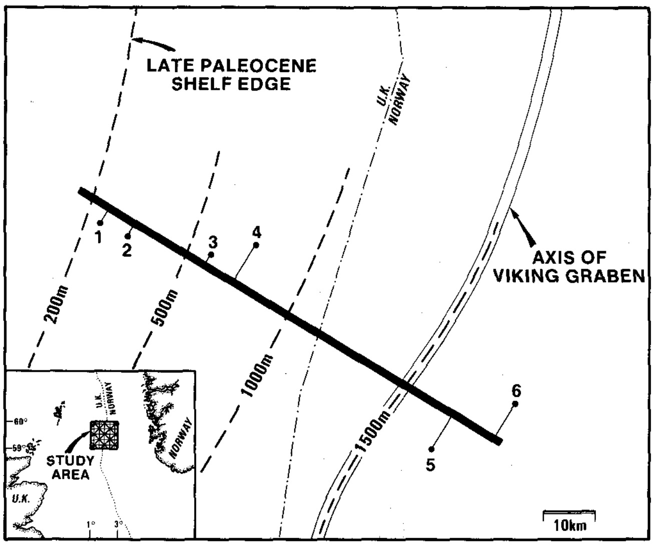

Fig. 1.
Well locations along paleoslope transect, Viking Graben, North Sea. Paleoslope contours are for Late Paleocene time.
Well 1 = Unocal 8/15-1; 2 = Unocal 9/11-4; 3 = Unocal 9/12A-5; 4 = Mobil 9/13-1; 5 = Esso 25/10-2; 6 = Esso 25/8-1.

WELL	SAMPLE TYPE	LITHOLOGIC DESCRIPTION	ESTIMATED AGE (Ma)
1	SIDEWALL	MICACEOUS, NON-CALCAREOUS CLAYSTONE	61.2
2	SIDEWALL	MICACEOUS, NON-CALCAREOUS CLAYSTONE	61.2
3	CUTTINGS (BELOW CASING SHOE)	NON-CALCAREOUS CLAYSTONE	61.2
4	CONVENTIONAL CORE	SLIGHTLY-SILTY, PYRITIC SHALE	60.9
5	CONVENTIONAL CORE	SILTY MUDSTONE	61.7-62.7
6	CONVENTIONAL CORE	MICACEOUS CLAYSTONE	61.7-62.7

Fig. 2.
Sample register for paleoslope transect study.
Note that all samples fall within a narrow time slice.

RESULTS

I. Taxonomic Composition:

All samples contain abundant Late Paleocene type-A "flysch-type" agglutinants (Gradstein and Berggren 1981). I identified a total of 68 agglutinated species assigned to 32 genera. Tubular-shaped astrorhizid fragments dominate all the samples, with species of *Trochammina*, *Haplophragmoides*, *Spiroplectammina*, and *Saccammina* being conspicuous but less abundant. Calcareous elements are either absent or extremely rare. Two samples contain a distinctive, large-sized radiolarian, *Cenosphaera lenticularis* (Grzybowski), which were included in the specimen counts.

II. Tubular-Shaped Agglutinants:

Tubular-shaped, single-chambered, fossil agglutinated foraminifera from deep-ocean paleoenvironments (chiefly astrorhizids and rhizaminids) present numerous difficulties to taxonomists attempting to construct a "natural classification" for these forms. The vast majority of fossil tubular-shaped specimens are broken fragments representing a smaller and usually unknown size portion of the pre-mortem test. Classification of Recent deep-ocean, tubular-shaped forms usually requires whole tests displaying important taxonomic features such as proloculi, central chambers and branches. Unfortunately, these features are structurally weak and rarely preserved in fossil material. Thus, fossil, tubular-shaped fragments rarely possess the diagnostic features necessary for specific or even generic identification. Schröder (1986) demonstrated the difficulty of assigning even generic names to Recent tubular-shaped fragments from the deep western North Atlantic.

Some Recent deep-ocean agglutinated species are non-selective when choosing building materials for their test (Schröder 1986). Thus, specimens of the same species from different bottom environments are morphologically dissimilar and often regarded as separate taxa. Similarly, Gooday (1986) suggested that three different living "species" of *Rhabdammina* from the abyssal Atlantic are actually different growth stages of one species.

Classification schemes proposed for Recent primitive agglutinated foraminifera based on wall texture and requiring thin-sectioning techniques (e.g. Hofker 1972) are difficult to apply to fossil material owing to diagenetic effects such as test collapse, distortion and recrystallization. These taxonomic difficulties associated with fossil tubular-shaped agglutinated foraminifera have led to a profusion of synonyms in the literature. Also, many primitive agglutinated species are geologically long ranging and extant in the deep ocean (Hofker 1972; Schröder 1986). Thus, many living species dredged from the deep ocean and described in the late 1800's (e.g. Brady 1884) are actually senior synonyms for fossil species described subsequently in the literature.

In classifying most of the tubular-shaped agglutinated specimens recovered from the samples in this study, I believe it is best not to add to the already confused taxonomic situation by assigning specific names. Instead, most of the tubular forms are assigned to four, informal taxonomic groups which in turn, are related to possible Recent generic analogs (see Taxonomy section).

III. Paleobathymetric Trends:

"Flysch-type" agglutinants from wells 1 and 2 (upper slope) are fine to medium-grained, white in color, and relatively medium-sized. Middle slope (wells 3 and 4) agglutinants are relatively coarse-grained, brownish-green to gray in color and relatively large-sized. On the basin floor (wells 5 and 6), specimens are fine-grained, dark green to white in color and relatively small-sized.

Analysis of the abundance distributions of the 68 species indicates that 11 of the more common species and species groups and one species of radiolarian had distinctive paleobathymetric ranges in the Late Paleocene Viking Graben (figure 3). Upper and middle slope assemblages are difficult to distinguish on the basis of species content alone. In general, coarse-grained species such as *Recurvoides* sp. cf. *R. gerochi* Pflaumann, *Psammosphaera fusca* Schultze and Tubular Group C are relatively less abundant in upper slope assemblages. *Tolypammina* sp. in upper slope assemblages is small-sized and attached to quartz grains only. Middle slope assemblages contain a relatively greater proportion of large-sized, coarse-grained species such as *P. fusca*, *R.* sp. cf. *R. gerochi*, Tubular Group C and *Tolypammina* sp. which is found attached to quartz grains and other specimens of agglutinated foraminifera. The fine-grained species *Spiroplectammina spectabilis* (Grzybowski) is relatively less abundant in middle slope than in upper slope and basin floor assemblages. Basin floor assemblages are distinctive from shallower assemblages and are characterized by *Pseudobolivina* sp., *Rzehakina minima* Cushman and Renz, *Recurvoides* ex. gr. *walteri* (Grzybowski) and Tubular Group D. Tubular Group A occurs less abundantly on the basin floor than in shallower assemblages. *Haplophragmoides walteri* (Grzybowski) is absent in the basin floor assemblages. The radiolarian *Cenosphaera*

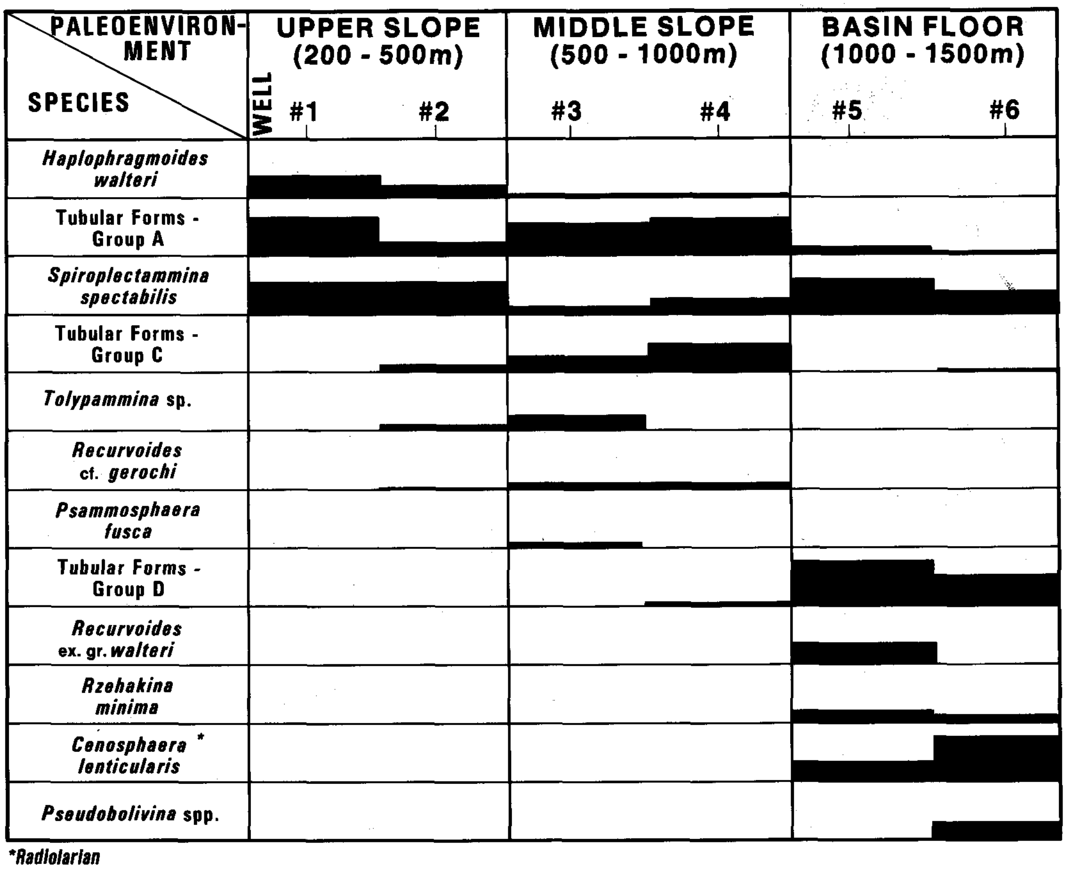

Fig. 3.
Relative abundance distributions if flysch-type agglutinated species along paleoslope transect.

lenticularis is restricted to the basin floor assemblages, supporting other reports which show the maximum abundance of radiolarians occurs in the deepest portions of marine basins (e.g. Ingle 1980).

IV. Relationship to Bottom Energy Conditions:

Reports of modern "flysch-type" agglutinants from the northwestern Atlantic continental margin (Schafer *et al.* 1983; Schröder 1986) indicated that small, delicate, fine-grained and often branching forms such as *Rhizammina* prefer fine-grained, low energy environments. Conversely, coarser-grained, robust genera including *Recurvoides*, *Psammosphaera* and *Rhabdammina* prefer areas of higher energy. Using this as a model for the Late Paleocene Viking Graben, the fine-grained species *Rzehakina minima*, *Pseudobolivina* sp., and Tubular Group D are concentrated in the basin floor and suggest a relatively tranquil environment in the area of wells 5 and 6. Conversely, the coarse-grained species *R.* sp. cf. *R. gerochi*, *P. fusca*, *Tolypammina* sp. and Tubular Group C are all concentrated on the middle slope and suggest higher-energy conditions were operative in the area of wells 3 and 4 during the Late Paleocene.

V. Relationship to Turbidity Current Deposition:

Figure 4 shows the number of agglutinated species, Shannon-Wiener diversity and equitability values of the six samples along the Viking Graben transect. Basinfloor samples (wells 5 and 6) have consistently-higher values than upper slope samples (wells 1 and 2) in accord with known trends for modern agglutinants (Scott *et al.* 1983; Jones and Charnock 1985). The middle slope samples (wells 3 and 4), however, have the highest and lowest values of the data set. A clue to a possible explanation for these extreme values lies in the coarse-grained nature of the agglutinated species that dominate these middle slope samples. As shown above, these coarse-grained speces suggest higher-energy environments. In the Late Paleocene Viking Graben, this higher energy was probably related to deposition via turbidity currents. Kaminiski et al. (this volume) plot Shannon-Wiener diversity values for Paleocene FTAs of Trinidad in both turbiditic and non-turbiditic sections. Sample diversities within turbidites show great variability, with values both higher and lower than those recorded for non-turbidites. This great range in values for the turbidites is probably related to the various hydraulic regimes within a turbiditic sequence. A winnowing flow might deposit a low diversity lag

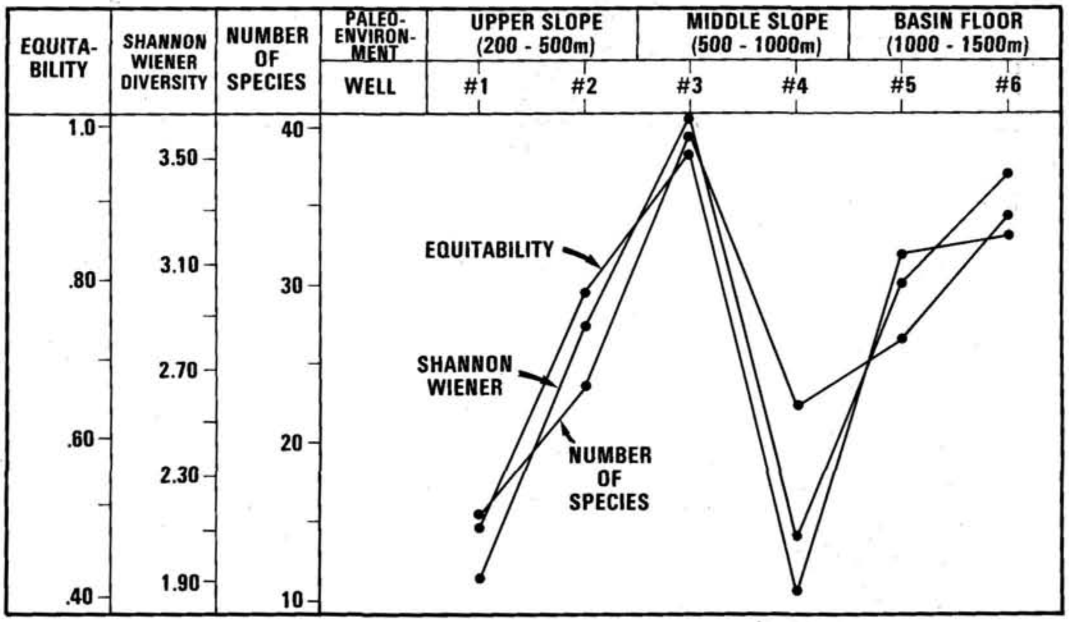

Fig. 4.
Faunal trends along paleoslope transect.

assemblage of agglutinants and a rapidly decelerating flow might deposit a high diversity assemblage of agglutinants derived form different sources (Schröder 1986). Thus, the extreme values im middle slope samples from the Viking Graben transect may reflect differing hydraulic regimes within turbidity current deposits. This also suggests that the distribution of species on the middle slope may be based to some degree on transported assemblages from shallower depths.

DISCUSSION

It has been clearly demonstrated that FTAs have an extensive (paleo)bathymetric distribution (see Introduction above). When environmental conditions of the sea bottom are conducive (see Miller et al. 1982, for discussion), FTAs will thrive, whether that favorable sea floor extends to the basin floor at 1500 m as in the Late Paleocene Viking Graben or to much greater depths as in the open ocean. "Flysch-type" taxa, therefore, probably cannot be used to quantify deep-water paleobathymetry on a worldwide basis. Thus, it may be more fruitful to look at relative depth changes of "flysch-type" agglutinants in various geological settings and see if there are consistent interregional (paleo)bathymetric patterns.

These types of studies are just now coming forth and some of the depth trends in the Viking Graben seem to agree with those reported elsewhere. For example, Jones and Charnock (1985) showed that the abundance of modern tubular-shaped astrorhizids (and komokiaceans) steadily increases from upper to lower bathyal depths (200-2250 m) relative to other "morphogroups" opf agglutinated foramiinifera. At abyssal depths (>2250 m), tubular-shaped forms decrease in abundance to values more similar to middle bathyal depths. These authors also showed that the abundance of globular saccamminids steadily increases from shelf edge to abyssal depths. Along the Viking Graben paleoslope transect, similar trends in the relative abundances of these "morphogroups" are observed (figure 5). Kaminski *et al.* (this volume) compare the paleobathymetric trends of "flysch-type" agglutinants from the Late Cretaceous and Paleocene of southern California, western North Atlantic margin, Trinidad, Labrador Sea, Polish Carpathians and Atlantic DSDP sites. Several genera and species consistently occur in greater abundance in the deeper facies of all these areas, including *Rhizammina* and *Rzehakina*. In the Late Paleocene Viking Graben, *Rzehakina minima* is restricted to the deepest paleoenvironment as is Tubular Group D, which bears a strong resemblance to modern *Rhizammina*. These similarities suggest that by utilizing a standardized taxonomy to

POSITION ALONG PALEOSLOPE TRANSECT / FLYSCH-TYPE "MORPHOGROUP"	WELLS 1 & 2 UPPER SLOPE (200-500m)	WELLS 3 & 4 MIDDLE SLOPE (500-1000 m)	WELLS 5 & 6 BASIN FLOOR (1000-1500m)
TUBULAR-SHAPED ASTRORHIZIDS	33	55	38
GLOBULAR-SHAPED SACCAMMINIDS	3	7	12

Fig. 5.
Average relative abundance [in %] of flysch-type morphogroups along Viking Graben paleoslope transect.

facilitate interregional comparisons, it may be possible to develop a relative paleobathymetric zonation based on "flysch-type" taxa.

As discussed above, some of the distributional patterns of Late Paleocene Viking Graben species may be explained using Recent data. A correlation exists between size, coarseness of test and diversity patterns with bottom energy conditions and turbidity current depositional processes. These findings suggest that with more research on both modern and fossil FTAs a comprehensive biofacies model for deep-sea fans is possible. This model, in conjunction with a refined relative paleobathymetric zonation, would give petroleum geoscientists a powerful predictive tool to aid the exploration of hydrocarbons in deep-water deposits containing FTAs.

TAXONOMY

Those species and species groups having distinct paleobathymetric distributions (figure 3) are treated in this section. Foraminifera are listed alphabetically under family, sensu Loeblich and Tappan (1984). Complete listing of synonymies is not attempted; instead, the original reference is given, followed by, in most cases, one or more references that illustrate and/or describe my concept of the species. Four informal taxonomic groups of tubular-shaped agglutinated foraminifera (Groups A,B,C,D) and a species of radiolaria are also described.

Family PSAMMOSPHAERIDAE Haeckel 1894.

Psammosphaera fusca Schultze 1875
Plate 1, figure 6.

Psammosphaera fusca Schultze 1875, plate 2, figure 8 – Hofker 1972, plate 7, figures 1-3.

Psammosphaera cf. *fusca* Schultze, Kaminski 1983, plate 3, figures 1-2.

Family AMMODISCIDAE Reuss 1862.

Tolypammina sp.
Plate 1, figure 7.

Test a sinuous tube, attached to quartz grains and other agglutinated species, rarely with bulbous proloculus; matrix wall white, shiny.

Family RZEHAKINIDAE Cushman 1933.

Rzehakina minima Cushman and Renz 1946.
Plate 2, figure 2.

Rzehakina epigona (Rzehak) var. *minima* Cushman and Renz 1946, plate 3, figure 5.

Rzehakina minima Cushman and Renz, Hanzliková 1972, plate 4, figure 11.

Family HAPLOPHRAGMOIDIDAE Maync 1952

Haplophragmoides walteri (Grzybowski 1898)
Plate 2, figure 6.

Trochammina walteri Grzybowski 1898, plate 11, figure 31

Haplophragmoides walteri (Grzybowski), Gradstein and Berggren 1981, plate 6, figure 6.

Recurvoides ex. gr. *walteri* (Grzybowski 1898)
Plate 2, figure 1.

Haplophragmium walteri Grzybowski 1898, plate 10, figure 24.

Recurvoides ex. gr. *walteri* (Grzybowski), Gradstein and Berggren 1981, plate 8, figures 4-7.

Recurvoides sp. cf. *R. gerochi* Pflaumann 1964.
Plate 2, figure 4.

Recurvoides gerochi Pflaumann 1964, plate 14, figure 1a-d.

Test small for the genus, commonly pink in color; chambers coarse-grained and numerous; sutures indistinct; quartz grains in final whorl tend to obscure the aperture.

Family SPIROPLECTAMMINIDAE Cushman 1927.

Spiroplectammina spectabilis (Grzybowski) 1898.
Plate 2, figure 5.

Spiroplecta spectabilis Grzybowski 1898, plate 12, figure 12.

Spiroplectammina spectabilis (Grzybowski), Kaminski 1984, plates 1,2 (with synonymy)

Family PSEUDOBOLIVINIDAE Wiesner 1931.

Pseudobolivina sp.
Plate 2, figure 3.

Test minute; chambers biserially arranged, 4 to 5 in each row; sutures depressed, pointing toward apical end at low angle; final two chambers inflated; aperture indistinct, terminal, slightly produced.

TUBULAR-SHAPED AGGLUTINATED FORAMINIFERA

Group A

Plate 1, figure1.

Test large sized; in straight, cylindrical segments, uncollapsed and circular in cross-section, fine to medium-grained; test wall sugary in appearance; annular constrictions common, branching not observed. Possible Recent analogs: *Rhabdammina*, *Bathysiphon*.

Group B

Plate 1, figure 5.

Test large sized; in straight to curved segments, fully to slightly collapsed; collapsed specimens often with median furrow; fine to coarse grained; test wall somewhat rough, annular constrictions common, rarely branched. Possible Recent analogs: *Rhabdammina*, *Hyperammina*, *Rhizammina*

Group C.

Plate 1, figure 4

Test large sized; in essentially straight segments, variably collapsed; extremely coarse-grained, with a few grains much larger than others and protruding from test wall, branching not observed. Possible Recent analogs: *Rhabdammina, Hyperammina, Astrorhiza?*

Group D

Plate 1, figures 2-3.

Test small sized; in curved segments, mostly collapsed; extremely fine-grained (matrix wall), delicate, very smooth and sometimes shiny, rarely branched, may have bulbous proloculus attached. Possible Recent analog: *Rhizammina.*

RADIOLARIA

Cenosphaera lenticularis (Grzybowski 1896)

Plate 2, figure 7.

Reophax lenticularis Grzybowski 1896, plate 8, figure 22.
Cenosphaera sp. King 1983, plate 1, figure 8.

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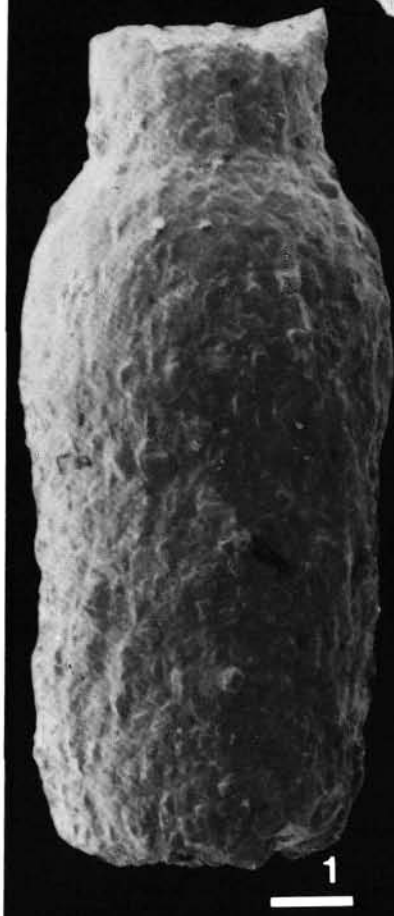
PLATE 1

Figure 1	Tubular Group A: Side view showing anular constrictian, bar = 100µm
Figures 2,3	Tubular Group D: 2, side view of branched specimen, bar = 50µm; 3, side view, bar = 100µm
Figure 4	Tubular Group C: side view, bar = 200µm
Figure 5	Tubular Group B: Side view showing median furrow, bar = 100µm
Figure 6	*Psammosphaera fusca* Schultze side view, bar = 100µm
Figure 7	*Tolypammina* sp. specimen attached to quarta grain, bar = 1000µm



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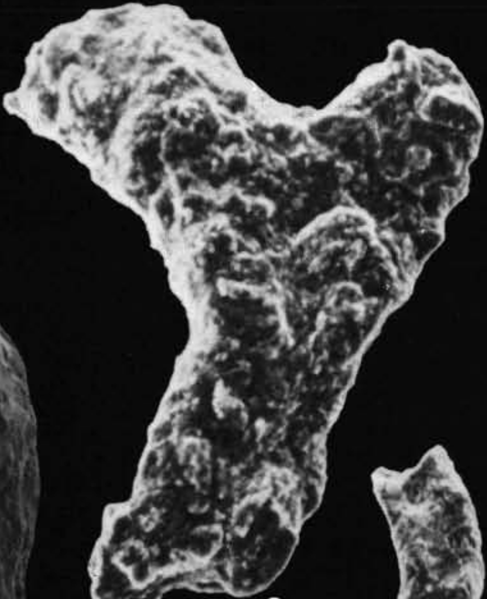

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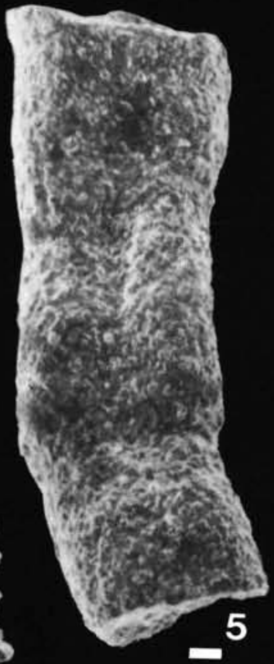

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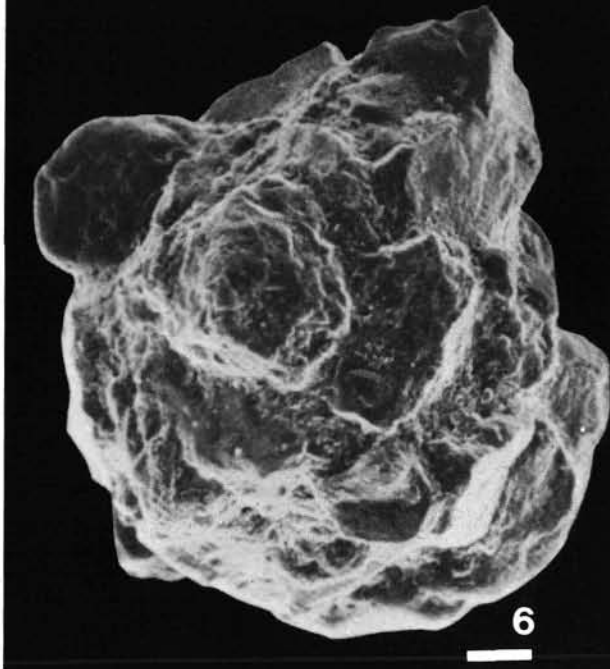

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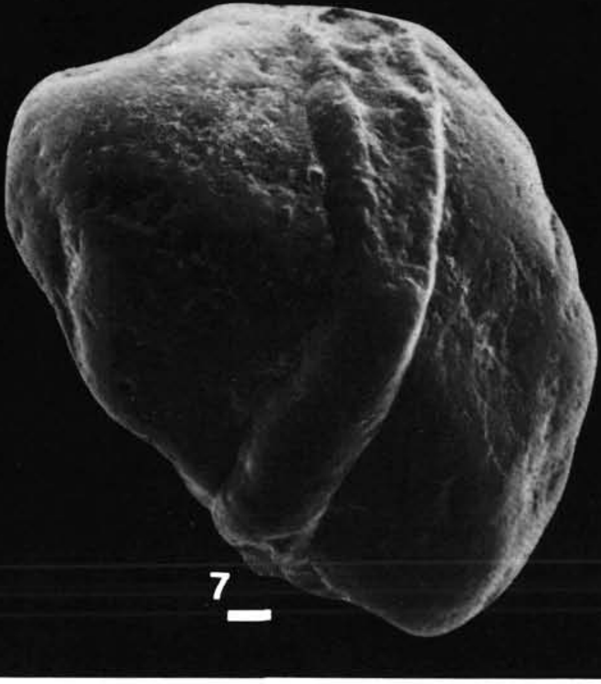

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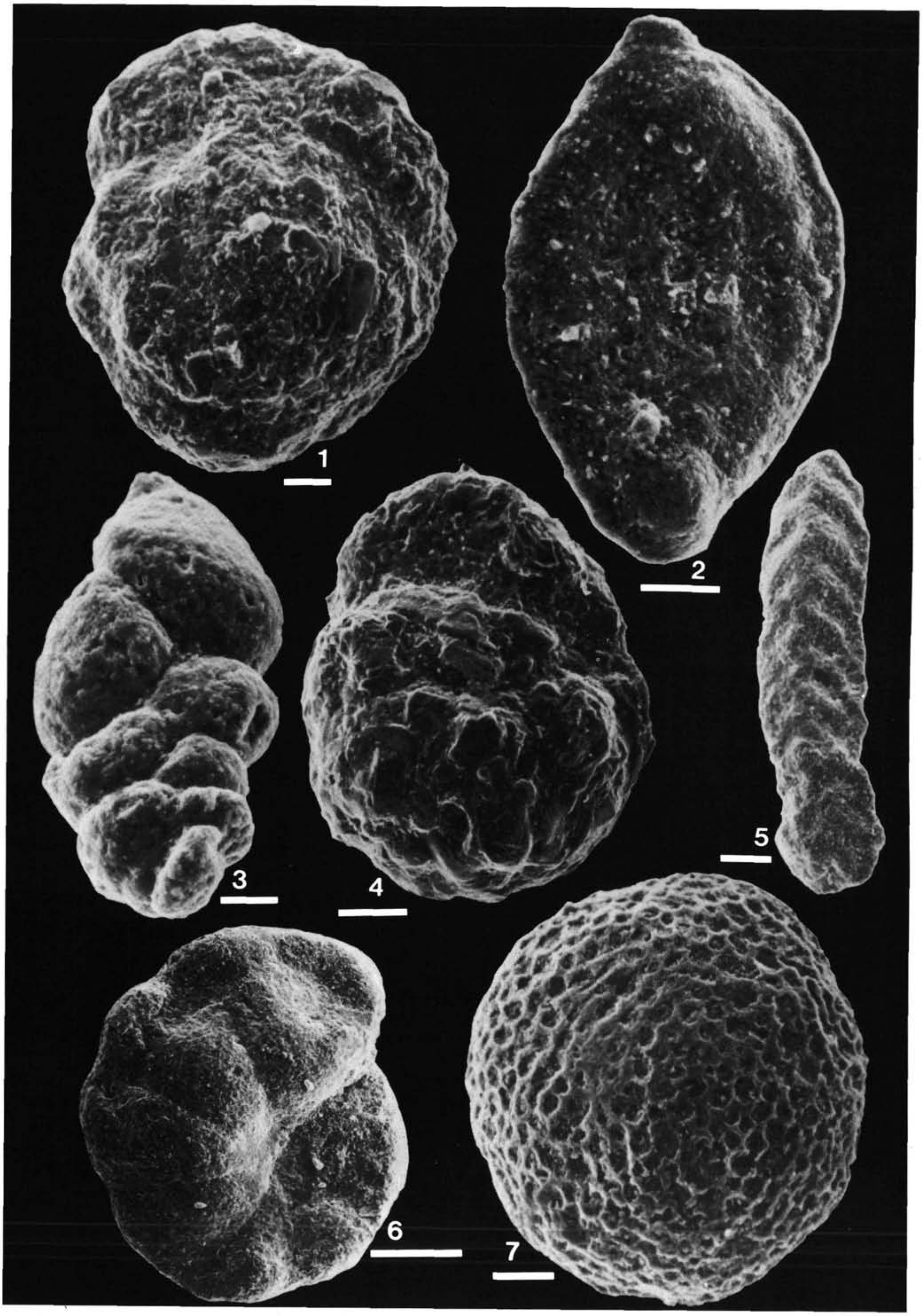
PLATE 2

Figure 1	*Recurvoides* ex. gr. *walteri* (Grzybowski) apertural view, bar = 50μm
Figures 2	*Rzehakina minima* Cushman and Renz side view, bar = = 50μm
Figure 3	*Pseudobolivina* sp. side view, bar = 25μm
Figure 4	*Recurvoides* sp. cf. *R. gerochi* Pflaumann apertural view, bar = 100μm
Figure 5	*Spiroplectammina spectabilis* (Grzybowski) side view, bar = 100μm
Figure 6	*Haplophragmoides walteri* (Grzybowski) side view, bar = 100μm
Figure 7	*Cenosphaera lenticularis* (Grzybowski) side view, bar = 50μm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