

Endemic and cosmopolitan Upper Cretaceous agglutinated foraminifera of the western African margin, equatorial and central Atlantic

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ABSTRACT

Three distinct Late Cretaceous agglutinated foraminiferal associations, characterising palaeobathymetric settings from the inner shelf to the abyss, are recognised along shelf to basin transects of the western African margin (equatorial and central Atlantic). These groupings are supported by the results of a correspondence analysis on 177 samples from the Benue Trough in Nigeria, Wells CM2, CM4 and CM10 offshore Senegal, DSDP Hole 367 in the Cape Verde Basin and ODP Hole 959 on the Côte d'Ivoire-Ghana Transform Margin.

1. A low diversity association dominated by organically cemented, coarsely agglutinated taxa, including *Ammotium nkalagum*, *Kutsevella* sp. 1 and *Ammobaculites* spp., is found in marginal marine sites, originally situated close to the palaeo-coastline (inner part of the Benue Trough in Nigeria, Wells CM2 and CM4 along the Casamance transect).

2. An agglutinated association of variable taxonomic composition is observed in open marine settings, situated on the present day continental shelf, but possibly at greater depth in the Late Cretaceous (Well CM10, and distal parts of the Tarfaya Basin). Changes in taxonomic composition appear related to fluctuations in the intensity of the clastic flux and/or oxygen minimum zone. Intermittent occurrences of *Gaudryina laevigata*, *Gaudryina pyramidata*, *Reophax* cf. *duplex*, *Ammomarginulina* sp. 1, *Hyperammina* spp., *Haplophragmoides* spp., *Trochammina* spp. and *Textulariopsis* spp. are recorded at Well CM10, whereas in the Tarfaya Basin marked fluctuations occur in the relative abundance of *Pseudoclavulina clavata*, *Gaudryina cretacea*, *Marssonella oxycona*, *Tritaxia capitosa*, *Spiroplectinella cretosa*, *Haplophragmoides* sp. A and *Dorothia* sp. 1.

3. A high diversity organically cemented agglutinated association including *Uvigerinammina jankoi*, *Karrerulina conversa*, *Rzehakina spiroloculinoides*, *Rzehakina epigona*, *Rzehakina inclusa*, *Saccammina grzybowskii*, *Saccammina placenta*, *Hyperammina dilatata*, *Caudammina gigantea* and *Caudammina ovula* characterises sub-CCD pelagic settings (DSDP Hole 367, ODP Hole 959).

Endemic agglutinated foraminifera are found in marginal marine assemblage and, to a lesser extent, in open shelf assemblages during regressive episodes. These endemic associations reflect the existence of limited connections with the open ocean in the shallower and more restricted parts of basins. Cosmopolitan deep-water agglutinated assemblages, with similar taxonomic composition in the North and South Atlantic occurred at least since the Santonian. These deep-water assemblages provide evidence for the existence of a rather uniform, oxic deep-water mass and an Atlantic ocean-wide deep-water circulation system since that time.

INTRODUCTION

Upper Cretaceous benthic foraminiferal assemblages from western African coastal basins bear a unique record of the palaeoceanographic evolution of the equatorial western African margin during the Late Cretaceous. Agglutinated foraminifera characterise a variety of marine settings along the western African margin of the equatorial Atlantic, from restricted inner neritic to sub-CCD abyssal depths. They provide useful biostratigraphic markers and palaeoenvironmental indicators, and may be used to constrain the palaeoceanographic history of the

margin, as it evolved from a transform margin setting to a passive stage during the Late Cretaceous and deep-water connections became established between the North and South Atlantic after the opening of the central Atlantic gateway. The distribution of Upper Cretaceous agglutinated foraminifera in western African coastal basins is still poorly understood, due to a lack of published data and the absence of a unified benthic foraminiferal systematic nomenclature. The few studies, which have been published to date, include the documentations of Upper Cretaceous agglutinated foraminifera from

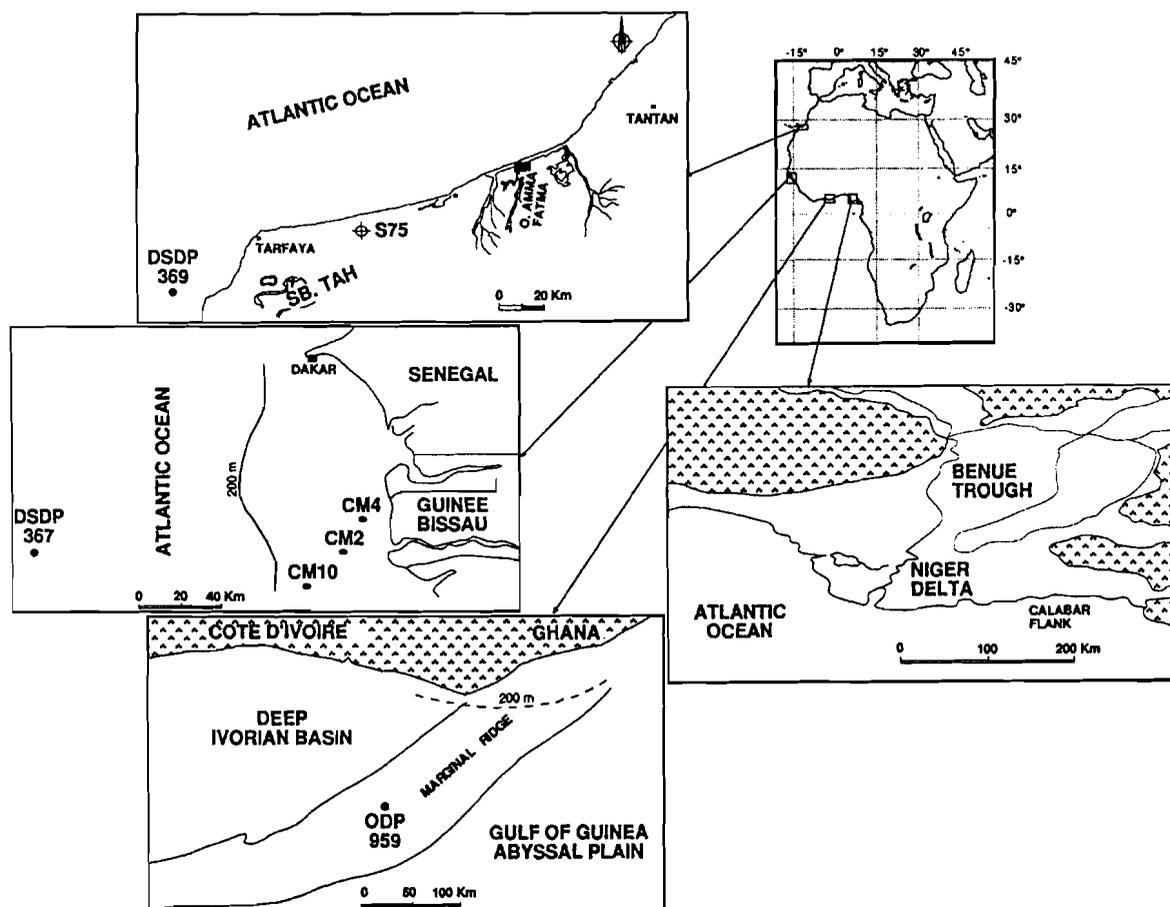


Figure 1. Location map for the Benue Trough in Nigeria, the Casamance Shelf offshore Senegal, DSDP Site 367, DSDP Site 369, ODP Site 959 and the Tarfaya Basin in southern Morocco.

Nigeria by Petters (1979, 1982), from Gabon by Volat *et al.* (1996) and from ODP Hole 959 on the Côte d'Ivoire-Ghana Transform Margin (CIGTM) by Kuhnt *et al.* (1998).

The main objectives of this work are to document the taxonomy and to investigate the distribution of Upper Cretaceous agglutinated foraminifera in equatorial coastal basins of western Africa along a latitudinal transect extending from Nigeria to Morocco. Material available for this study includes samples from onshore sections of the Benue Trough in Nigeria, cuttings and cored sections from three commercial wells drilled on the inner/middle and outer shelf of the Casamance margin offshore Senegal, samples from DSDP Hole 367 in the Cape Verde Basin, samples from ODP Hole 959 on the CIGTM and samples from onshore sections of the Tarfaya Basin in southern Morocco (Figure 1). The study also includes taxonomic comparisons with benthic foraminiferal assemblages from DSDP Hole 369, off southern Morocco and with published reports from Gabon and Nigeria. The arrangement of studied localities along shelf to basin transects will help to clarify palaeobathymetric distribution patterns along the western equatorial African margin during the Late Cretaceous and will provide information on the sea level history of the margin.

LOCATION AND GEOLOGICAL SETTING

Benue Trough, Nigeria

Our samples were taken from five locations in the Benue Trough: the Gongila Formation in the Ashaka limestone quarry (Northern Benue Trough), the Pindiga Formation in the Pindiga creek, southwest of Pindiga village (Northern Benue Trough), the Nkalagu Quarry (Central Benue Trough), the Lokpanta (Central Benue Trough) and the Ngbanocha sections (Southern Benue Trough). The lithology and sample positions in the Ashaka and Pindiga sections are shown in Figure 2. Similar information for the Nkalagu Quarry and the Lokpanta and Ngbanocha sections can be found in Holbourn *et al.* (1999b).

The Pindiga and Gongila Formations in the Northern Benue Trough consist of alternating marine limestone and shale/mudstone about 30 m thick for the Ashaka section and 60 m thick for the Pindiga section. The lower part of the Gongila Formation overlies the fluvio-deltaic sequence of the Bima sandstone and reflects the global late Cenomanian transgressive phase. It consists mainly of biogenic shallow water limestones, dated as late Cenomanian to early Turonian from their rich ammonite content (Popoff *et al.*, 1986). The upper part of the Gongila Formation is characterized by a

ASHAKA & PINDIGA SECTIONS (NORTHERN NIGERIA)

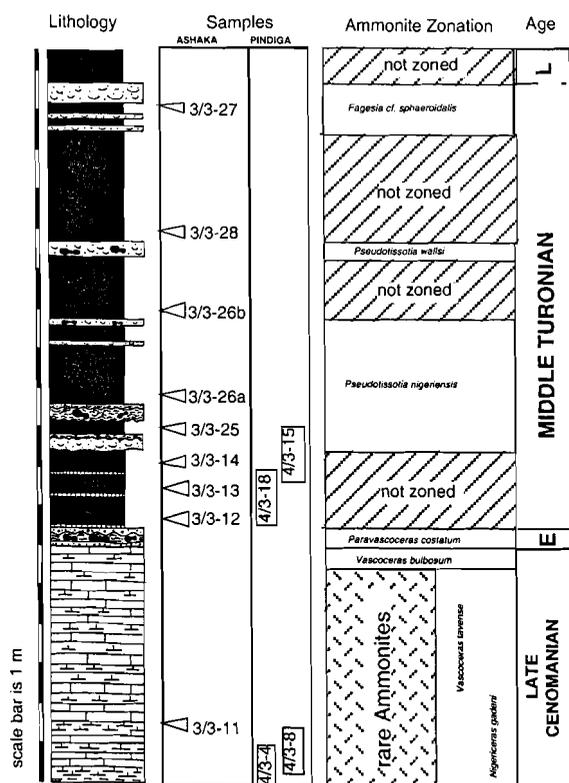


Figure 2. Lithology and positions of studied samples in the Ashaka and Pindiga sections in the Northern Benue Trough, Nigeria. Stratigraphy based on the ammonite zonation of Popoff *et al.* (1986).

sequence of dark grey fissile shales in which some thin lumachelle beds are intercalated, probably representing tempestites. Ammonites within these limestone layers indicate a middle Turonian age (Popoff *et al.*, 1986).

The Pindiga Formation is located approximately 100 km south of the Gongila-Ashaka area and represents part of the sedimentary fill of the Pindiga-Gombe Basin (Allix, 1983), where the rates of sedimentation were high from the Coniacian to the Maastrichtian (Popoff *et al.*, 1986). The outcrop studied consists of a predominantly shaly sequence with calcareous concretions and intercalations of biotrital limestones. The ammonite content in the Pindiga section concentrated in the limestone layers, indicates a late Cenomanian to early Turonian age (Popoff *et al.*, 1986). Generally, the Cenomanian/Turonian of the Pindiga section is thicker, more complete and less condensed than the Gongila Formation in the Ashaka Quarry.

The Turonian to Coniacian sediments from the Central and Southern Benue Trough consist of marginal clastic sequences on the edge of the basin and of black, laminated organic rich calcareous marls and limestones, overlain by fine grained sandstones, lumachelle beds and limestones with hardgrounds and tempestites in the central part of the basin. This sedimentary sequence corresponds to the

late Cenomanian/Turonian global eustatic sealevel rise, which resulted in the build-up of a wide shelf platform on the western flank of the basin, where condensed sections, tempestites and tidalites can be observed (Ojoh, 1988). After the Santonian compressive phase the uplifted region was then subjected to an important erosional stage during the Campanian (Ojoh, 1988). The palaeoenvironments of the Central and Southern Benue Trough have been interpreted as coastal areas to the north ranging to a deep outer shelf with shelf slope transition to the south (Kuhnt *et al.*, 1990). Two major lithostratigraphic units are recognised in the Turonian to Coniacian sedimentary succession (Ojoh, 1988):

1. *Nara Unit* (Turonian): The lower part of this unit is characterized by black, laminated organic-rich calcareous marls and limestones, with rich early Turonian inoceramid faunas (*Inoceramus opalensis*, *Sergipia* spp., determined by E.G. Kauffmann). The microfauna in this sequence is characterized by rich, purely planktonic foraminiferal assemblages of the Cenomanian/Turonian transition, which contain the zonal species *Whiteinella archaeocretacea*. These sediments are considered as the local expression of the global Cenomanian/Turonian boundary anoxic event (CTBE). The middle and upper part of the unit consists of fine-grained sandstone, lumachelle beds, tempestites, limestones and hardgrounds, and commonly exhibits characteristic features of condensed sequences. Typical ammonites are *Fagesia involuta*, *Pseudotissotia wallsi*, *Hoplitoides* sp. and *Coilopoceras cf. requienianum* of middle to late Turonian age (Ojoh, 1988).

2. *Awgu Unit* (Coniacian): This unit consists of platform carbonates and dark, silty argillites or fine-grained calcareous sandstones with *Gaudryceras* sp., *Inoceramus lusatie* and *Inoceramus schloenbachi* (Ojoh, 1988).

Casamance Shelf, offshore Senegal

The Senegal Basin is the largest of the Mesozoic West African basins, extending over Mauritania, Senegal, Gambia and Guinea Bissau and offshore to the Cape Verde Islands. Several exploration wells were drilled on the Casamance Shelf, offshore Senegal, which recovered extensive Upper Cretaceous sedimentary sequences. The most seaward of the wells CM10 is situated close to the shelf edge, while Wells CM2 and CM4 are in more proximal locations (Figure 1). Thick Turonian to Maastrichtian sedimentary sequences were recovered at Well CM2 (over 1600 m), Well CM4 (over 1200 m) and Well CM10 (over 1200 m). The Turonian at Well CM2 is approximately 150 m thick and consists of dark brown and bituminous clays. The Coniacian to Santonian is approximately 350 m thick and corresponds to dark claystones intercalated with calcareous and occasionally sandy layers. Similar lithological sequences were recov

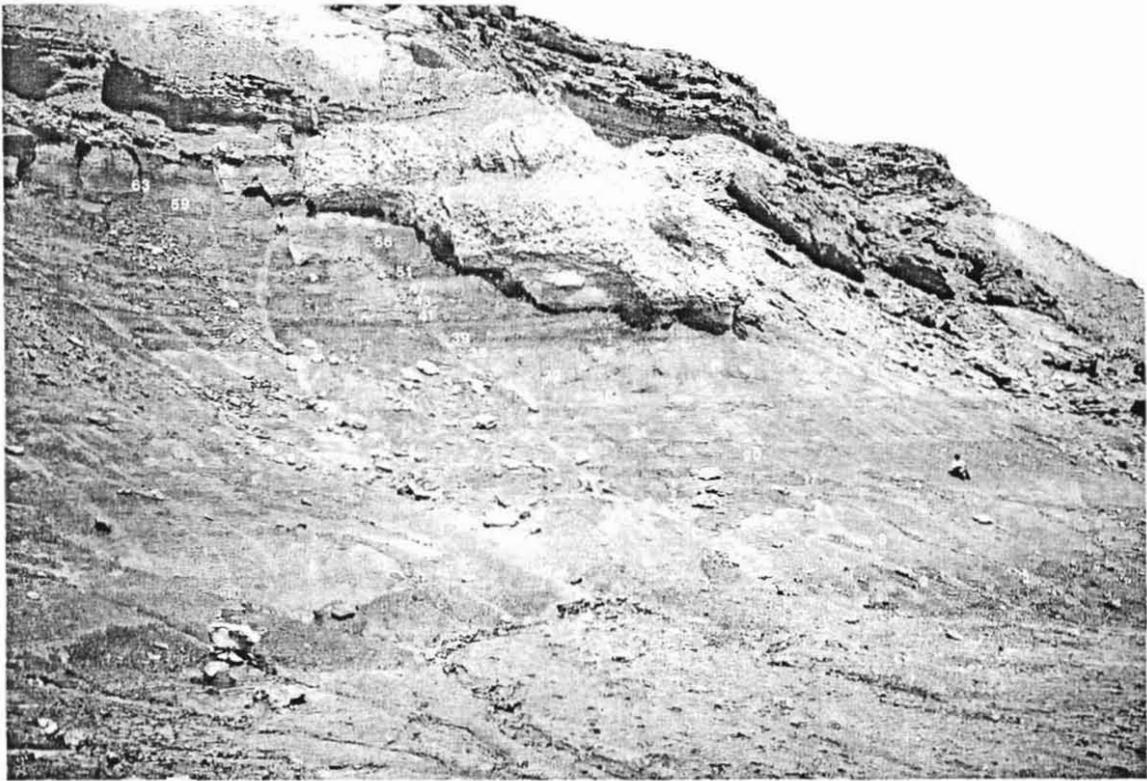


Figure 3. Lithology and positions of studied samples in the Sebkhah Tah section in southern Morocco.

ered at Well CM4, where the Turonian is nearly 100 m thick and the Coniacian to Santonian just under 200 m. At Well CM10 the Turonian is approximately 150 m thick and the Coniacian to Santonian, which corresponds to dark claystones and calcareous claystones with some lighter clayey calcareous layers, is 100 m thick. The Campanian to Maastrichtian successions at the three sites consist of dark claystones with silty, sandy or calcareous intervals (approximately 400 m at Wells CM2 and CM4 and 150 m at Well CM10) and an increasing silt and sand content towards the top of the successions. Details of the lithology and the positions of the studied samples from these wells can be found in Holbourn *et al.* (1999a).

Upper Cretaceous benthic foraminiferal assemblages in cutting samples from offshore Casamance Maritime 10 (Well CM10), off Senegal were documented by Ly & Kuhnt (1994). These authors interpreted the palaeoenvironment as a middle-outer shelf subjected to an intensified oxygen minimum zone under upwelling conditions during the Late Cretaceous. An integrated study of the benthic foraminiferal assemblages, clay minerals, kerogen types and carbonate microfacies in core and cutting samples from four offshore wells along a transect across the Casamance margin, extending from the inner shelf to the abyss was carried out by Holbourn *et al.* (1999a). Results from this study provided evidence that a productivity-driven oxygen minimum zone (OMZ) was established along the Casamance margin during most of the Late

Cretaceous. During sea level highstands at the Cenomanian/Turonian boundary and in the early Campanian the OMZ intensified and expanded to reach more proximal environments of the inner shelf (Wells CM2 and CM4).

Tarfaya Basin, southern Morocco

The Tarfaya Basin is an Atlantic coastal basin extending along southern Morocco between latitudes 28°N and 24°N, which has remained tectonically stable since the Cretaceous. Marginal marine sediments of Albian age are exposed along the northern edge of the basin. Extensive Upper Cretaceous sedimentary successions of Cenomanian to Turonian age are found along the coast and in the central part of the basin. Bituminous marls were deposited in the central part of the Tarfaya Basin during the Turonian in an open shelf setting, in water depth in the order of 200 to 300 m (Kuhnt *et al.*, 1990). These marls have high values of Total Organic Carbon (TOC) and are characterised by abundant planktonic foraminifera. Benthic foraminifera are either absent or consist of extremely low diversity calcareous assemblages, showing cyclic variations in abundance. These sediments partly correspond to the global anoxic event at the Cenomanian/Turonian boundary (CTBE). Approximately 50 km east from the town of Tarfaya, in the central part of the basin, a 20 m sedimentary succession of early Campanian age is exposed at Sebkhah Tah. Details of the lithology and the positions of the studied samples from this section can be found in Figure 3 and in

Holbourn *et al.* (1999b). The Sebkhah Tah succession consists of alternating dark and light marl layers, which show little alteration and contain diverse benthic foraminiferal assemblages including a large proportion of agglutinated forms. A preliminary investigation of the benthic foraminiferal assemblages, clay minerals and kerogen types indicated that the original environment of deposition was an outer shelf or upper slope receiving a high phytodetritus flux derived from enhanced surface productivity (Holbourn *et al.*, 1999b).

DSDP Holes 367, 369 and ODP Hole 959

DSDP Hole 367, was drilled in a water depth of 4748 m in the Cape Verde Basin, at 12°29.2'N, 20°02.8'W, approximately 330 km west of Wells CM2, CM4 and CM10. DSDP Hole 367 and the Casamance wells form an East to West coast to basin transect across the Senegal margin. DSDP Hole 369 was drilled in a water depth of 1752 m on the continental slope off southern Morocco at 26° 35.5'N, 14° 59'W, and is the offshore continuation of the Tarfaya transect. Lithological and sedimentological descriptions of the cores recovered from DSDP Sites 367 and 369 can be found in Lancelot, Seibold *et al.* (1977). ODP Hole 959D was drilled in a water depth of 2090.7 m on the northern flank of the Côte d'Ivoire-Ghana marginal ridge at 3°37.656'N, 2°44.149'W, on a small plateau close to the top of the Côte d'Ivoire-Ghana marginal ridge. This location already belongs palaeogeographically to the South Atlantic and may be roughly considered as an offshore prolongation of the Nigerian transect. Lithological and sedimentological descriptions of the cores recovered from this site can be found in Mascle, Lohman, Clift *et al.* (1996).

METHODS

For micropalaeontological studies, the samples were dried, weighed, soaked in distilled water and wet-sieved through a 63 µm (#230 mesh) screen; then, the residue was dried. Consolidated samples were first treated with a buffered 5% hydrogen peroxyde solution to help break up before sieving. In most cases the hydrogen peroxyde treatment did not lead to complete disintegration of the clay. These samples were dried and soaked in a concentrated anionic tenside solution (REWOQUAT of REWO Chemie, Steinau an der Straße, Germany), which usually disintegrated even slightly silicified samples. In DSDP/ODP core samples and commercial cuttings the complete residue was picked for benthic foraminifera. Most of the onshore samples and large core samples from commercial wells were split with a standard Otto-splitter. Fragments of tubular species were counted as one individual. Indeterminable fragments or extremely deformed specimens were picked but not included in the counts. Faunal occurrences only were recorded for cutting samples. The foraminiferal slides are housed in the

Micropalaeontology collections of the Institut für Geowissenschaften at the Christian Albrechts University in Kiel. Electron micrographs were made on a Camscan SEM at the Institut für Geowissenschaften at the Christian Albrechts University in Kiel.

Correspondence analysis was carried out using the correspondence factor analysis software package ECOLOGIX written in 1982 by M. Rioux (Montpellier University). ECOLOGIX was run on a CRAYVAX computer at the University of Kiel. Quantitative distribution charts of agglutinated foraminifera were combined into a coded matrix for a total of 177 samples with frequency counts of 144 taxa of agglutinated foraminifera (Table 1). Original counts of benthic foraminifera were converted into frequency counts as follows:

Number of foraminifera	Frequency
1-3	1 or r
4-10	2 or f
11-50	3 or c
>50	4 or a

A more detailed description of the application of correspondence analysis to micropalaeontological data sets is given in Saint-Marc & Berggren (1988) and Kuhnt & Moullade (1991).

FAUNAL ASSEMBLAGES

The available set of samples can be grouped into three main settings according to their palaeogeographic position: (1) marginal marine sites, which were situated close to the palaeo-coastline (inner part of the Benue Trough in Nigeria, Wells CM2 and CM4 along the Casamance transect); (2) open marine settings, situated on the present day continental shelf, but which may have been at greater depth in the Late Cretaceous (outer part of the Benue Trough, Nigeria; Well CM10, and distal parts of the Tarfaya Basin); (3) deep marine sites (ODP Hole 959 on the CIGTM, DSDP Hole 367 in the Cape Verde Basin, and DSDP Hole 369 off southern Morocco). These initial palaeogeographical settings are reflected by the grouping of agglutinated foraminifera in the correspondence analysis, which was run on a total of 177 samples from the Benue Trough in Nigeria, Wells CM2, CM4 and CM10 offshore Senegal, DSDP Hole 367 and ODP Hole 959 (Table 1; Figures 4 and 5).

Discrimination of assemblages

The correspondence analysis shows a distinct pattern in the distribution of agglutinated foraminifera at the five studied locations (Figures 4 and 5). The agglutinated assemblages from DSDP Hole 367 and ODP Hole 959 exhibit little variance in their position on the correspondence factor axes and differ

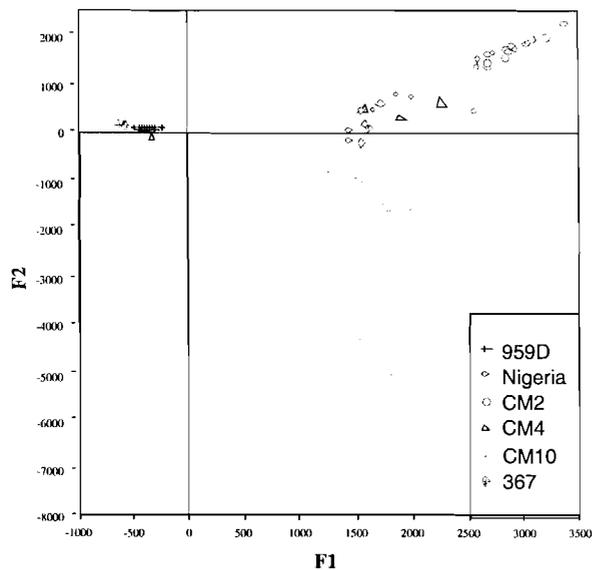


Figure 4. Correspondence analysis. Projection of samples on axes 1-2.

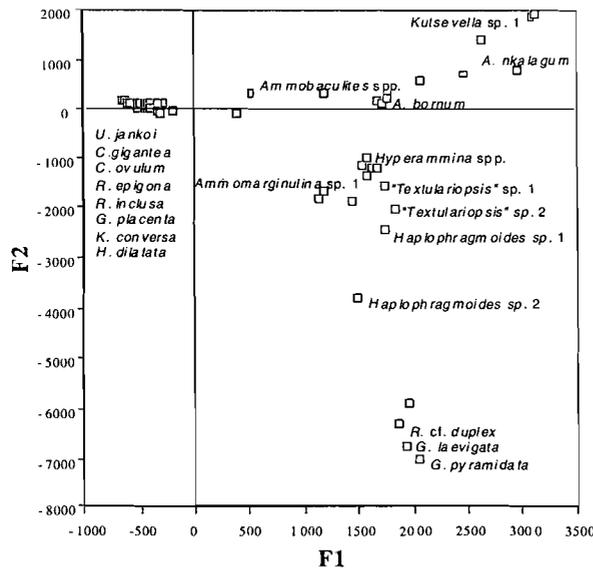


Figure 5. Correspondence analysis. Projection of variables on axes 1-2 showing representative taxa.

markedly from the assemblages of Nigeria (Ashakar, Pindiga, Ngalagu, Lokpanta and Ngbanocha sections) and the Casamance Shelf (Wells CM2, CM4 and CM10). The assemblages from Nigeria and from the most proximal wells on the Casamance Shelf (CM2 and CM4) plot close together but still exhibit a significant degree of variability. The assemblages from the most distal well on the Casamance Shelf (CM10) vary markedly in their position along the second factor axis and have a distinct composition. Thus, the correspondence analysis allows three main assemblages to be recognised (Figures 4 and 5): (1) a deep-sea assemblage at DSDP Hole 367 and ODP Hole 959 with a well defined, diverse composition, (2) an outer shelf assemblage (Well CM10), with a highly

variable composition and (3) a marginal marine low diversity assemblage (Nigeria, Wells CM2 and CM4), showing some variability in composition.

Palaeoenvironmental interpretation of assemblages *Marginal marine assemblages*

Upper Cretaceous benthic foraminiferal assemblages from inner shelf settings of the Benue Trough, Nigeria (Ashaka and Pindiga sections, Nkalagu Quarry, Lokpanta and Ngbanocha sections) and the Casamance Shelf, Senegal (Wells CM2 and CM4) exhibit extremely low diversity and are characterised by agglutinated foraminifera with coarsely agglutinated, organically cemented tests. Characteristic taxa are *Ammotium nkalagum*, *Ammotium bornum*, *Kutsevella* sp. 1, *Trochammina* sp. 1 and *Ammobaculites* spp. There is significant variation in the relative proportions of these taxa, probably reflecting different ecological preferences in a shallow and variable environment. The sediments from these localities, which typically contain abundant Type III organic matter and clay mineral assemblages dominated by the detrital minerals chlorite, illite and kaolinite, also indicate a shallow inner shelf setting receiving a high clastic input from the nearby continent (Holbourn *et al.*, 1999b). Benthic foraminiferal assemblages of similar composition were documented by Volat *et al.* (1996) from the Upper Cretaceous of Gabon and were interpreted by these authors as diagnostic of shallow, restricted, neritic conditions.

Outer shelf assemblages

Coniacian to Maastrichtian assemblages from Well CM10 on the Casamance Shelf generally contain buliminid associations but are intermittently dominated by agglutinated taxa, including *Gaudryina laevigata*, *Gaudryina pyramidata*, *Reophax* cf. *duplex*, *Ammomarginulina* sp. 1, *Hyperammina* spp., *Haplophragmoides* spp., *Trochammina* spp. and *Textulariopsis* spp. The palaeoenvironment of this area of the Casamance Shelf was interpreted as a middle-outer shelf subjected to an intensified OMZ during most of the Late Cretaceous (Ly & Kuhnt, 1994; Holbourn *et al.*, 1999b). The intermittent occurrence of large numbers of agglutinated taxa within the assemblages may reflect episodic increases in terrigenous flux from mainland Africa and/or fluctuations in the development of the OMZ on the outer shelf. Changes in the intensity of the clastic flux and OMZ were probably the main factors controlling the distribution of agglutinated foraminiferal assemblages on the Casamance Shelf during the Late Cretaceous.

The composition of the Lower Campanian benthic foraminiferal assemblages from the Sebkhah Tah section in the Tarfaya Basin differs markedly from that of the Casamance Shelf. This may be partly a reflection of the pelagic, carbonate-dominated sedimentation with low terrigenous flux in the Tarfaya Basin. The assemblages show variations in vertical

distribution, which appear related to changes in TOC values. In the lighter intervals at the base of the section (0 to 11.5 m) *Pseudoclavulina clavata*, *Gaudryina cretacea*, *Marssonella oxycona*, *Tritaxia capitosa*, *Spiroplectinella cretosa*, *Haplophragmoides* sp. A and *Dorothia* sp. 1 are recorded along with abundant nodosariids and gavelinellids. A marked change in assemblage composition and in the diversity of agglutinated foraminifera occurs in the darker interval above (11.5 to 15 m), where TOC reaches maximum values. The assemblages become strongly dominated by buliminids and bolivinids and by the agglutinated species *Haplophragmoides* sp. A and *Spiroplectinella cretosa*, while other agglutinated forms disappear. In the upper part of the section (15 to 20 m), where TOC values decrease, the relative proportion of buliminids and bolivinids declines and some agglutinated forms, initially present in the lower part of the section, reappear. The abundance of planktonic foraminiferal tests, including large numbers of heterohelicids and the occurrence of radiolarians in the assemblages as well as the high content of Type II organic matter in the sediments suggest high surface water productivity (Holbourn *et al.*, 1999b). Changes in the composition of the assemblages probably reflects changing oxygenation levels at the sediment/water interface in response to fluctuations in carbon flux rates to the seafloor and/or changing bottom water circulation.

Deep-sea assemblages

The Campanian to Maastrichtian benthic foraminiferal assemblages from DSDP Hole 367 in the Cape Verde Basin and from ODP Hole 959 on the CIGTM are characterised by organically cemented Deep-Water Agglutinated Foraminifera (DWAF) typically found in Upper Cretaceous sediments deposited below the CCD in the North Atlantic (Kuhnt *et al.*, 1998). Characteristic species are *Uvigerinammina jankoi*, *Karrerulina conversa*, *Rzehakina spiroloculinoides*, *Rzehakina epigona*, *Rzehakina inclusa*, *Saccammina grzybowskii*, *Saccammina placenta*, *Hyperammina dilatata*, *Caudammina gigantea* and *Caudammina ovula*.

The Campanian to Maastrichtian assemblages from ODP Hole 959 reflect well ventilated, oligotrophic conditions in an increasingly deeper bathyal to abyssal setting, except for a short interval in the early Campanian. This interval, characterised by low diversity assemblages of opportunistic deep-water benthic foraminifera ("Biofacies B"), probably corresponds to the Early Campanian Event (Kuhnt *et al.*, 1998). This palaeoceanographic event is recorded at various North Atlantic DSDP and ODP holes and in outcrop sections in Spain, Italy, Romania, Germany and Morocco. It may represent a short term warming episode during which the increased formation of warm saline bottom waters led to changes in the deep circulation of the Central Atlantic. This event is not registered at DSDP Hole

367, where stratigraphic resolution is poor due to spot coring.

PALAEOBIOGEOGRAPHY

Coniacian to Santonian marginal assemblages from the Casamance Shelf, dominated by *Ammotium nkalagum*, *Ammotium bornum*, *Kutsevella* sp. 1, *Trochammina* sp. 1 and *Ammobaculites* spp., closely resemble Turonian to Coniacian assemblages from the Benue Trough, Nigeria and assemblages documented by Volat *et al.* (1996) from Gabon. The composition of the assemblages suggests that a significant degree of endemism existed in these coastal basins, and points to the existence of migration barriers restricting faunal distribution during the Turonian to Santonian. By contrast, the occurrence of cosmopolitan agglutinated taxa in assemblages from the more distal Well CM10 on the Casamance Shelf, indicates that more open marine conditions prevailed on the outer shelf from the Coniacian to Maastrichtian with open connections to the North and South Atlantic Ocean.

The upper bathyal agglutinated foraminifera from the Sebkhah Tah section of the Tarfaya Basin are cosmopolitan, reflecting the existence of a well established oceanic circulation in this part of the basin. The Campanian to Maastrichtian assemblages from DSDP Hole 369 at the foot of the continental slope, on a direct transect from the Tarfaya Basin, show high faunal diversity but differ in composition from the assemblages of the Sebkhah Tah section. This is probably due to the reduced phytodetritus flux to the seafloor as particles sink to greater depths further out into the basin. Oxygen is consequently less depleted at these depths and the OMZ no longer intersects the seafloor. Virtually all of the species observed at Site 369 are cosmopolitan, providing further evidence for the existence of a cosmopolitan deep-water benthic foraminiferal fauna in the Late Cretaceous Atlantic Ocean.

Campanian to Maastrichtian assemblages from ODP Hole 959 and Coniacian to Maastrichtian assemblages from DSDP Hole 367 consist exclusively of DWAF, indicating that these sites were below the CCD. Changes in the composition of lower Turonian to lower Campanian assemblages at ODP Hole 959 reflect the subsidence history of this site during the active stage of the CIGTM, from a shelf setting to sub CCD depths. The Coniacian to Santonian benthic foraminiferal assemblages from ODP Hole 959 on the CIGTM are initially dominated by buliminid associations (Holbourn & Kuhnt, 1998). However, an overall increase in benthic foraminiferal diversity and in the proportion of DWAF in the Santonian assemblages signals a decrease in carbon flux and the gradual subsidence of the seafloor. The similarity in the composition of DWAF agglutinated assemblages from DSDP Hole 367, ODP Hole 959 and other DSDP and ODP holes in the North Atlantic provide evidence that a deep

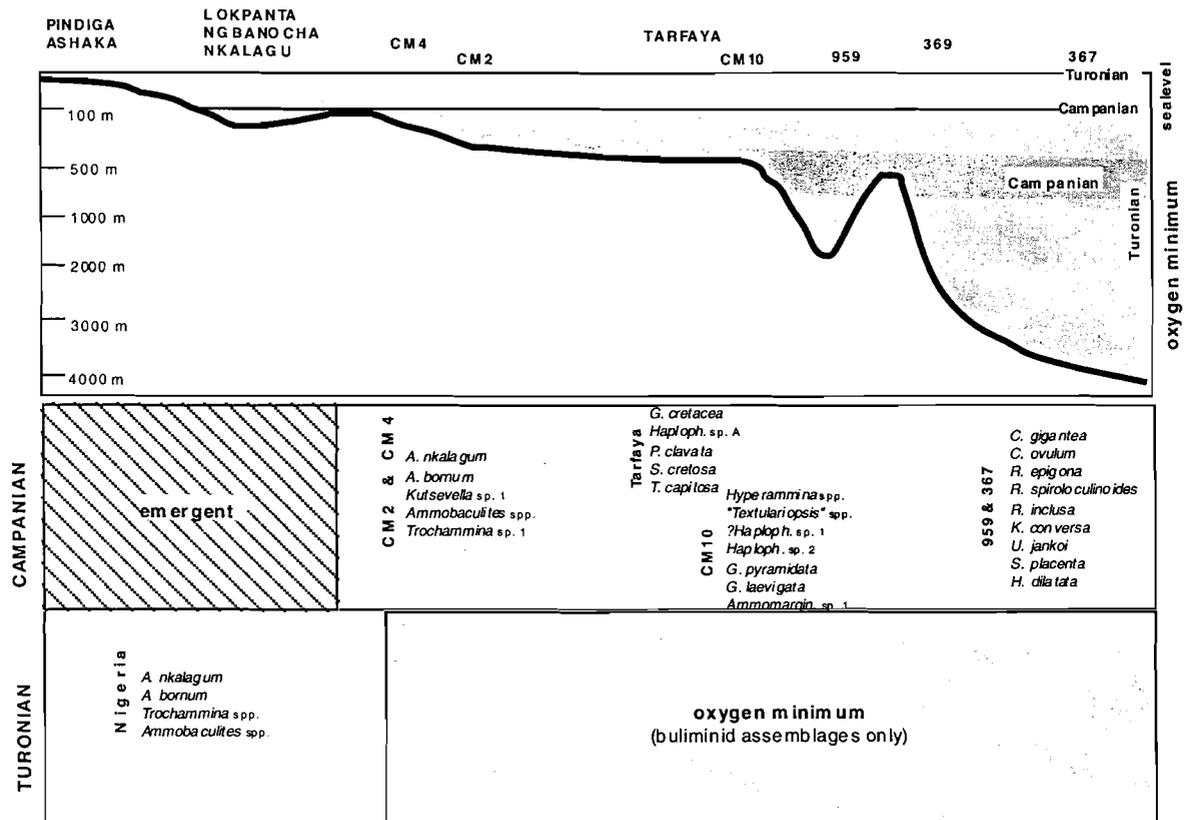


Figure 6. Late Cretaceous associations of agglutinated foraminifera in shelf to basin transects of the western equatorial African margin.

water circulation system was well established between the North and South Atlantic by the end of the Santonian.

CONCLUSIONS

Three distinctive Late Cretaceous associations of agglutinated foraminifera, characterising palaeobathymetric settings from the inner shelf to the abyss, are recognised in shelf to basin transects along the western equatorial African margin (Figure 6).

1. A low diversity association dominated by coarsely agglutinated taxa with organic cement including *Ammotium nkalagum*, *Kutsevelia* sp. 1 and *Ammobaculites* spp. is typically found in marginal marine environments of Nigeria, Gabon and Senegal. This association exhibits a high degree of endemism, and reflects limited connections with the open ocean in the shallower and more restricted parts of equatorial African basins.

2. The composition of the agglutinated association in shelf and upper slope environments is more variable. Intermittent occurrences of *Gaudryina laevigata*, *Gaudryina pyramidata*, *Reophax* cf. *duplex*, *Ammomarginulina* sp. 1, *Hyperammina* spp., *Haplophragmoides* spp., *Trochammina* spp. and *Textulariopsis* spp. on the Casamance Shelf probably reflect changes in terrigenous sedimentation and/or periodic contraction or expansion of the OMZ. Changes in the relative abundance of *Pseudoclavulina clavata*, *Gaudryina cretacea*,

Marssonella oxycona, *Tritaxia capitosa*, *Spiroplectinella cretosa*, *Haplophragmoides* sp. A and *Dorothyia* sp. 1 in the Tarfaya Basin appear related to fluctuations in the organic matter export flux from enhanced surface production, affecting oxygen resources at the seafloor. Shelf and upper slope assemblages from the Senegal Basin and Tarfaya Basin contain large numbers of cosmopolitan taxa, providing evidence that open connections existed between these coastal basins and the North and South Atlantic.

3. A Campanian to Maastrichtian deep-sea association is characterised by cosmopolitan DWAF including *Uvigerinammina jankoi*, *Karrerulina conversa*, *Rzehakina spiroloculinoides*, *Rzehakina epigona*, *Rzehakina inclusa*, *Saccammina grzybowskii*, *Saccammina placenta*, *Hyperammina dilatata*, *Caudammina gigantea* and *Caudammina ovula*. Diversity is generally high, reflecting well ventilated, oligotrophic conditions in a pelagic setting, except in the lower Campanian of ODP Hole 959. This impoverished early Campanian agglutinated biofacies probably indicate a major change in the deep circulation system of the Central Atlantic.

Endemic agglutinated foraminifera are observed only in marginal marine assemblages and, to a lesser extent, in open shelf assemblages during regressive periods. Cosmopolitan deep-water agglutinated assemblages, with similar taxonomic composition in the North and South Atlantic occurred at least since

the Santonian. These deep-water assemblages provide evidence for the existence of a rather uniform, oxic deep water mass and an Atlantic ocean wide deep-water circulation system since that time.

TAXONOMY

Generic definitions follow Loeblich & Tappan (1987). Quotation marks are used for tentative generic assignments in cases where the definition of the genus does not take wall structure into account. Open nomenclature is used for taxa that do not closely match published descriptions. The following abbreviations are used:

cf. for taxa similar to a known species but different in some detail.

sp. 1, 2... for species which do not match published descriptions.

sp. and spp. for taxa not determinable at the specific level.

DWAF from DSDP Holes 367 were previously documented by Krashenninikov & Pflaumann (1977). Updated taxonomic references for these taxa can be found in Holbourn *et al.* (1999a). DWAF from ODP Hole 959 were documented by Kuhnt *et al.* (1998). The taxonomic concept of these forms follows Kuhnt & Kaminski (1990) and Kaminski & Geroch (1993).

Ammobaculites sp. 1

Plate 4, Figs 7-9.

Diagnostic features. Coarsely agglutinated test with well developed initial planispiral whorl and broad, curved or rectilinear, evolute portion. Six or more chambers surround a distinct umbilicus in the planispire. Four or more low, wide chambers in the evolute portion are separated by depressed sutures.

Remarks. Resembles *Ammobaculites stephensoni* Cushman illustrated by Volat *et al.* (1996, pl. 9, fig. 156).

Range and Occurrence. Late Cretaceous in Well CM2, Casamance Shelf, Senegal.

Ammobaculites sp. 2

Plate 3, Fig. 8.

Diagnostic features. Coarsely agglutinated test with small initial planispiral whorl and long, narrow, curved or rectilinear, evolute portion.

Range and Occurrence. Late Cretaceous in Well CM2, Casamance Shelf, Senegal.

Ammomarginulina sp. 1

Plate 5, Figs 1-3.

Diagnostic features. Small, strongly compressed, coarsely agglutinated test showing tendency to become uncoiled. Chambers around the distinct umbilicus numerous and separated by depressed, oblique sutures.

Remarks. Most of our specimens do not have a well-developed evolute portion.

Range and Occurrence. Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

Ammotium bornum Petters, 1982

Plate 7, Figs 2-5.

Ammotium bornum Petters, 1982, pl. 2, figs 10-12.

Remarks. Differs from *A. nkalagum* and *A. nvalum* by its narrow, elongate shape and its small, involute initial portion. Intermediate forms between *A. bornum* and *A. nkalagum* are found.

Range and Occurrence. Albian to Santonian in central West Africa (Petters, 1982.)

Ammotium nkalagum Petters, 1982

Plate 5, Figs 4-7; Plate 6, Figs 9-12.

Ammotium nkalagum Petters, 1982, pl. 2, figs 4-6.

Ammotium nkalagum Petters. - Volat *et al.*, 1996, pl. 9, figs 158-161.

Remarks. Differs from *A. nvalum* by its wider and flabelliform shape. Our specimens are morphologically similar to modern *Ammotium*, typically found in neritic, brackish environments (J. Nagy, pers. comm., 1997).

Range and Occurrence. Turonian to Santonian in central West Africa (Petters, 1982). Recorded in the Turonian from Gabon (Volat *et al.*, 1996).

Ammotium nvalum Petters, 1982

Ammotium nvalum Petters, 1982, pl. 2, figs 1-3.

Remarks. Differs from *A. nkalagum* and *A. bornum* by its broad, ovate test, tapering towards the final chamber and its fairly smooth wall.

Range and Occurrence. Turonian to Santonian in central West Africa (Petters, 1982).

Dorothyia sp. 1

Plate 1, Figs 10-11.

Diagnostic features. Elongate, gently flaring, smoothly cemented test with last two chambers larger and markedly inflated.

Range and Occurrence. Occurs in the lower Campanian in the Tarfaya Basin, Morocco.

Gaudryina cretacea (Karrer, 1870)

Plate 2, Figs 8-9 & 12.

Verneuilina cretacea Karrer, 1870, pl. 1, fig. 1.

Gaudryina cretacea (Karrer). - Kuhnt, 1987, pl. 4, fig. 3; pl. 36, figs L7-10. - Almogi-Labin *et al.*, 1990, pl. 1, fig. 4. - Bolli *et al.*, 1994, figs 23.26.

Gaudryina laevigata Franke, 1914

Plate 3, Figs 1 & 3.

Gaudryina laevigata Franke, 1914, pl. 27, figs 1-2. - Ly & Kuhnt, 1994, pl. 2, figs 5-7.

Gaudryina pyramidata Cushman, 1926

Plate 3, Figs 2 & 4.

Gaudryina laevigata Franke var. *pyramidata* Cushman, 1926, pl. 16, fig. 8.
Gaudryina pyramidata Cushman. - Ly & Kuhnt, 1994, pl. 2, fig. 14.

?Haplophragmoides sp. 1

Plate 3, Figs 9-10.

Haplophragmoides excavatus Cushman & Waters. - Ly & Kuhnt, 1994, pl. 1, figs 9-10.
Haplophragmoides gr. *walteri* (Grzybowski, 1898). - Volat *et al.*, 1996, pl. 7, figs 128-137.

Diagnostic features. Planispiral, involute test with slightly lobulate, acute periphery. Ten to eleven chambers in the last whorl, inflated around the umbilicus and flattened at the periphery, are separated by depressed, curved or sigmoidal sutures forming a distinctive stellate pattern around the umbilicus. Wall is finely agglutinated with a smooth, polished finish.

Remarks. Wall shows a distinct alveolar structure. A detailed study of the wall structure is necessary to determine the generic affiliation of this taxon.

Range and Occurrence. Campanian-Maastrichtian in Gabon (Volat *et al.*, 1996). Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

Haplophragmoides sp. 2

Plate 3, Figs 6-7.

Diagnostic features. Inflated, involute test with nine or more inflated chambers in the last whorl, very rounded periphery and distinct, depressed umbilicus.

Remarks. Specimens are often compressed and deformed through diagenesis. Closely resembles *Haplophragmoides impensus* Martin, although our specimens are coarser-grained than the one illustrated by McNeil & Caldwell (1981, pl. 11, fig. 9). Appears to have a deeper umbilicus and more numerous chambers than *Haplophragmoides impensus* Martin, figured by Volat *et al.* (1996, pl. 7, figs 107-116).

Range and Occurrence. Campanian-Maastrichtian in Gabon (Volat *et al.*, 1996). Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

Haplophragmoides sp. A

Plate 1, Figs 3 & 5-8.

Diagnostic features. Involute to slightly evolute, coarsely agglutinated test with eight to eleven inflated chambers in the last whorl, round periphery and marked open umbilicus.

Range and Occurrence. Occurs in abundance in samples with highest TOC values in the lower Campanian of the Tarfaya Basin, Morocco.

Hyperammina spp.

Plate 4, Figs 1 & 5.

Remarks. *Hyperammina* represent 50% or more of all tests in Coniacian to Santonian sediments of Well CM10 on the Casamance Shelf.

Kutsevella sp. 1

Plate 5, Figs 8-13.

Diagnostic features. Compressed, evolute, coarsely agglutinated test showing tendency to become uncoiled with inflated chambers separated by depressed sutures.

Remarks. Brown organic lining visible in the inner whorls of some tests. Oval, areal aperture rarely visible.

Range and Occurrence. Late Cretaceous in Well CM2, Casamance Shelf, Senegal.

Marssonella oxycona (Reuss, 1860)

Plate 2, Figs 13-15.

Gaudryina oxycona Reuss, 1860, pl. 12, fig. 3.
Marssonella oxycona (Reuss). - Bartenstein & Bolli, 1986, pl. 2, figs 6-7.
Marssonella oxycona oxycona (Reuss). - Bolli *et al.*, 1994, figs 25.5-6.

Nothia robusta (Grzybowski, 1898)

Plate 1, Figs 1-2.

Dendrophyra robusta Grzybowski, 1898, pl. 10, fig. 7.
Rhabdammina robusta (Grzybowski). - Volat *et al.*, 1996, pl. 2, figs 13-14.

Plectina lenis (Grzybowski, 1896)

Plate 4, Fig. 18.

Spiroplecta lenis Grzybowski, 1896, pl. 9, figs 24-25.
Plectina lenis (Grzybowski). - Volat *et al.*, 1996, pl. 11, figs 207-209.

Pseudoclavulina clavata Cushman, 1926

Plate 2, Figs 10-11.

Pseudoclavulina clavata Cushman, 1926, pl. 17, fig. 4.

Reophax cf. duplex Grzybowski, 1896

Plate 4, Figs 2-3.

cf. *Reophax duplex* Grzybowski, 1896, 8, figs 23-25.
 cf. *Reophax duplex* Grzybowski. - Ly & Kuhnt, 1994, pl. 1, figs 1-4, text-figs 3/1-19 & 4/1-7.

Reophax globosus Sliter, 1968

Plate 4, Fig. 4.

Reophax globosus Sliter, 1968, pl. 1, fig. 12.
Reophax globosus Sliter. - Ly & Kuhnt, 1994, text-fig. 4/10.

Spiroplectammina chicoana Lalicker, 1935,

Plate 4, Fig. 19.

Spiroplectammina chicoana Lalicker, 1935, pl. 1, figs 8-9.
Quasispiroplectammina chicoana (Lalicker). - Bolli *et al.*, 1994, figs 21.28-29.

Spiroplectinella cretosa (Cushman, 1932)

Plate 2, Figs 4-7.

Spiroplectamina laevis (Roemer) var. *cretosa* Cushman, 1932, pl. 11, fig. 3.

Spiroplectamina laevis Cushman. - Almogi-Labin *et al.*, 1990, pl. 1, figs 1-3.

Spiroplectamina cretosa Cushman. - Hanzlíková, 1972, pl. 10, fig.9.

"Textulariopsis" sp. 1

Plate 4, Figs 14-15.

Diagnostic features. Elongate, narrow, strongly compressed, finely agglutinated test with slightly diverging sides. Inflated, numerous chambers are separated by fine, depressed sutures.

Range and Occurrence. Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

"Textulariopsis" sp. 2

Plate 4, Figs 12-13.

Diagnostic features. Large, elongate, finely agglutinated test with rounded periphery and markedly diverging sides. Ten to 15 inflated chambers in the last whorl are separated by fine, slightly depressed sutures.

Range and Occurrence. Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

"Textulariopsis" sp. 3

Plate 4, Figs 10-11.

Diagnostic features. Elongate, compressed, test with lobulate, rounded periphery and strongly diverging sides. Twelve to fifteen wide, low, inflated chambers in the last whorl are separated by distinctly depressed, curved sutures. Wall is fine to medium-grained and noncalcareous.

Range and Occurrence. Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

***Tritaxia capitosa* (Cushman, 1933)**

Plate 1, Figs 9 & 12-13; Plate 2, Figs 1-3.

Gaudryinella capitosa Cushman, 1933, pl. 5, fig. 8.

Pseudogaudryinella capitosa (Cushman). - Olsson & Nyong, 1984, pl. 4, figs 6-8.

***Trochammina* sp. 1**

Plate 4, Figs 16-17.

Diagnostic features. Large medium to coarse-grained, smoothly cemented test with four inflated chambers in the last whorl separated by depressed sutures.

Remarks. Specimens are often compressed and deformed through diagenesis.

Range and Occurrence. Late Cretaceous in Well CM10, Casamance Shelf, Senegal.

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REFERENCES

- Allix, P. 1987. Environnements mésozoïques de la partie Nord-Orientale du fossé de la Benue (Nigeria). Benue Seminar. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, 11, 155-157.
- Almogi-Labin, A., Bein, A. & Sass, E. 1990. Agglutinated foraminifera in organic-rich neritic carbonates (Upper Cretaceous, Israel) and their use in identifying oxygen levels in oxygen-poor environments. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. & Scott, D.B. (eds) *Palaeoecology, Biostratigraphy, Palaeoceanography and Taxonomy of Agglutinated Foraminifera*. NATO ASI Series C, Mathematical and Physical Sciences, 327, 565-585.
- Bartenstein, H. & Bolli, H.M. 1986. The Foraminifera in the Lower Cretaceous of Trinidad, W.I Part 5: Maridale Formation, upper part; *Hedbergella rohri* zone. *Eclogae Geologicae Helveticae* 7, (3), 945-999.
- Bolli, H. M., Beckmann, J.P. & Saunders, J.B. 1994. *Benthic foraminiferal biostratigraphy of the south Caribbean region*. 408 pp., Cambridge University Press, Cambridge.
- Cushman, J.A. 1926. The foraminifera of the Velasco Shale of the Tampico Embayment. *Bulletin of the American Association of Petroleum Geologists*, 10, (1/6), 581-612.
- Cushman, J.A. 1932. *Textularia* and related forms. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 8, (4), 86-97.
- Cushman, J.A. 1933. New American Cretaceous Foraminifera. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 9, (3), 49-64.
- Franke, A. 1914. Die Foraminiferen und Ostracoden des Emschers, besonders von Obereving und Derne nördlich Dortmund. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 66 (3), 428-443.
- Grzybowski, J. 1896. Otwornice czerwonych ilów z Wadowic. *Rozprawy Wydziału Matematyczno-przyrodniczego, Akademia Umiejętności w Krakowie*, serya 2, 30, 261-308.
- Grzybowski, J. 1898. Otwornice pokładów naftonośnych okolicy Krosna. *Rozprawy Wydziału Matematyczno-Przyrodniczego, Akademia Umiejętności w Krakowie*, serya 2, 33, 257-305.
- Hanzlíková, E. 1972. Carpathians Upper Cretaceous Foraminiferida of Moravia (Turonian-Maastrichtian). *Rozprawy Ústředního Ústavu geologického*, 39, 1-160.
- Holbourn, A.E.L. & Kuhnt, W. 1998. Turonian-Santonian benthic foraminiferal assemblages from Site 959D (Côte d'Ivoire-Ghana Transform Margin, Equatorial Atlantic): Indication of a Late Cretaceous oxygen minimum zone. In: Mascle, J., Lohman, G.P., Moullade, M. (eds). *Proceedings of the Ocean Drilling Program, Scientific Results*, 159, College Station, TX (Ocean Drilling Program), 375-388.
- Holbourn, A.E.L., Kuhnt, W., El Albani, A., Ly, A. & Herbin, J.P. 1999a. Palaeoenvironments and palaeobiogeography of the Late Cretaceous Casamance Transect (Senegal, NW Africa): Distribution patterns of benthic foraminifera, organic carbon and terrigenous flux. *Neues Jahrbuch für Geologie und Paläontologie*, 212, 335-377.

- Holbourn, A.E.L., Kuhnt, W., El Albani, A., Pletsch, T., Luderer, F. & Wagner, T. 1999b. Upper Cretaceous palaeoenvironments and benthic foraminiferal assemblages from potential source rocks from the western African margin, central Atlantic. *Geological Society Special Publication*, **153**, 195-222.
- Kaminski, M.A. & Geroch, S. 1993. A revision of foraminiferal species in the Grzybowski Collection. In: Kaminski, M.A., Geroch, S. & Kaminski, D.G. (eds) *The Origins of Applied Micropalaeontology: The School of Josef Grzybowski*. Grzybowski Foundation Special Publication, **1**, 239-323.
- Karrer, F. 1870. Ueber ein neues Vorkommen von oberer Kreideformation in Leitersdorf bei Stockerau und deren Foraminiferenfauna. *Jahrbuch der K.K. Geologischen Reichsanstalt*, **20**, 157-184.
- Krashennikov, V.A. & Pflaumann, U. 1977. Cretaceous agglutinated foraminifera of the Atlantic Ocean off West Africa (Leg 41, Deep Sea Drilling Project). In: Lancelot, Y., Seibold, E. et al. *Initial Reports of the Deep Sea Drilling Project*, **41**, 565-580.
- Kuhnt, W. 1987. *Biostratigraphie und Palaeoenvironment der Kreideserien des westlichen Rif und Betikum - ein Ansatz zur Rekonstruktion der Kreide-Palaeogeographie des Gibraltarbogens*. Dissertation, Universitaet Tuebingen, 1-271.
- Kuhnt, W. & Kaminski, M.A. 1990. Paleocology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and western Tethys. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. & Scott, D.B. (eds). *Palaeoecology, Biostratigraphy, Palaeoceanography and Taxonomy of Agglutinated foraminifera* NATO ASI Series C, Mathematical and Physical Sciences, **327**, 433-505.
- Kuhnt, W., Herbin, J.P., Thurow, J. & Wiedmann, J. 1990. Distribution of Cenomanian-Turonian Organic Facies in the Western Mediterranean and Along the Adjacent Atlantic Margin. In: Huc, A.Y. (ed.), *Deposition of Organic Facies*. AAPG Studies in Geology, **30**, 133-160.
- Kuhnt, W., Moullade, M. & Kaminski, M. 1998. Upper Cretaceous, K/T Boundary and lowermost Paleocene agglutinated foraminifera from Hole 959D. In: Mascle, J., Lohman, G.P., Moullade, M. (Eds). *Proceedings of the Ocean Drilling Program, Scientific Results*, **159**, College Station, TX (Ocean Drilling Program), 389-412.
- Lalicker, C.G. 1935. New Cretaceous Textulariidae. *Contributions from the Cushman Laboratory for Foraminiferal Research*, **11**, 1-13.
- Lancelot, Y., Seibold, E. et al. 1977. *Initial Reports of the Deep Sea Drilling Project*, **41**, Washington (U.S. Government Printing Office), 1-1259.
- Loeblich, A.R. & Tappan, H. 1987. *Foraminiferal Genera and their Classification*. 1182 pp., Van Nostrand Reinhold, New York.
- Ly, A. & Kuhnt, W. 1994. Late Cretaceous benthic foraminiferal assemblages of the Casamance shelf (Senegal, NW Africa) - indication of a Late Cretaceous oxygen minimum zone. *Revue de Micropaléontologie*, **27**, 49-74.
- Mascle, J., Lohman, G.P., Clift, P.D. et al. 1996. *Proceedings of the Ocean Drilling Program, Initial Reports*, **159**, College Station, TX (Ocean Drilling Program), 1-616.
- McNeil, D.H. & Caldwell, W.G.E. 1981. Cretaceous Rocks and their foraminifera in the Manitoba Escarpment. *Geological Association of Canada, Special Paper*, **21**, 1-439.
- Ojoh, K.A. 1988. *Evolution géodynamique des bassins albosantonien du sud-ouest du fossé de la Bénoué (Nigeria)*. Thèse Aix-Marseille III, 1-241.
- Olsson, R.K. & Nyong, E.E. 1984. A paleoslope model for Campanian-Lower Maastrichtian foraminifera of New Jersey and Delaware. *Journal of Foraminiferal Research*, **14**, (1), 50-68.
- Petters, S.W. 1979. Paralic arenaceous foraminifera from the Upper Cretaceous of the Benue Trough, Nigeria. *Acta Palaeontologica Polonica*, **14**, (4), 451-473.
- Petters, S.W. 1982. Central West African Cretaceous-Tertiary benthic foraminifera and stratigraphy. *Palaeontographica Abt. A*, **179**, 1-104.
- Popoff, M., Wiedmann, J. & de Klasz, I. 1986. The Upper Cretaceous Gongila and Pindiga Formations, northern Nigeria: Subdivisions, age, stratigraphic correlations and paleogeographic implications. *Eclogae Geologicae Helvetiae*, **79**, 343-363.
- Reuss, A.E. 1860. Die Foraminiferen der westphälischen Kreideformation. *Sitzungsberichte der Mathematische-Naturwissenschaftliche Klasse der Kayserliche Akademie der Wissenschaften in Wien*, **40**, 147-238.
- Saint-Marc, P. & Berggren, W.A. 1988. A quantitative analysis of Paleocene benthic foraminiferal assemblages in Central Tunisia. *Journal of Foraminiferal Research*, **18**, (2) 97-113.
- Sliter, W.V. 1968. Upper Cretaceous foraminifera from southern California and northwestern Baja California, Mexico. *Paleontological Contributions, University of Kansas, Protozoa*, **7**, 1-141.
- Volat J.L., Hugo, B. & Bignoumba-Ilogue, J. 1996. Foraminifères arénacés du Crétacé supérieur du Gabon. *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine*, **20**, (1), 229-275.



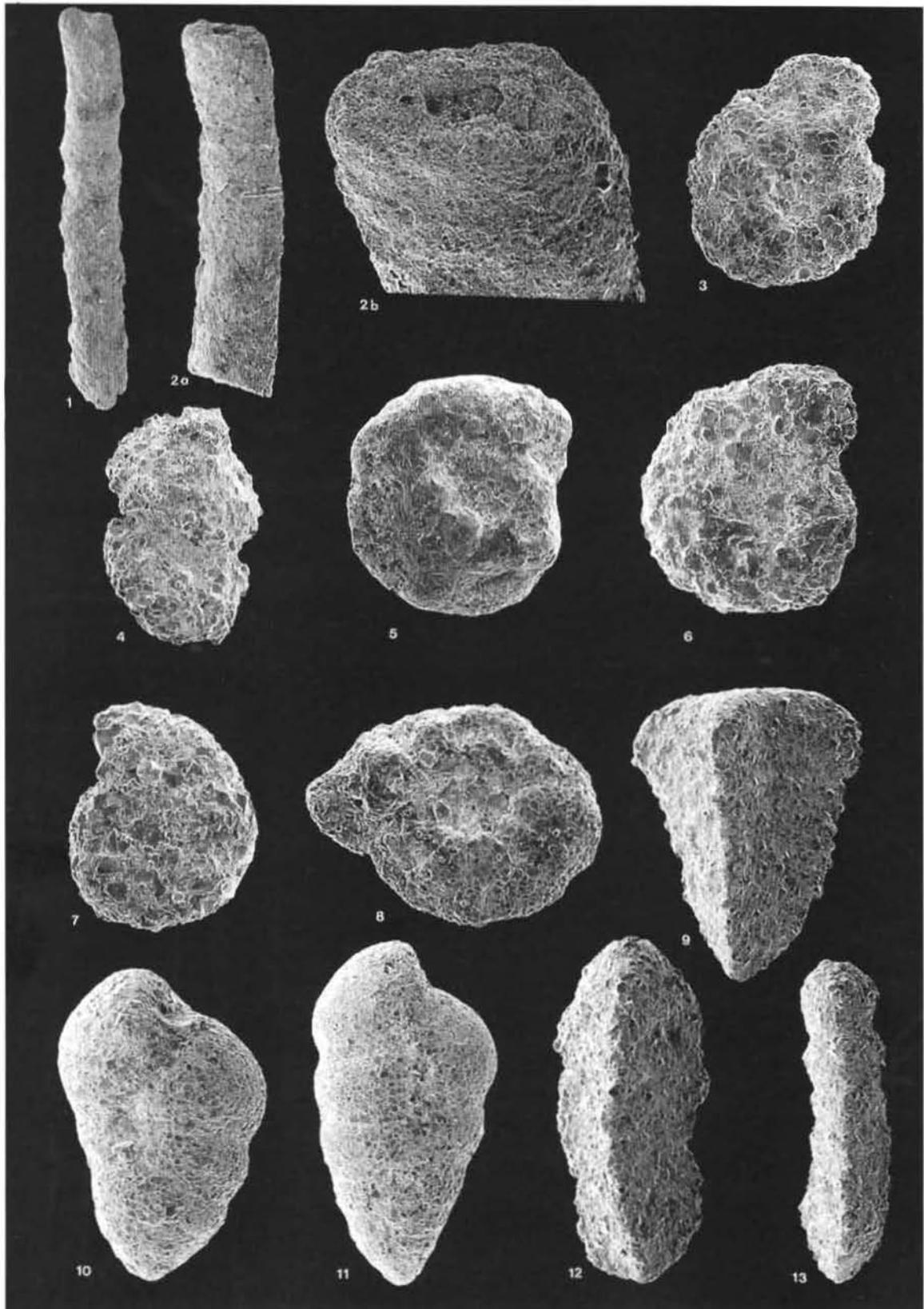


Plate 1. Tarfaya Basin (height of specimens in μm). 1. *Nothia robusta* (Grzybowski), (4850 μm), Sample TAH 37. 2a, b. *Nothia robusta* (Grzybowski), (2900 μm), Sample TAH 37. 3. *Haplophragmoides* A, (520 μm), Sample TAH 39a. 4. *Reophax* sp., (750 μm), Sample TAH 63. 5. *Haplophragmoides* A, (520 μm), Sample TAH 39a. 6. *Haplophragmoides* A, (560 μm), Sample TAH 56. 7. *Haplophragmoides* A, (450 μm), Sample TAH 56. 8. *Haplophragmoides* A, (280 μm), Sample TAH 41. 9. *Tritaxia capitosa* (Cushman), (1020 μm), Sample TAH 32. 10. *Dorothia* sp. 1, (630 μm), Sample TAH 36. 11. *Dorothia* sp. 1, (780 μm), Sample TAH 36. 12. *Tritaxia capitosa* (Cushman), (1360 μm), Sample TAH 37. 13. *Tritaxia capitosa* (Cushman), (1020 μm), Sample TAH 32.

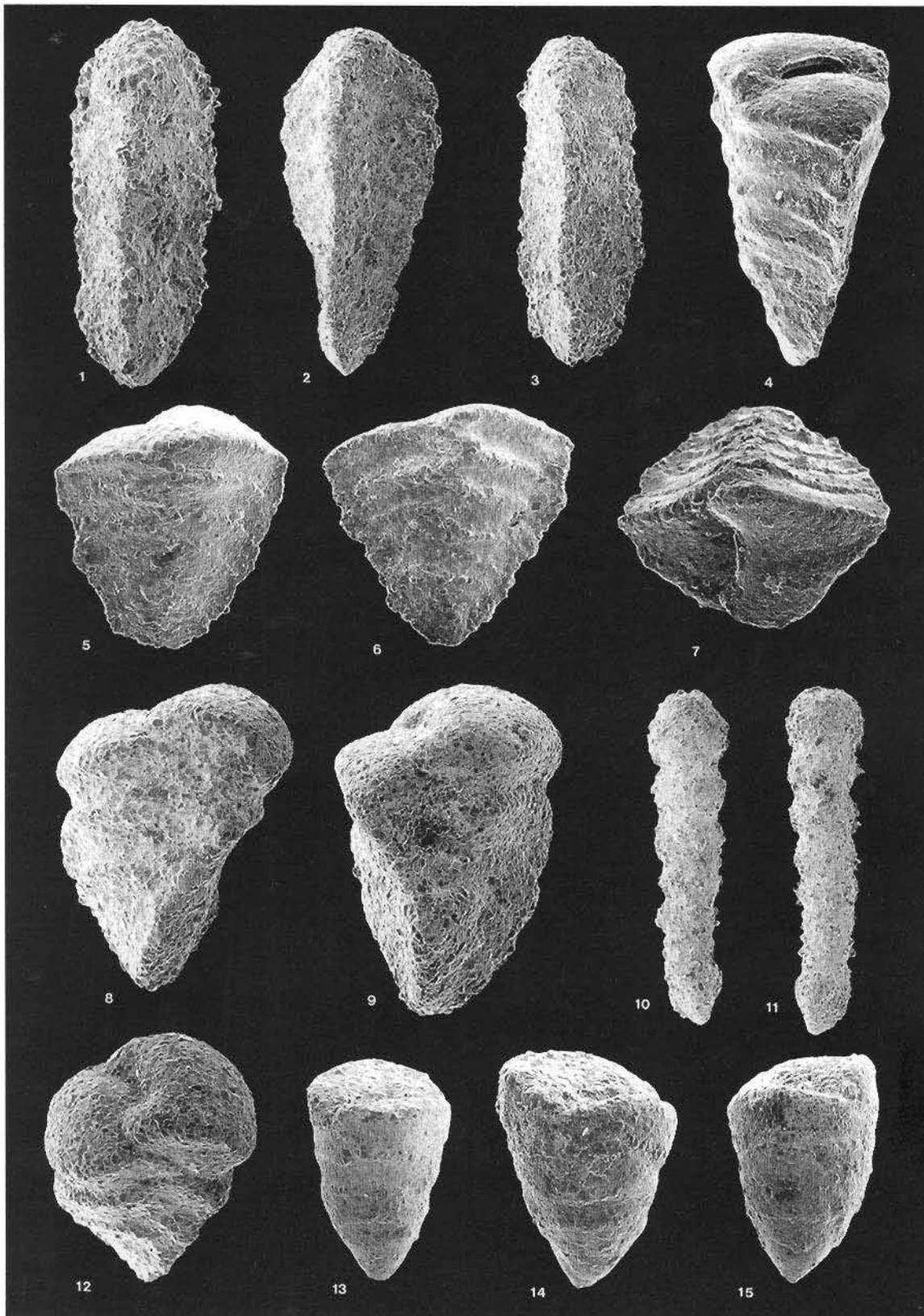


Plate 2. Tarfaya Basin (height of specimens in μm). 1. *Tritaxia capitosa* (Cushman), (1150 μm), Sample TAH 32. 2. *Tritaxia capitosa* (Cushman), (1220 μm), Sample TAH 32. 3. *Tritaxia capitosa* (Cushman), (1470 μm), Sample TAH 32. 4. *Spiroplectinella cretosa* (Cushman), (590 μm), Sample TAH 39. 5. *Spiroplectinella cretosa* (Cushman), (470 μm), Sample TAH 39. 6. *Spiroplectinella cretosa* (Cushman), (630 μm), Sample TAH 39. 7. *Spiroplectinella cretosa* (Cushman), (490 μm), Sample TAH 39. 8. *Gaudryina cretacea* (Karrer), (930 μm), Sample TAH 39. 9. *Gaudryina cretacea* (Karrer), (900 μm), Sample TAH 39. 10. *Pseudoclavulina clavata* Cushman, (1930 μm), Sample TAH 39. 11. *Pseudoclavulina clavata* Cushman, (1980 μm), Sample TAH 39. 12. *Gaudryina cretacea* (Karrer), (870 μm), Sample TAH 39. 13. *Marssonella oxycona* (Reuss), (580 μm), Sample TAH 39. 14. *Marssonella oxycona* (Reuss), (530 μm), Sample TAH 39. 15. *Marssonella oxycona* (Reuss), (580 μm), Sample TAH 39.

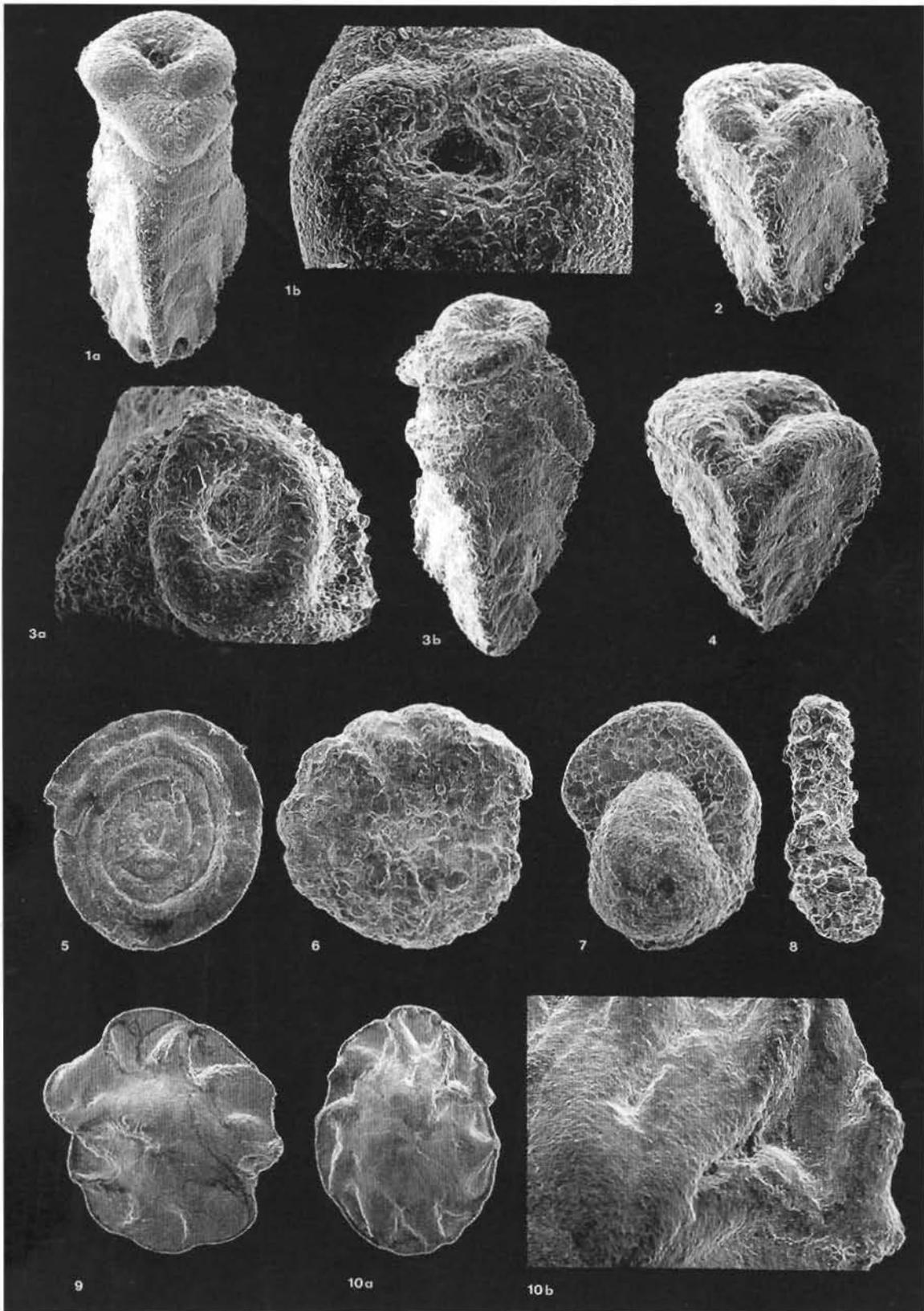


Plate 3. Casamance Shelf, offshore Senegal (height of specimens in μm). 1a, b. *Gaudryina laevigata* Franke, (930 μm), Sample CM10-C4, T2. 2. *Gaudryina pyramidata* Cushman, (510 μm), Sample CM10-C4, T2. 3a, b. *Gaudryina laevigata* Franke, (460 μm), Sample CM10-C4, T2. 4. *Gaudryina pyramidata* Cushman, (660 μm), Sample CM10-C4, T2. 5. *Ammodiscus* sp., (450 μm), Sample CM10-C2, T2. 6. *Haplophragmoides* sp. 2, (680 μm), Sample CM2-C3, 1976.6-1977.5 cm. 7. *Haplophragmoides* sp. 2, (590 μm), Sample CM10-C4, T3. 8. *Ammobaculites* sp. 2, (770 μm), Sample CM2-C3, 1971-1972 cm. 9. ?*Haplophragmoides* sp. 1, (870 μm), Sample CM10-C3, T6. 10a, b. ?*Haplophragmoides* sp. 1, (450 μm), Sample CM10-C3, T6.



Plate 4. Casamance Shelf, offshore Senegal (height of specimens in μm) 1. *Hyperammina* sp., (490 μm), Sample CM10-C3, T3. 2. *Reophax* cf. *duplex* Grzybowski, (830 μm), Sample CM10-C4, T5. 3. *Reophax* cf. *duplex* Grzybowski, (1080 μm), Sample CM10-C4, T3. 4. *Reophax globosus* Sliter, (640 μm), Sample CM10-C2, T5. 5. *Hyperammina* sp., (260 μm), Sample CM10-C5, T1. 6. *Rhabdammina* sp., (650 μm), Sample CM2-C3, 1972.8-1973.6 cm. 7. *Ammobaculites* sp. 1, (530 μm), Sample CM2-C3, 1971-1972 cm. 8. *Ammobaculites* sp. 1, (520 μm), Sample CM2-C3, 1976.6-1977.5 cm. 9. *Ammobaculites* sp. 1, (630 μm), Sample CM2-C3, 1976.6-1977.5 cm. 10. "*Textulariopsis*" sp. 3 (330 μm), Sample CM10-C2, T1. 11. "*Textulariopsis*" sp. 3 (520 μm), Sample CM10-C2, T2. 12. "*Textulariopsis*" sp. 2, (560 μm), Sample CM10-C3, T2. 13. "*Textulariopsis*" sp. 2, (570 μm), Sample CM10-C3, T2. 14. "*Textulariopsis*" sp. 1, (260 μm), Sample CM10-C5, T3. 15. "*Textulariopsis*" sp. 1, (300 μm), Sample CM10-C5, T3. 16. *Trochammina* sp. 1, (300 μm), Sample CM10-C3, T6. 17. *Trochammina* sp. 1, (430 μm), Sample CM10-C3, T6. 18. *Plectina lenis* (Grzybowski), (640 μm), Sample CM2-C3, 1971-1972 cm. 19. *Spiroplectammina chicoana* Lalicker, (380 μm), Sample CM10-C5, T1.

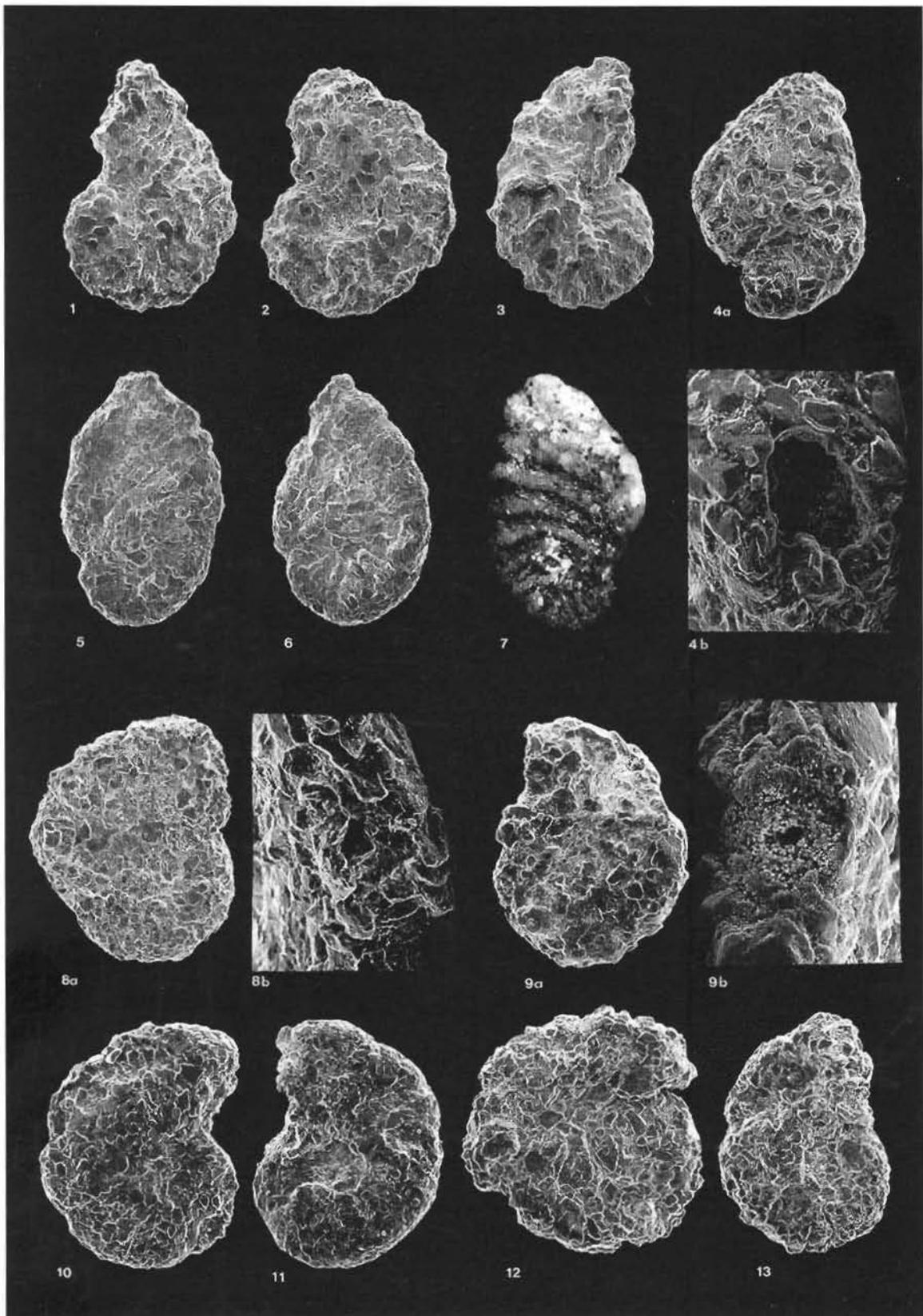


Plate 5. Casamance Shelf, offshore Senegal (height of specimens in μm). 1. *Ammomarginulina* sp. 1, (320 μm), Sample CM10-C3, T6. 2. *Ammomarginulina* sp. 1, (330 μm), Sample CM10-C3, T6. 3. *Ammomarginulina* sp. 1, (330 μm), Sample CM10-C3, T6. 4a, b. *Ammotium nkalagum* (960 μm), Sample CM2-C3, 1985.4 -1986.2cm. 5. *Ammotium nkalagum* (660 μm), Sample CM2-C3, 1976.6-1977.5 cm. 6. *Ammotium nkalagum* (650 μm), Sample CM2-C3, 1976.6-1977.5 cm. 7. *Ammotium nkalagum* (850 μm), Sample CM2-C3, 1976.6-1977.5 cm. 8a, b. *Kutsevella* sp. 1, (540 μm), Sample CM2-C3, 1979.5-1980.5cm. 9a, b. *Kutsevella* sp. 1, (390 μm), Sample CM2-C3, 1979.5-1980.5cm. 10. *Kutsevella* sp. 1, (330 μm), Sample CM2-C3, 1971-1972 cm. 11. *Kutsevella* sp. 1, (510 μm), Sample CM2-C3, 1971-1972 cm. 12. *Kutsevella* sp. 1, (440 μm), Sample CM2-C3, 1976.6-1977.5 cm. 13. *Kutsevella* sp. 1, (440 μm), Sample CM2-C3, 1976.6-1977.5 cm.

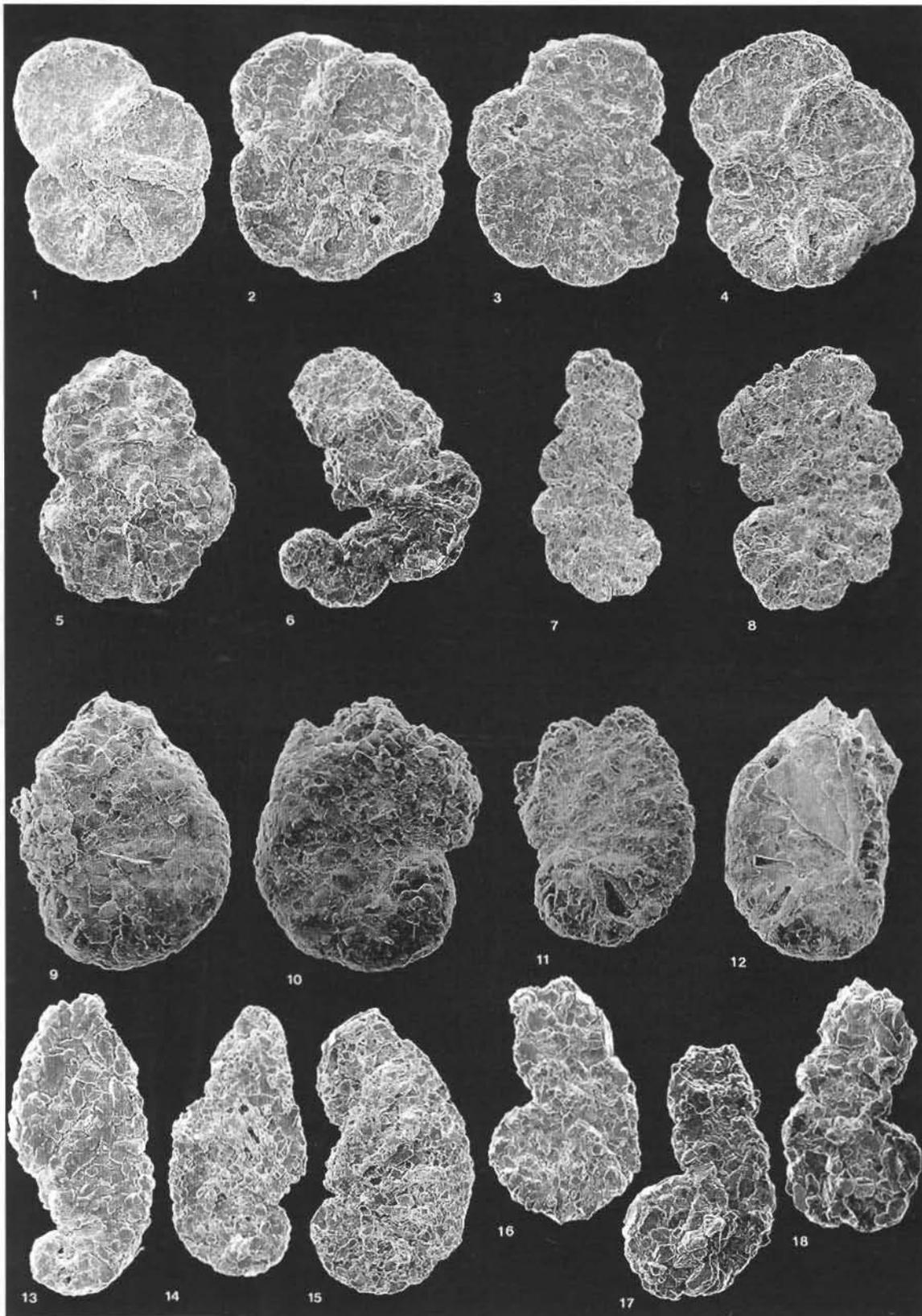


Plate 6. Benue Trough, Nigeria (height of specimens in μm). 1-4. *Trochammina* sp., (230 μm , 270 μm , 300 μm , 310 μm), Sample 3/3-14, Ashaka quarry. 5. ?*Kutsevella* sp., (560 μm), Sample 3/3-14, Ashaka quarry. 6-8. *Ammobaculites* sp., (630 μm , 890 μm , 950 μm), Sample 3/3-14, Ashaka quarry. 9-10. *Ammotium nkalagum* Petters, (570 μm , 570 μm , 700 μm , 750 μm), Sample 4/3-18, Pindiga section. 13. *Ammotium* sp. (intermediate form between *A. bornum* and *A. nkalagum*), (330 μm), Sample 3/3-26B, Ashaka quarry. 14-15. *Ammotium* sp., (490 μm , 520 μm), Sample 3/3-14, Ashaka quarry. 16-18. *Ammobaculites* sp., (480 μm , 360 μm , 460 μm), Sample 3/3-26B, Ashaka quarry.

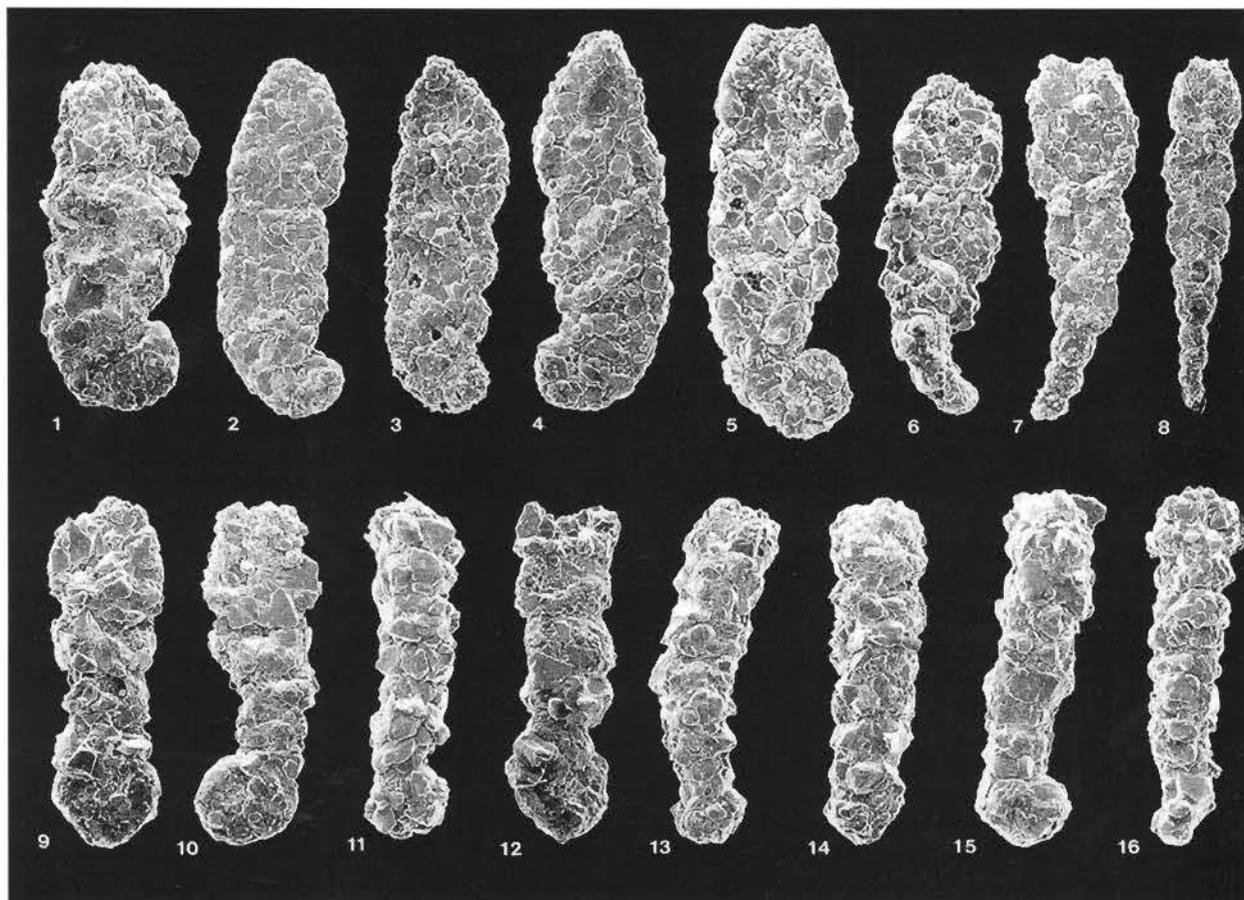


Plate 7. Benue Trough, Nigeria (height of specimens in μm). 1. *Ammotium* sp., (720 μm). Sample 4/3-4, Pindiga section. 2-4. *Ammotium bornum* Petters, (390 μm , 370 μm , 400 μm), Sample 3/3-26B, Ashaka quarry. 5. *Ammotium bornum* Petters, (360 μm), Sample 3/3-14, Ashaka quarry. 6-8. *Reophax* sp., (310 μm , 290 μm , 420 μm), Sample 3/3-26B, Ashaka quarry. 9-16. *Ammobaculites* sp., (740 μm , 720 μm , 730 μm , 720 μm , 730 μm , 720 μm , 630 μm , 940 μm), Sample 4/3-4, Pindiga section.