Late Cretaceous deep-water agglutinated foraminiferal assemblages from the North Atlantic and its marginal seas

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With 4 figures and 2 tables

Zusammenfassung

Die stratigraphische und biogeographische Verbreitung von mehr als 170 Arten sandschaliger benthischer Tiefwasser-Foraminiferen wurde im Nordatlantik und seinen Randmeeren untersucht. Hierbei wurden die in den einzelnen Untersuchungsgebieten unterschiedlichen Paläoenvironment-Bedingungen (Wassertiefe, Sauerstoffverhältnisse am Ozeanboden, detritischer Eintrag und Beeinträchtigung des Substrats durch Strömungs- und Sedimentationsprozesse) zu der jeweiligen taxonomischen Zusammensetzung der agglutinierenden Benthos-Fauna in Beziehung gesetzt. Für den Zeitraum vom Turon bis zum Maastricht ließen sich zwölf charakteristische Vergesellschaftungen agglutinierender Tiefwasser-Foraminiferen unterscheiden, die in sechs Hauptgruppen zusammengefaßt werden können:

1. Kontinentalhang-Vergesellschaftungen hoher Breiten
2. Kontinentalhang-Vergesellschaftungen niedriger bis mittlerer Breiten
3. Flysch-Vergesellschaftungen
4. Vergesellschaftungen pelagischer Kalke (»Scaglia«-Typ)
5. Abyssale gemischt kalkschalige und agglutinierende Benthos-Vergesellschaftungen
6. Abyssale rein agglutinierende Vergesellschaftungen

Biogeographische Unterschiede in der Faunenzusammensetzung korrelieren vor allem mit der geographischen Breite, wobei besonders das Fehlen kalkschaliger Elemente in Faunen hoher Breiten auffällt. Ost-West-Unterschiede sind von geringerer Bedeutung, die Mehrzahl der Arten tritt in allen untersuchten Gebieten auf und kann als kosmopolitisch angesehen werden.

Faunenschnitte können im basalen Turon, im mittleren Campan und an der Kreide/Tertiär-Grenze beobachtet werden. Diese Zeitabschnitte sind durch überregionale paläoozeanographische Events charakterisiert, die wahrscheinlich auch das Tiefsee-Benthos beeinflußt haben. Dieser Zusammenhang zwischen der Evolution agglutinierender Tiefsee-Foraminiferen und globalen, zeitkonstanten Events ermöglicht eine biostratigraphische Gliederung der Sub-CCD Serien des Nordatlantik mit Hilfe sandschaliger Foraminiferen, die sich weitgehend mit den Zonierungen, die in den Flyschzonen der Karpathen und Alpen entwickelt wurden, korrelieren läßt.

Abstract

The stratigraphic and biogeographic distribution of more than 170 species of deep-water agglutinated benthic foraminifers (DWAF) from the North Atlantic and adjacent marginal seas has been compared with paleoenvironmental data (e.g. paleobathymetry, oxygenation of the bottom waters, amount of terrigenous input and substrate disturbance). Six general types of assemblages, in which deep water agglutinated taxa occur, are defined from the Turonian to Maastrichtian times:

1. High latitude slope assemblages
2. Low to mid latitude slope assemblages
3. Flysch-type assemblages
4. Deep water limestone assemblages (»Scaglia«-type)
5. Abyssal mixed calcareous-agglutinated assemblages
6. Abyssal purely agglutinated assemblages

Latitudinal differences in faunal composition are observed, the most important of which is the lack or extreme paucity of calcareous forms in high latitude assemblages. East-to-west differences appear to be of comparatively minor importance. Most DWAF species occur in all studied regions and are thus considered as cosmopolitan.

Biostratigraphic turnovers in the taxonomic content of assemblages are observed in the lowermost Turonian, mid-Campanian and in the upper Maastrichtian to lowermost Paleocene. These datum levels correspond to inter-regional and time-constant paleooceanographic events, which probably also affected the deep-water benthic biota. This allows us to use deep-water agglutinated foraminifers for biostratigraphy in the North Atlantic sequences deposited below CCD and to geographically extend the currently used zonal schemes which have been established in the Carpathian and Alpine areas.

Résumé

La répartition stratigraphique et biogéographique de plus de cent soixante dix espèces de foraminifères benthiques agglutinants d'eaux profondes de l'Océan Atlantique Nord et des mers adjacentes a été examinée en fonction des paramètres du paléoenvironnement (paléobathymétrie, oxygénation et dynamique des eaux de fond, apports détritiques terrigènes). Sur une période s'étendant du Turonien au Maestrichtien, six

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types principaux d'associations, comprenant en tout ou partie des taxons agglutinants profonds, ont été définis:

1. associations de talus en haute latitude
2. associations de talus en basse latitude
3. associations de type flysch
4. associations de calcaires pélagiques (type »Scaglia«)
5. associations abyssales de type mixte avec foraminifères à test calcaire et foraminifères agglutinants
6. associations abyssales uniquement composées d'agglutinants.

Des différences latitudinales sont apparues dans la composition faunique: la plus importante réside dans l'absence ou la très grande rareté des formes à test calcaire dans les associations de haute latitude. Des différences en longitude, d'est en ouest, apparaissent comparativement d'importance mineure. La plupart des espèces de foraminifères agglutinants d'eaux profondes se rencontrent dans toutes les régions étudiées et peuvent donc être considérées comme ubiquistes.

De nettes coupures biostratigraphiques, fondées sur des renouvellements fauniques, sont décelées au Turonien basal, au Campanien moyen et au passage Meastrichtien supérieur-Paléocène basal. Ces niveaux repères correspondent à des événements paléo-océanographiques isochrones et d'extension supra-régionale, qui ont probablement affecté aussi les formes benthiques d'eaux profondes. Ceci nous incite à utiliser les foraminifères benthiques profonds pour la biostratigraphie des séries Nord-Atlantique déposées sous la CCD et par corrélation nous permet d'étendre géographiquement l'usage de zonations initialement définies dans le domaine alpino-carpathique.

Краткое содержание

Исследовали стратиграфическое распространение более, чем 170 видов агглютинированных фораминифер бентоса из седиментов глубоководных отложений. В отдельных исследованных областях постарались установить связь между палеоусловиями среды отложения (глубина воды, количество кислорода в придонных горизонтах ее, принос детрита и влияние течений и процессов седиментации) и сообществами определенных таксономических групп аллютинированной фауны бентоса. В интервале от Турона до маастрихта удается выделить 12 характерных сообществ агглютинированных глубоководных фораминифер, которые можно свести в 6 групп таким образом:

1. Сообщества материкового склона высоких широт.

2. Сообщества материкового склона низких и средних широт.

3. Сообщества флиша.

4. Сообщества на пелагических известняках (Тип Scaglia).

5. Абиссальные сообщества бентоса, как агглютинированного, так и с известковым скелетом.

6. Абиссальные сообщества бентоса из исключительно агглютинированных фораминифер.

Биогеографические различия распространения сообществ фауны удается коррелировать прежде всего с географической широтой, причем в высоких широтах бросается в глаза отсутствие видов с известковым ске-

летом. Различия между восточной и западной частью океана играют второстепенную роль; большенство видов отмечено во всех исследованных регионах и их можно считать космополитами.

Смену фауны можно наблюдать на базисе турона, в среднем кампане и на рубеже мел/третичный период. Эти отрезки времени характеризуются сверхрегиональными палеогеографическими событиями, которые, по всей вероятности, повлияли на бентос глубин. Такая зависимость эволюции агглютинированных фораминифер глубоководья и глобальных, временно связанных событий, разрешает провести биостратиграфические подразделиния на субсерии в северной Атлантике по агглютинированным фораминиферам, которые можно коррелировать с зонами, развитыми во флишах Карпат и Альп.

1. Introduction

The sample base for this study consists of material from twelve different localities in various depositional and paleogeographic settings in and around the late Mesozoic North Atlantic and Western Tethys oceans (Fig. 1).

We studied foraminiferal assemblages from four localities along the western side of the North Atlantic. From north to south, these areas are:

1. Labrador Margin: Commercial wells North Leif I-05, 2580-2700 m, Gudrid H-55, 8640-8730 feet, and Indian Harbour M-52, 10030-10810 feet. This area occupies a high latitude (54° 21'51''N for the Indian Harbour M-52 well), »boreal« paleogeographic position, possibly located in a silled marginal basin. The depositional environment is characterized by bathyal water depths, a high amount of fine-grained terrigenous clastic input, and oxygen-deficient bottom and interstitial waters (GRADSTEIN & BERGGREN, 1981).

2. DSDP Site 603 (Cores 21 through 33): This site is in a mid-low latitude (35°29.71'N) »tethyan« paleogeographic position, at abyssal water depths below the CCD (calcite compensation depth). The basin was relatively sediment-starved, and bottom waters were well oxygenated (VAN HINTE, WISE, et al., 1987).

3. DSDP Site 543 (Cores 5 through 10): This site is located in a low latitude (15°42.738'N), »tropical« paleogeographic position, at abyssal water depths, but close to and partly reaching above the CCD. The environment was well oxygenated with low terrigenous input (HEMLEBEN & TRÖSTER, 1984).

4. Trinidad: This area is situated in a low latitude (around 11°N) »tropical« paleogeographic position, and at bathyal water depths. The sedimentary environment was characterized by frequent fine-grained clastics (marly sedimentation), a high

sedimentation rate, and poorly oxygenated bottom and interstitial water (KAMINSKI et al., 1988).

We studied eight localities along the eastern side of the North Atlantic. These are listed from north to south:

5. Italy (Gubbio section, Umbrian Apennines): This site occupies a mid latitude (43°22'N), »tethyan« paleogeographic position, at bathyal water depths well above the CCD. The environment was sediment-starved, well-oxygenated, and the typical sediments are red pelagic »Scaglia«-type limestones (ARTHUR, 1979).

6. Northern Spain (Turonian to early Paleocene of the Zumaya basin): The sedimentary basin is located in a mid latitude (43°21'N), »tethyan« paleogeographic position, at bathyal water depths well above the CCD. Sedimentation was dominated by abundant clastic input (turbidite sediments), and changes in sediment colour from red to green or dark gray indicate variable bottom water conditions from oxygen-deficient (e.g. Campanian-Lower Maastrichtian) to well-oxygenated (e.g. Middle Maastrichtian to lower Paleocene) (KUHNT, unpublished).
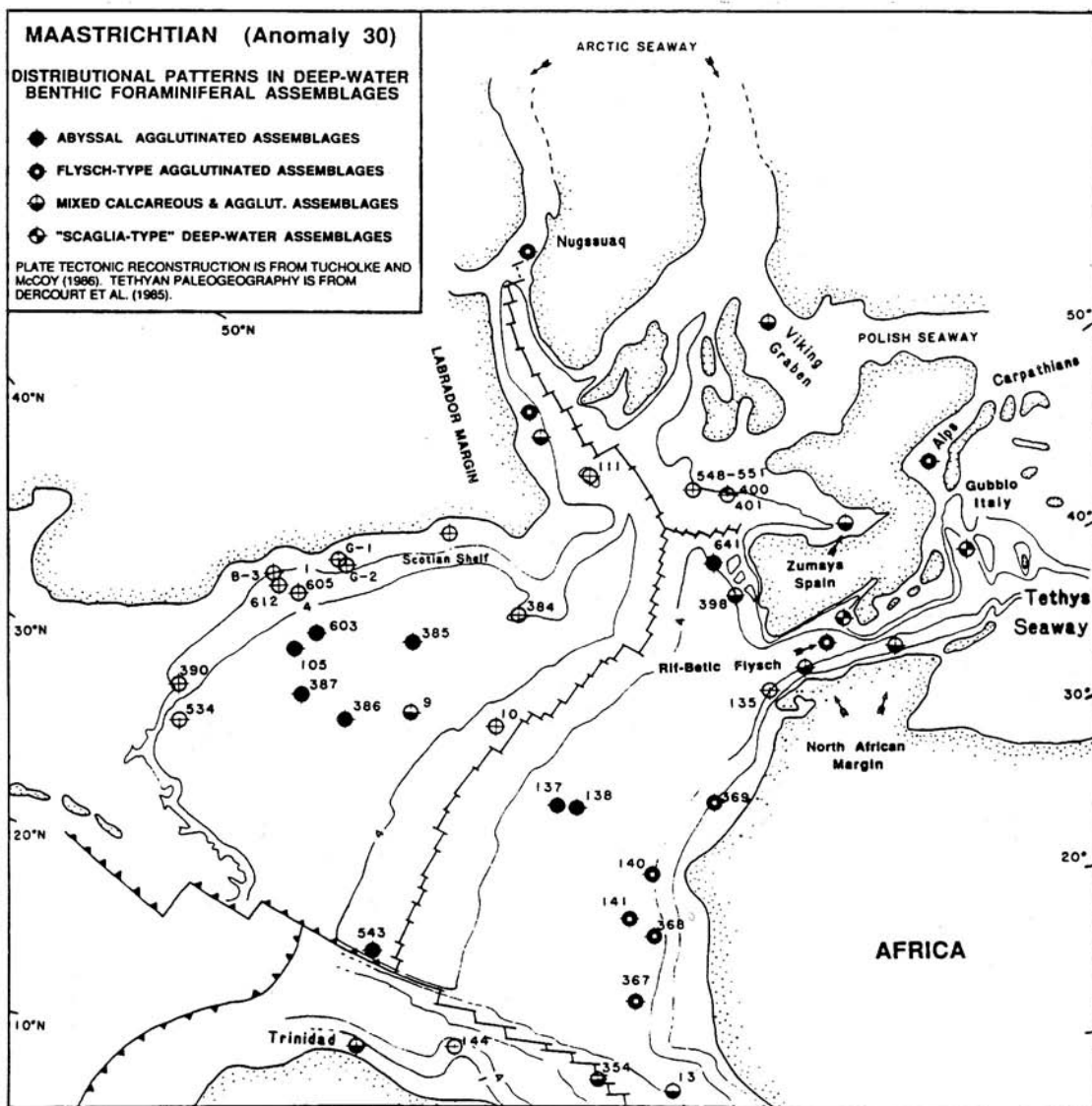

Fig. 1. Paleogeographic map of the late Cretaceous North Atlantic and Western Tethys including the distribution of deep water benthic foraminiferal assemblages.

7. ODP Site 641 (Cores 1 through 6): This site occupies a mid latitude (42°09.3'N), »tethyan« paleogeographic position, at abyssal water depths below the CCD. The basin was sediment-starved, and the sedimentation of red zeolitic clay indicates well-oxygenated bottom waters (BOILLOT, WINTERER & MEYER et al., 1987).

8. Southern Spain (South Iberian paleomargin: Penibetic zone near Ronda): This area is in a mid-low latitude (36°51'N), »tethyan« paleogeographic position, at bathyal water depths well above the CCD. The environment was characterized by very low fine-grained clastic input and well-oxygenated bottom waters. The typical sediments are red pelagic marls and limestones (KUHNT, 1987).

9. Rif-Betic Flysch (remainders of the Gibraltar-Tethyan seaway in Southern Spain and Northern Morocco): This basin is in a mid-low latitude (around 36°N), »tethyan« paleogeographic position, at deep bathyal to abyssal water depths (deposition below the CCD); oxygen conditions at the seafloor varied, depending on the relative position of the sections in relation to local fan systems (THUROW & KUHNT, 1986).

10. Northern Morocco and Algeria (North African paleomargin): This area is in a mid-low latitude (35°–37°N), »tethyan« paleogeographic position, at bathyal water depths. Sediments reflect a high amount of fine-grained terrigenous input and slightly oxygen-deficient bottom-water conditions (KUHNT & OBERT, 1989).

11. DSDP Site 137 (Cores 1 through 6): This site is located on the Eastern Atlantic abyssal plain, in a mid-low latitude (25°55.53'N), »tethyan« paleogeographic position, at abyssal water depths below the CCD. The abyssal plain is sediment-starved, and bottom waters were highly oxygenated (BERGER & VON RAD, 1972).

12. Northwest-African Margin (DSDP Site 141, Cores 7 to 9; Site 367, Cores 15 and 16; Site 368, Cores 50 to 56): These two sites are situated in a low latitude (12°29.2'N to 19°25.16 N), »tropical« paleogeographic position. These sites differ from the other DSDP/ODP Sites studied by a remarkably higher amount of terrigenous clastics, and probably less well-oxygenated bottom or interstital water conditions (DEAN et al., 1977).

These twelve localities cover a broad variety of paleogeographic and paleoenvironmental settings over the whole North Atlantic and its marginal seas. The taxonomic composition of Turonian to Maastrichtian agglutinated foraminiferal assemblages found in several of these localities have been recently studied in detail (MILLER et al., 1982; HEMLEBEN &

TRÖSTER, 1984; KUHNT, 1987; KAMINSKI et al., 1988a; MOULLADE et al., 1988; KUHNT, submitted). In this study we examine the biostratigraphic distribution, community structure and environmental conditions of these biofacies characterized by deep water agglutinated foraminifers (DWAF). This comparative study is regarded as a first step in the evaluation of the importance of various environmental factors on the Upper Cretaceous bathyal and abyssal benthic agglutinated foraminiferal communities in and around the North Atlantic ocean.

2. Definition of characteristic benthic foraminiferal biofacies

Six different DWAF biofacies have been recognized according to the taxonomic composition of assemblages, their paleogeographic setting, and their occurrence within characteristic Upper Cretaceous sedimentary formations of the North Atlantic Ocean and adjacent basins. The taxonomic composition of selected examples of these six assemblages-types is given in Tab. 1. The paleobiogeographic distribution of four main groups of Upper Cretaceous benthic foraminiferal assemblages is depicted in Fig. 1. The main features of the Upper Cretaceous DWAF biofacies are as follows:

Mixed calcareous and agglutinated assemblages of the North Atlantic continental margins (Fig. 1)

1. High latitude slope DWAF biofacies

General features: Flysch-type (see definition below) agglutinated foraminifers dominate the low to medium diversity benthic foraminiferal assemblages. Calcareous benthic foraminifers and calcareous agglutinating ataxophragmiids are rare or absent, indicating the influence of a local calcium carbonate lysocline. The greenish gray claystones of this environment on the Labrador margin appear to be deposited under slightly oxygen-deficient bottom water conditions (GRADSTEIN & BERRGGREN, 1981).

Occurrence: Campanian-Paleocene of the distal part of the Labrador Margin (e.g. the Indian Harbour M-52 well). Similar assemblages have been observed in the Maastrichtian-Paleocene of the North Sea (Viking Graben) and offshore West Greenland in the region of Nugssuaq (GRADSTEIN & BERGGREN, 1981) (Fig. 1).

2. Low and mid-latitude slope DWAF biofacies

General features: Highly diverse »mixed« assemblages with unconstant, and often large numbers

of calcareous benthic foraminifers and calcareous agglutinating ataxophragmiids. Depending on the bathymetric position on the slope, the number of planktonic foraminifers reaches up to 99% of the foraminiferal assemblages.

Occurrence: North African Margin, Iberian Margins (e.g. Subbetic Zone, Zumaya section), and Trinidad (KAMINSKI et al., 1988a).

Flysch-type agglutinated assemblages (Fig. 1):

3. Flysch-type DWAF biofacies

General features: Purely agglutinated assemblages of astrorhizids, ammodiscids, rzehakinids, hormosinids, lituolids and siliceous agglutinating ataxophragmiids (e. g. *Karreriella, Pseudobolivina, Uvigerinammina*). Diversity and taxonomic composition of the assemblage vary according to substrate, detrital input, and bottom water oxygenation.

Occurrence: DSDP sites of the Northwest African Margin (140, 141, 367, 368, 369), distal parts of the North African Margin, distal, carbonate-free claystones in southern Trinidad, Venezuela, and Flysch Zone in the Gibraltar Seaway. Flysch-type assemblages often grade into slope assemblages, and both types can be encountered (but at different stratigraphic levels) within a single section (e. g. in southern Trinidad).

»Scaglia-type« deep-water assemblages (Fig. 1):

4. Deep water limestone DWAF biofacies

General features: Well diversified agglutinated assemblages with large numbers of rhizamminids and tiny, finely agglutinating species. Spiroplectamminids and ataxophragmiids (e.g. *Matanzia varians*) also occur in several samples. Calcareous benthic foraminifers and calcareous agglutinated forms were present but are lost due to the preparation method (etching with HCI). Moreover, some of the typical »flysch-type« species such as *Hormosina gigantea, Rzehakina epigona* and *Recurvoides spp.* are rare or absent.

Occurrence: »Scaglia Rossa« respectively »Couches Rouges« limestones of the Western Mediterranean area (see KUHNT, submitted). Similar assemblages have been observed in HCI-residues of the Turonian gray pelagic limestone and Danian red pelagic limestone interbedded in the turbidite sequence of the Zumaya section. This might indicate that »Scaglia-type« assemblages succeeded slope assemblages when the fine-grained detrital input ceased.

Abyssal agglutinated assemblages (Fig. 1):

5. Abyssal mixed calcareous-agglutinated biofacies

General features: Assemblages with large numbers of deep-water calcareous benthic foraminifers and calcareous agglutinating forms occur in addition to a highly diversified agglutinated fauna, consisting of tiny, finely agglutinating species. The occurrence of abyssal mixed calcareous/agglutinated assemblages coincide with the Maastrichtian fall of the oceanic CCD in the North Atlantic (TUCHOLKE & VOGT, 1979), and the resulting sedimentation of the calcareous Crescent Peak member within the Plantagenet formation (JANSA et al., 1979).

Occurrence: Campanian-Maastrichtian of DSDP Hole 543A (see HEMLEBEN & TRÖSTER, 1984), Maastrichtian of Site 385.

6. Abyssal DWAF biofacies

General features: Highly diverse exclusively agglutinated fauna, consisting of tiny, finely agglutinating species. These assemblages correspond to the abyssal agglutinated faunas, first described from the Pacific and Indian oceans (KRASHENINNIKOV, 1973, 1974), and is characterized by small smooth *Haplophragmoides* and species of *Paratrochaminoides, Pseudobolivina, Praecystammina*, and *Labrospira*. The rzehakinids are absent.

Occurrence: Plantagenet Formation of the abyssal part of the Upper Cretaceous North Atlantic, seaward of the clastic influence supplied by the continental margins and below the oceanic CCD (see MOULLADE et al., 1988).

Tab. 1. Biogeographic and stratigraphic distribution of 174 Upper Cretaceous deep water agglutinated foraminiferal species ▶ in the North Atlantic and its marginal seas.
The following abbreviations are used:
LOCALITY (see introduction): LAB = Labrador Margin, well Indian Harbour M52, 10030–10810 feet; TRIN = Trinidad (for details see KAMINSKI et al., 1988a); MES = Mesorif zone, section M83, North African paleomargin, Northern Morocco; ZUM = Zumaya section, Northern Spain; GIB = Gibraltar arch area, Rif-Betic flysch units; PEN = Penibetic Zone, Southern Spain; GUB = Gubbio section, Central Italy; the numbers refer to DSDP/ODP Sites.
AGE: T = Turonian; C = Coniacian; S = Santonian; Ca (in the range chart C) = Campanian; M = Maastrichtian
ASSEMBLAGE TYPE: 1 = high latitude slope assemblages; 2 = low latitude slope assemblages; 3 = flysch-type assemblages; 4 = deep water limestone assemblages; 5 = abyssal mixed calcareous-agglutinated assemblages; 6 = abyssal purely agglutinated assemblages.

LOCALITY / AGE / ASSEMBLAGE TYPE	T C S C M	LAB Ca-M 1	TRIN Ca-M 2	MES Ca-M 2	ZUM T-M 2	GIB T-M 3	141 Ca-M 3	367 Ca-M 3	368 Ca-M 3	PEN T-Ca 4	GUB T-M 4	543A Ca-M 5	137 Ca-M 6	641A T-M 6	603B T-M 6
Ammobaculites agglutinans	---	X													
Ammobaculites aubertae	---	X													
Ammobaculites jarvisi	---	X	X	X	X										
Ammobaculites sp.3	---	X	X		X										
Ammobaculites sp.4	---	X													
Ammodiscus asperellus	---											X	X		
Ammodiscus cretaceus	--- --- --- --- ---	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ammodiscus glabratus	---	X	X		X		X	X		X	X				
Ammodiscus infimus	--- --- ---					X									
Ammodiscus pennyi	--- ---		X	X			X	X			X		X		
Ammodiscus cf. pennyi	--- ---								X	X					
Ammodiscus peruvianus	--- ---	X	X	X	X		X	X	X						
Ammodiscus planus	--- ---	X	X	X	X	X	X	X		X	X				
Ammodiscus sp.1	--- ---						X	X			X				
Ammolagena clavata	--- ---	X	X												
Ammosphaeroidina pseudopauciloculata	--- --- ---	X	X	X	X		X	X		X	X				X
Arenobulimina dorbignyi	--- ---	X	X		X							X			
Aschemonella carpathica	--- ---				X	X			X		X				
Aschemonella ex gr. grandis	--- ---	X	X	X	X	X	X	X	X						
Bathysiphon spp.	--- --- --- ---	X	X	X	X	X	X	X	X						
Bolivinopsis parvissimus	--- ---											X	X		
Budashevaella trinitatensis	--- ---	X	X					X							
Clavulinoides aspera	---	X										X			
Clavulinoides eggeri	---			ex gr.						X					
Clavulinoides subparisiensis	---				X					X		X			
Cribrostomoides sp. 1	--- ---									X	X				
Cribrostomoides trinitatensis	-	X	X	X	X				X						
Dendrophrya ex gr. excelsa	--- --- --- ---		X	X	X	X	X	X							
Dendrophrya latissima	--- ---		X			X	X	X	X						
Dorothia crassa trochoides	--- ---		X	X	X							X			
Dorothia oxycona	--- --- ---	X	X	X	X			X		X		X			
Dorothia retusa	--- ---	X	X	X	X					X					
Dorothia sp.1 (coarse)	--- ---	X													
Gaudryina ex gr. cretacea	--- ---	X	X	X	X					X					
Gaudryina pyramidata	--- ---	X	X	X						X		X			
Gaudryina sp. 1	---	X													
Glomospira charoides	--- --- ---	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Glomospira diffundens	--- ---	X	X			X	X	X	X						
Glomospira gordialis	--- --- ---	X	X	X	X	X	X	X	X	X		X	X	X	X
Glomospira irregularis	--- ---	X	X	X	X	X	X	X	X	X		X	X	X	X
Glomospira serpens	--- ---		X	X	X	X					X	X			
Glomospirella gaultina	--- ---	X	X	X	X	X	X	X	X	X		X	X	X	X
Glomospirella grzybowskii	---		X	X		X	X					X			
Goesella rugosa	--- ---		X	X						X					
Haplophragmium problematicus	--- --- -				cf.					X	X			X	X
Haplophragmoides bulloides	--- --- ---													X	X
Haplophragmoides cf. concavus	--- --- --- --- ---			X	X					X				X	X
Haplophragmoides eggeri	---		X												
Haplophragmoides fraudulentus	--- --- ---											X		X	
Haplophragmoides cf. glabra	--- ---	X	X												
Haplophragmoides herbichi	--- --- -														
Haplophragmoides horridus	--- ---		X					X	X						
Haplophragmoides kirki	---	X													
Haplophragmoides cf. linki	--- ---													X	
Haplophragmoides menitens	--- --- --- ---											X	X	X	
Haplophragmoides multicamerus	--- --- ---													X	
Haplophragmoides multiformis	--- ---											X	X	X	?
Haplophragmoides perexplicatus s.l.	--- ---											X	X	X	X
Haplophragmoides pseudokirki	--- ---												X		X
Haplophragmoides retroseptus	--- ---	X	X	X			X		X						
Haplophragmoides sp.1	--- --- ---				X					X	X		X		
Haplophragmoides ex gr. suborbicularis	--- ---	X	X						X	X	X				
Haplophragmoides cf. walteri	--- --- ---	X	X	X	X					X	X	X		X	X
Hormosina crassa	--- --- --- ---					X		X		X		X	X	X	X
Hormosina excelsa	- - - -	X				X		X	X	X		X			
Hormosina gigantea	--- ---	X		X	X	X		X		X		X		X	
Hormosina ovuloides	- - - -		X	X	X	X		X	X	X		X	X	X	
Hormosina ovulum	- - - -	X	X	X	X	X	X	X	X	X		X	X		X
Hormosina trinitatensis	--- ---		X												
Hormosina velascoensis	--- ---	X	X	X	X	X		X		X	X	X			
Hormosinella distans	--- --- ---									X	X		X		
Hormosinella sp. 141	- -						X								
Hyperammina dilatata	--- --- ---	X	X	X	X	X		X		X					X
Hyperammina elongata	--- --- ---	X	X		X	X		X		X	X	X			X
Hyperammina subdiscreta	--- --- ---							X		X	X	X	X		X
Kalamopsis dubia	--- ---			X			X								
Kalamopsis grzybowskii	-	X	X	X	X	X	X	X	X	X		X	X		X
Karreriella conversa	--- --- ---	X	X	X	X	X	X	X	X	X		X		X	X
Karreriella horrida	---	X	X	X	X	X	X	X	X				X	X	X
Labrospira inflata	--- ---											X	X	X	
Labrospira pacifica	--- ---		X									X	X	X	
Labrospira sp.1	---	X													
Lagenammina sp.1	--- ---		X				X								
Lituotuba lituiformis	- - - -	X	X	X	X	X		X	X	X	X				
Matanzia varians	---	X	X	X	X						X				
Paratrochamminoides acervulatus	--- ---	X		X		X	X					X	X	X	
Paratrochamminoides heteromorphus	--- ---				X	X	X					X	X		

Tab. 1A.

LOCALITY / AGE / ASSEMBLAGE TYPE	T	C	S	M	LAB Ca-M 1	TRIN Ca-M 2	MES Ca-M 2	ZUM Ca-M 2	GIB T-M 3	141 Ca-M 3	367 Ca-M 3	368 Ca-M 3	PEN T-Ca 4	GUB T-M 4	543A Ca-M 5	137 Ca-M 6	641A T-M 6	603B T-M 6
Paratrochamminoides intricatus s.l.	---	---	---	---											X	X	X	
Paratrochamminoides irregularis			---	---	X	X	X		X	X	X			X				
Paratrochamminoides semipellucidus s.l.	---	---	---	---											X	X	X	
Paratrochamminoides sp.1			---	---									X	X				
Paratrochamminoides sp.2			---	---							X	X	X	X	X			
Paratrochamminoides sp.3			---	---							X	X	X					
Paratrochamminoides spp.	---	---	---	---				X	X		X		X	X	X	X	X	X
Phenacophragma elegans				.		X												
Plectorecurvoides / Recurvoides spp.	---	---	---	---	X	X	X	X	X				X	X	X	X	X	X
Plectorecurvoides parvus			.	.											X			
Plectorecurvoides rotundus			.	.											X			
Praecystammina globigerinaeformis			---	---									X	X	X		X	X
Praecystammina(?) cf. globigerinaeformis			---	---						X	X		X	X	X	X	X	X
Psammosphaera fusca	.	.	---	---	X				X		X							
Psammosphaera scruposa	.	.	---	---	X	X	X	X	X						X	X	X	
Pseudobolivina cuneata	---	---	---	---						X		X	X	X		X	X	X
Pseudobolivina lagenaria	---	---	---	---						X		X	X	X	X	X	X	X
Pseudobolivina munda	---	---	---	---						X		X	X	X	X	X	X	X
Pseudobolivina sp.1	---	---																X
Pseudobolivina sp.2	---	---										X						X
Pseudobolivina sp.3			---	---									X	X				
Pseudobolivina sp.4			---	---								X	X					
Pseudobolivina spp.				---	X			X										
Recurvoides anormis				---		X	X				X							
Recurvoides deflexiformis				---	X	X	X				X							
Recurvoides gerochi				---	X	X					X	X				X		
Recurvoides cf. subturbinatus			---	---		X				X	X	X				X		
Recurvoides walteri			---	---	X		X			X	X	X				X		
Reophax aff. dentaliniformis	---	---	---	.	.												X	X
Reophax duplex				---	X	X	X	X	X	X	X							
Reophax globosus				---	X	X												
Reophax pilulifer				---	X		X		X	X	X	X						
Reophax sp.2	---	---	---		X	X					X		X	X				
Reophax sp.3	---	---												X				
Reophax sp.4	---												X					
Reophax sp.5				---										X				
Reophax subfusiformis				---	X	X												
Reophax cf. subnodulosus	.	.	.				X											
Rhabdammina spp.	---	---	---	---	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhizammina cf. algaeformis	-	T	C	S						X	X	X	X	X	X	X	X	X
Rhizammina grzybowskii				---		X												
Rhizammina indivisa	---	---	---	---	X	X	X	X	X	X	X	X	X		X	X	X	X
Rzehakina epigona			.	---	X	X	X	X	X	X	X	X	X	X				
Rzehakina fissistomata				.			X		X		X	X						
Rzehakina inclusa			---	---			X		X		X			X				
Rzehakina minima			.	.		X												
Saccammina grzybowskii	---	---	---	---	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Saccammina placenta			.	---	X	X	X	X	X				X	X				X
Saccammina cf. placenta	---	---	---	---					X	X	X	X	X	X	X			
Saccammina sphaerica	---	---		---									X	X	X	X	X	X
Saccorhiza ramosa cf.	---	---												X				
Silicosigmoilina perplexa	.			---						X	X	X						
Sphaerammina gerochi				---		X			λ	X	X	X						
Spiroplectammina aff. dentata	-	.	---	---	X	\	\	\					X	X	X			
Spiroplectammina israelskyi			---	---			\						X	X	X			
Spiroplectammina cf. israelskyi				---				\							X			
Spiroplectammina laevis	-	.	.	---			\	\					X	X	X			
Spiroplectammina navarroana				---	X	\	\											
Spiroplectammina aff. spectabilis				---	X	\	\	\						X				
Spiroplectammina subhaeringensis	-	---	-						λ						X			
Spiroplectinata (?) sp.1	-																	
Subreophax guttifer	---	---	---	---				X					X	X				X
Subreophax pseudoscalaris				-	X	X		X			X							
Subreophax scalaris	---	---	---	---	X	X	X		X	X	X	X	X	X	X	X		X
Subreophax sp.1				---						X	X			X				
Subreophax splendidus			---	---				X		X	X			X				
Thurammina sp.	---	---		---		X			X	X								
Tolypammina sp. 1	---	---	---	---									X	X				
Tolypammina sp. 2	---	---		---									X	X				
Tolypammina sp. 3				-										X				
Trochammina altiformis	---	---	---	---	X	X					X							
Trochammina bulloidiformis			---	---								X					X	X
Trochammina deformis			---	---	X			X	X	X	X	X	X	X				
Trochammina ex gr. globigeriniformis			---	---	X			X				X						X
Trochammina gyroidinaeformis	---	---	---												X	X	X	X
Trochammina sp.1 (coarse)				---			X											
Trochammina spp.	---	---	---	---	X	X	X	X	X			X		X				X
Trochamminoides dubius				---		X	X			X				X				
Trochamminoides cf. dubius				---								X	X	X				X
Trochamminoides proteus			---	---		X	X	X			X	X		X				
Trochamminoides cf. proteus	---	---	---					X			X	X		X				
Trochamminoides subcoronatus				---	X	X				X	X							
Turritellella shoneana				-										X	X			
Uvigerinammina jankoi	---	---	-	---	X			X	X		X	X	X	X	X		X	X
Verneuilina cretacea			---	---				X					X		X			
Verneuilinoides polystrophus				---		X		X					X	X				

Tab. 1B.

Associated with all the above mentioned biofacies occur assemblages, which are especially adapted to oxygen-deficient bottom water conditions. They are generally characterized by low diversity and dominance of »primitive« ammodiscacea. Examples and distribution pattern of these assemblages (biofacies B) are discussed in greater detail below.

3. Paleoecology of deep-water agglutinated foraminifers (DWAF)

Several of the above described features characterizing the distribution of Upper Cretaceous DWAF biofacies are comparable with environmental data collected on Cenozoic and modern agglutinated deep-water foraminifers (JONES & CHARNOCK, 1985; KAMINSKI, 1985; SCHRÖDER, 1986; KAMINSKI, 1987; SCHRÖDER, 1988; KAMINSKI et al., 1988b). These authors demonstrated that the distribution of modern deep-water agglutinated foraminifers is influenced by several factors, such as:
- paleobathymetry
- oxygenation of bottom and interstitial waters
- detrital input
- nutrition
- availability of calcium carbonate
- factors which control community equilibrium (e.g. substrate disturbance by bottom hydrodynamics)

We shall briefly discuss the importance of some of these environmental factors in the distribution of Upper Cretaceous DWAF in the North Atlantic and along its margins.

The paleobathymetric distribution of Upper Cretaceous DWAF assemblages in the North Atlantic can be reconstructed for the Maastrichtian time slice from a high-latitude transect of wells (with inreasing paleodepth) on the Labrador Margin (KAMINSKI, 1988). A mid- to low-latitude transect was studied along the thrusted North African Margin in the Tellian Units of the Moroccan Rif (KUHNT, 1988). Continental margin sequences in bathyal water depths have been encountered in Trinidad, along the North Iberian margin (Zumaya basin and western Pyrenees), and within the Betic seaway of Southern Spain. Additional data on abyssal paleodepths come from DSDP/ODP sites along the Northwest African Margin, Galicia Margin and North American Margin (Fig. 1).

Changes in the taxonomic composition of benthic foraminiferal assemblages along these transects were compared to general faunal trends like plankton/benthos-ratios, diversity, and abundance of agglutinated species. All the collected data led to the discrimination of characteristic foraminiferal biofacies which define five bathymetrical zones in low to mid-latitudes. The

first three paleobathymetric assemblages serve to subdivide the low and mid-latitude slope assemblages described earlier.

1. Upper Slope (200–500 m water depth): besides rare flysch-type forms (e.g. *Glomospira*), calcareous agglutinating forms like *Matanzia, Verneuilina, Gaudryina, Goesella, Arenobulimina, Dorothia,* and *Spiroplectammina* (corresponding to the *Marssonella*-association of HAIG, 1979) are common. Generally, this assemblage shows optimal benthos diversity and a high plankton/benthos-ratio.

2. Middle Slope (500–1500 m water depth): Flysch-type forms (e.g. *Glomospira, Ammodiscus, Hormosina, Paratrochamminoides, Rhabdammina*) become an important component among the agglutinated forms; *Rzehakinids* and calcareous agglutinating ataxiophragmiids of the »*Marssonella* association« are also common. The amount of calcareous forms, especially planktonics, is quite variable (from almost zero to 99%) due to a local carbonate lysocline and/or diagenetic dissolution.

3. Lower Slope (1500–>2500 m water depth): characterized by a *Rhabdammina* - assemblage/Flysch-type agglutinated assemblages with a high dominance of tube-like morphotypes (e.g. *Rhabdammina, Dendrophrya*). Calcareous benthic and planktonic foraminifers are rare or absent, often fragmented and/or corroded, and restricted to forms with a high dissolution-resistance.

4. Abyssal *Recurvoides-Paratrochamminoides*-assemblages: Occurring in regions with significant detrital input. Exclusively composed of flysch-type agglutinated forms without any autochthonous calcareous foraminifers (deposition below CCD). The diversity of several agglutinated groups (e.g. *Paratrochamminoides, Recurvoides,* astrorhizids, hormosinids) is usually greater than in slope-assemblages.

5. Abyssal *Labrospira-Praecystammina*-assemblages: Purely agglutinated assemblage consisting mainly of small smooth-walled forms being typical for late Cretaceous deep oceanic basins in a distal location with low detrital input.

Paleobathymetric patterns in northern (high-latitude slope) assemblages (Labrador Margin) differ from low-latitude assemblages by the lack of a shallow »*Marssonella* association« of calcareous ataxophragmiids. Maastrichtian assemblages of the outer shelf and upper slope contain abundant coarse tubular species and lituolids with only very rare calcareous ataxophragmiids. Maastrichtian deeper assemblages contain more abundant *Glomospira, Hormosina, Paratrochamminoides, Ammosphaeroidina, Praecystammina* and finely agglutinated lituolids (*Cribrostomo-*

AGE	CARTWRIGHT FORMATION - LABRADOR MARGIN			PLANTAGENET - F.
	NORTH LEIF I-O5 2465-2505 m	GUDRID H-55 8640-8730 ft.	INDIAN HARBOUR M-52 10510-10810 ft.	DSDP HOLE 641A Cores 1-3
	specific diversity S = 48	S = 50	S = 57	S = 21
C A M P A N I A N - M A A S T R I C H T I A N	ABUNDANCE Rhabdammina spp.	Glomospira charoides	Glomospira charoides	Rhizammina spp.
	Bathysiphon spp.	Bathysiphon spp.	Recurvoides walteri	Hormosina ovulum
	Rhizammina spp.	Karreriella horrida	Rhabdammina spp.	Glomospira charoides
	Glomospira charoides	Rhabdammina spp.	Bathysiphon spp.	Paratrochamminoides
	Recurvoides walteri	Recurvoides walteri	Uvigerinammina jankoi	Hormosina crassa
	Ammodiscus cretaceus	Ammodiscus cretaceus	Karreriella horrida	Recurvoides spp.
	Haplo. suborbicularis	Haplo. glabra	Ammodiscus cretaceus	Glomospira irregularis
	Karreriella horrida	Hormosina ovulum	Hormosina ovulum	Karreriella spp.
	Haplo. retroseptus	Cribrostomoides (smooth)	Glomospira gordialis	Haplo. perexplicatus
	Saccammina complanata	Rhizammina spp.	Cribrostomoides (smooth)	Labrospira
	Trochammina deformis	Saccammina complanata	Rhizammina spp.	Haplo. multicamerus
	Hormosina ovulum	Saccammina placenta	Haplo. eggeri	Ammodiscus cretaceus
	B A T H Y A L Increasing paleodepth ▷			A B Y S S A L

Tab. 2. Paleobathymetric distribution of agglutinated taxa in the northern Atlantic (modified from KAMINSKI, 1988). Taxa are listed in order of decreasing relative abundance. S = Number of species present in assemblage; dephts in meters or feet indicate depth in the well.

ides, *Haplophragmoides* and *Labrospira*). Campanian deep assemblages additionally contain abundant *Uvigerinammina*. These patterns are summarized in Tab. 2.

O x y g e n a t i o n   o f   b o t t o m   w a t e r s also appears to be an important factor for the composition of some of the Upper Cretaceous deep water agglutinated foraminiferal assemblages.

For example, two different biofacies have been observed in the abyssal Plantagenet formation of the North Atlantic at DSDP/ODP Holes 603B and 641A (MOULLADE et al., 1988), in which DWAF differ in abundance, preservation, diversity, and taxonomic composition:

Biofacies A, characterized by well-preserved, highly diversified assemblages, which consist of specimens which have a brownish siliceous agglutinating wall. Specific of these assemblages are tiny smooth-walled specimens of the genera *Labrospira*, *Haplophragmoides*, *Pseudobolivina*.   Additional   forms   include *Haplophragmium lueckei*, *Uvigerinammina jankoi*, *Hormosina* spp., *Karreriella* spp., *Trochammina* spp.

Biofacies B consists of impoverished assemblages, often composed of compressed specimens showing a generally whitish agglutinating wall. Typical components of this biofacies are various species of *Ammodiscus*, *Glomospira*, *Glomospirella*, and tube shaped

forms (mainly rhizamminids). Additionally occur *Uvigerinammina, Hormosina, Haplophragmoides concavus, Recurvoides* spp., *Karreriella* and *Paratrochamminoides*. All these forms are more characteristic of the »A-type« assemblage, as defined by GRADSTEIN & BERGGREN (1981).

In Holes 603B and 641A these two assemblages show a characteristic distribution pattern: Biofacies A is associated with the typically brown zeolitic clay sedimentary facies of the North Atlantic Plantagenet Formation. In Hole 641A it occurs continuously upsection, above Sample 103-641A-6X-7, 15–18 cm (Fig. 2). In Hole 603B, Biofacies A occurs in an interval from Sample 93-603B-33R-1, 48–52 cm to Sample 93-603B-27R-1, 90–93 cm, and then again in Cores 93-603B-25R-3 and upsection (Fig. 3). The brownish colour of the corresponding sediments and the low TOC (= total organic carbon) values measured in these intervals suggest that these highly diversified assemblages lived in a well-oxygenated environment.

Biofacies B occurs in both Holes 603B and 641A in beds immediately overlying the CTBE (»Cenomanian-Turonian Boundary Event«) anoxic event. In Hole 603B, a re-occurrence is also depicted in Cores 93-603B-26 and 25R (Lower to Middle Campanian biosiliceous event, »LMCE«). These assemblages are associated with grayish or greenish-gray claystones,
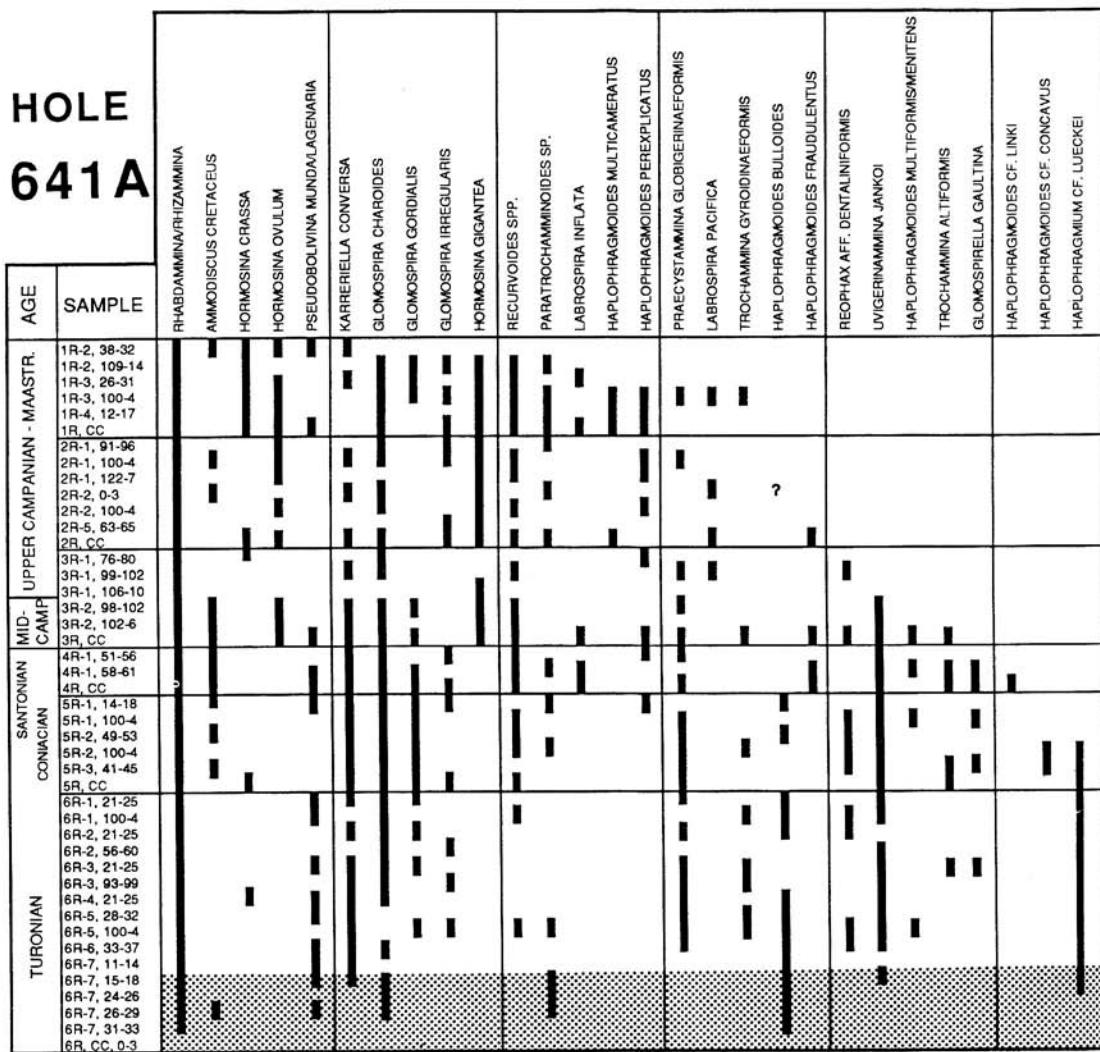
HOLE 641A

Fig. 2. Distribution of deep water agglutinated foraminifers in ODP Hole 641A (completed after MOULLADE et al., 1988). The dotted area indicates the period of oxygen-deficient conditions following the Cenomanian/Turonian boundary event (CTBE), which is characterized by the low-diversity biofacies B of agglutinated foraminifers.

which show slightly increased TOC-values in some cases (HERBIN et al., 1987; KATZ, 1987; MEYERS, 1987; RULLKÖTTER et al., 1987), thus indicating somewhat oxygen-depleted bottom and interstitial waters (Fig. 3).

In DSDP Hole 543A (north of Trinidad), the whitish »Biofacies B« assemblage occurs in Core 543A-5R in sediments of probable Paleocene age which directly underly biosiliceous sediments of the B. bidartensis Zone (latest Paleocene-earliest Eocene). As in the other two examples, the diversity and abundance of DWAF in Biofacies B is lower than in the Campanian-Maastrichtian Biofacies A assemblage observed in Cores 543A-6R and 543A-7R.

It is of special interest that biofacies B is generally associated with biosiliceous, radiolarian-rich sediments, which probably indicate enhanced surface productivity. The synecology of the biofacies B is consistent with the idea of high surface productivity. *Ammodiscus*, *Glomospirella* and *Glomospira* are regarded as epifaunal detritus-feeders (JONES & CHARNOCK, 1985) and presumably are well-adapted to take advantage of an increased amount of food particles derived from the surface layer of the ocean.

Detrital input and substrate disturbance are further important environmental factors controlling the community structure of

deep water agglutinated foraminiferal faunas. Successive recolonization of the sea floor after a turbiditic event has been postulated as the cause of small-scale vertical changes in foraminiferal assemblages in hemipelagic sediments above turbidites in alpine flysch deposits (GRÜN et al., 1964; BUTT, 1981). Vertical changes in assemblage composition from an astrorhizid-dominated assemblage directly above the coarse layer of a turbidite to a more diverse assemblage higher in the hemipelagite was thus interpreted as evidence of recolonization of the sea floor after a turbiditic event. VERDENIUS & VAN HINTE (1983) defined in the Norwegian-Greenland Sea a »frontier-area subfauna« of primitive forms and a diverse »mature subfauna« which was interpreted as a later stage of the recolonization. Dominance of frontier faunas or mature faunas in bulk samples consequently was attributed to turbidite intensity.

A generalized model of the effect of substrate disturbance on the structure of modern DWAF communities has been developed by KAMINSKI (1987). In tranquil areas, which are covered by fine-grained pelagic sediment, and provide stable environments for benthic organisms, the agglutinated fauna is dominated by species of Komokiacea and Astrorhizidae. These forms have branching tubular tests and live in the flocculent surface layer, e.g. the suspension-feeding species *Rhizammina algaeformis*. Generally, the agglutinated assemblage is comparatively highly diverse and contains a large proportion of species which utilize fine-grained material in the construction of their test. Disturbed environments are characterized by a coarse-grained substrate, consisting of coarse detrital sand and reworked planktonic and benthic foraminiferal tests.

The *in situ* agglutinated fauna commonly is of low diversity, and contains a large proportion of species which utilize coarse-grained material in the construction of their tests, reflecting the coarse nature of their substrate. The fauna is dominated by robust, non-branching species of Astrorhizidae and a number of lituolids and trochamminids. These groups are epifaunal, and constitute the morphogroup of surface-dwelling herbivores, detritivores and omnivores (JONES & CHARNOCK, 1985).

Upper Cretaceous deep water agglutinated benthic communities exhibit surprising analogies with the distribution pattern and community structure of modern DWAF assemblages. Typical examples for communities of tranquil environments are the »Scaglia-type« assemblages of the Western Mediterranean pelagic limestones and the abyssal assemblages of the North Atlantic Plantagenet Formation. Both assemblages exhibit the characteristic features of dominating rhizamminids and a large proportion of species which utilize fine-grained material in the construction of their test, including fossil forms which resemble modern Komokiaceans. Assemblages of the Western Mediterranean flysch zones exhibit a large variety of benthic agglutinated foraminiferal communities, including typical assemblages for areas with disturbed environments and a rapid succession of turbidites and benthic storms. The distribution pattern of these benthic foraminiferal communities in time and space can provide valuable information about regional tectonic effects, such as the relationship between depocenters and continental breakup or collision.

The availability of calcium carbonate appears to be a major factor controlling the

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Fig. 3. DSDP Hole 603B, Cores 25 to 29. Distribution of deep water agglutinated foraminifers at Santonian-Campanian times, including the oxygen-depletion paleoceanographic event (dotted area) of the Lower/Middle Campanian (LMCE) (completed after MOULLADE et al., 1988). In the following list, the tolerant species, which characterize the oxygen-depletion environmental event (biofacies B) are printed in bold letters (column 2):

A. *Uvigerinammina jankoi*
B. *Recurvoides spp.*
C. *Trochammina gyroidinaeformis*
D. *Pseudobolivina lagenaria* and *munda*
E. *Karreriella horrida* and *conversa*
F. *Trochammina altiformis*
G. **Rhizammina, Dendrophrya, Rhabdammina, Bathysiphon**

H. *Haplophragmoides concavus*
J. *Glomospira charoides*
K. *Hyperammina spp.*
L. *Ammodiscus cretaceus* and **Ammodiscus sp.**
M. **Glomospirella gaultina**
N. *Hormosina ovulum*
O. *Hormosina gigantea* (*one specimen only, possibly a result of caving)

The triangles mark the first or last occurrences of the biostratigraphic important species (*Hormosina gigantea, Trochammina altiformis* and *Uvigerinammina jankoi*). The position of the Santonian/Campanian boundary is based on palynological (HABIB & DRUGG, 1987; HERBIN et al., 1987) and radiolarian data (MOULLADE et al., 1988). Radiolarian-dominated biofacies are marked by black bars in column 3, sediment colours are symbolized in column 4 (white: brown-red oxygenated sediments; black: green-gray-black sediments, deposited under oxygen depletion conditions; dotted: clastic sediments). TOC values (column 4) according to HERBIN et al. (1987), KATZ (1987), MEYERS (1987) and RULLKÖTTER et al. (1987), specific diversity (number of specimens present in sample) is given in column 5. Thickness is not to scale (only recovered part of each core is taken into account).   ▶
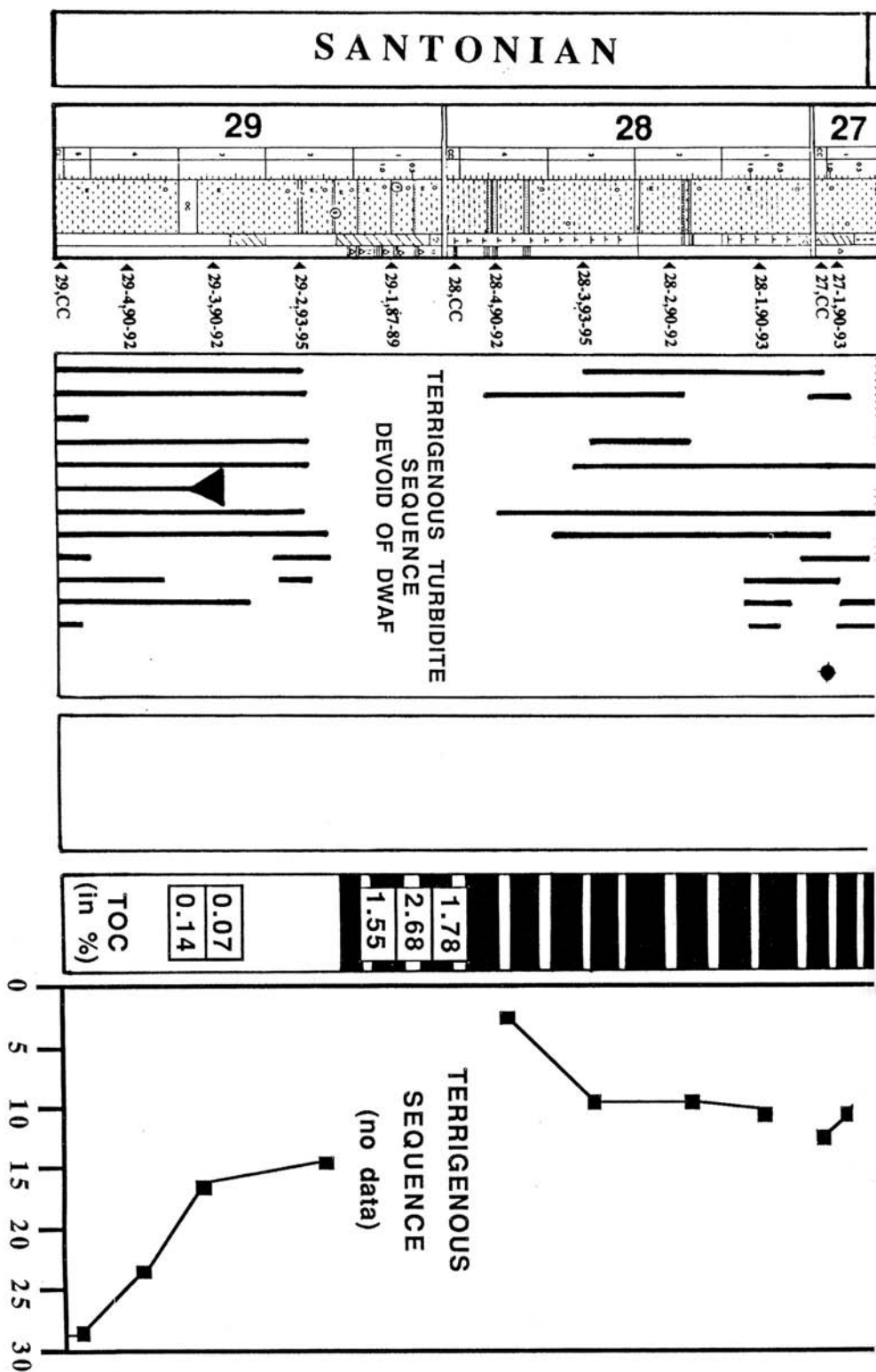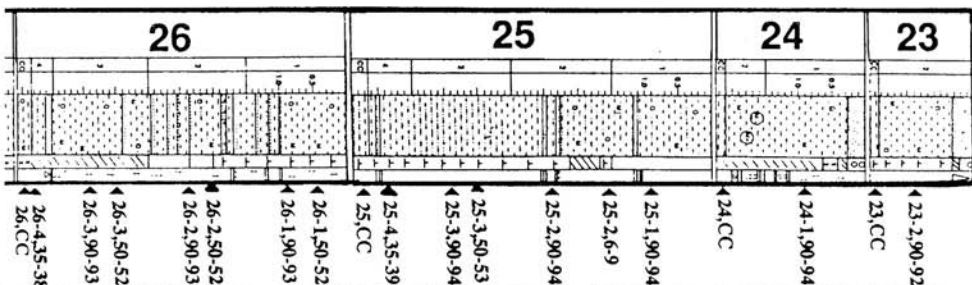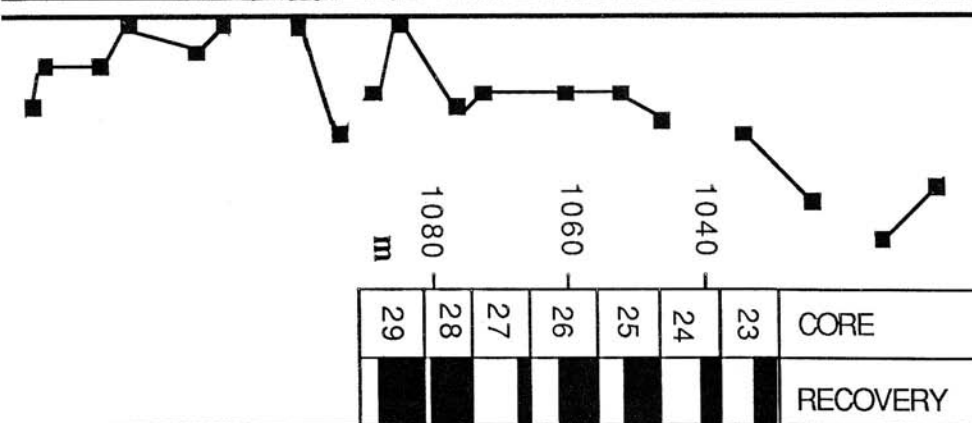
CAMPANIAN
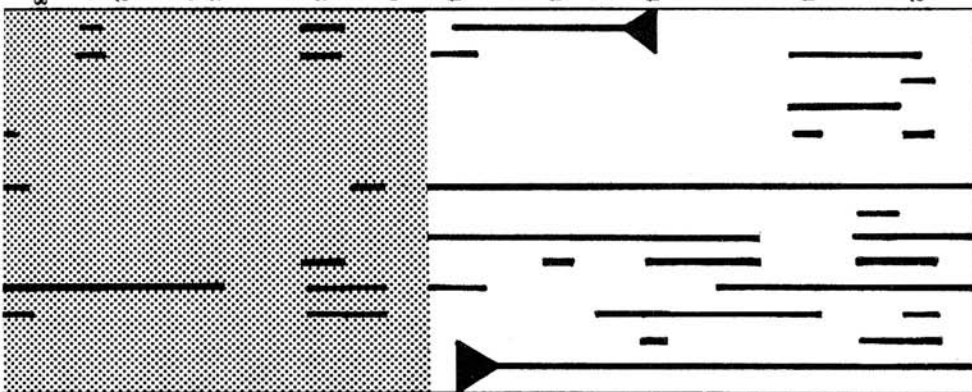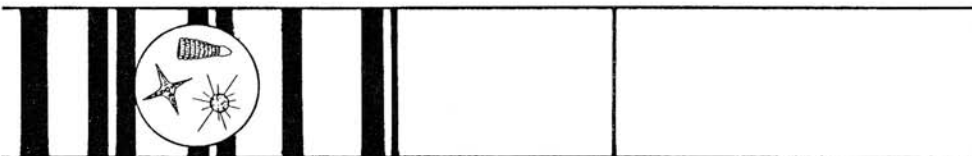
diversity of generic groups with calcareous cement. The calcareous ataxophragmiids (*Arenobulimina, Clavulinoides, Dorothia* and *Gaudryina*) are more typical of low latitude assemblages in carbonate environments. These forms are locally abundant in Trinidad, DSDP Hole 543A, Northern Morocco, Southern Spain and Zumaya, but rare in the Indian Harbour well on the Labrador Margin, and absent in abyssal DSDP Sites and in typical flysch-type assemblages, deposited below the CCD. Hence, the availability of calcium carbonate is largely a function of the position of the carbonate lysocline and CCD, i.e. water depth, water masses, paleo-latitude and input of biogenic or detritic carbonate into the basin.

4. Paleoceanographic events

During the Mid to Late Cretaceous and Paleocene, the evolution of oceanic biota underwent a period characterized by three major global paleoceanographic events:
- the Cenomanian/Turonian Boundary Event (CTBE),
- a Lower/Middle Campanian Event (LMCE),
- the K/T Boundary Event (KTBE)

The influence of these events on the evolution of marine zooplankton has already been demonstrated (e.g. planktonic foraminifers and radiolarians: LUTERBACHER & PREMOLI SILVA, 1962; WONDERS, 1979; CARON, 1985; KUHNT et al., 1986). In the deep-sea environments, both the CTBE and LMCE are characterized by radiolarian blooms (THUROW, 1988). This may indicate periods of enhanced upwelling and siliceous plankton productivity in the surface waters, which may have led to expanded and intensified short-term oxygen minima. These events also appear to coincide with significant faunal changes in the deep water agglutinated foraminifers.

The CTBE is characterized by predominating biosiliceous sedimentation and shows distinct and marked anoxic facies in the deep-sea (THUROW et al., 1982; HERBIN et al., 1986; THUROW et al., 1988). This event is accompanied by important taxonomic changes in deep-water benthic foraminifers (GEROCH & NOWACK, 1984; KUHNT, 1987; MOULLADE et al., 1988). In the deep-water limestones of the Western Mediterranean and in the North Atlantic Plantagenet Formation, beds corresponding to the CTBE are devoid of benthic foraminifers, and overlying beds are characterized by rare and low-diversity agglutinated assemblages (mainly indeterminable »tubes« and species of the family Ammodiscidae). Radiolarians dominate the microfossil assemblages during this period.

Benthic foraminifers re-occur in Lower-Middle Turonian, and diversified benthic assemblages can be observed in the Middle-Upper Turonian (P. helvetica and M. schneegansi Zones), with characteristic *Haplophragmium problematicum – Uvigerinammina jankoi* assemblages.

The LMCE is characterized by the intercalation of a biosiliceous facies in the Tethyan pelagic realm (NEAGU, 1968; DUMITRICA, 1970; HERM, 1962; BUTT, 1981; EMPSON-MORIN, 1984; KUHNT, 1987). A predominantly radiolarian biofacies has also been observed across this interval in the zeolitic clays (sub-CCD deposits of the Plantagenet formation) of the North Atlantic Ocean (EMPSON-MORIN, 1984; MOULLADE et al., 1988; THUROW, 1988). In both cases, this biosiliceous event coincides with a major faunal change in agglutinated foraminifers (MOULLADE et al., 1988): the *Uvigerinammina jankoi* assemblage, which dominated the Turonian-Santonian sequences, is replaced by a *Hormosina gigantea* assemblage, which characterizes Upper Campanian and Maastrichtian biofacies in flysch series and zeolitic claystones deposited below the CCD.

The effects of the K/T boundary event on deep marine benthic organisms are more poorly understood. Generally, benthic foraminiferal species were less strongly affected by this event than planktonic foraminifera (KELLER, 1988). A number of researchers have pointed out that there were either few extinctions among deep-water benthic foraminifera at the end of the Cretaceous (BECKMANN, 1960; HILLEBRANDT, 1965; KUHNT & KAMINSKI, 1989) or that extinctions occurred not suddenly but over a longer period of time (WEBB, 1973; DAILEY, 1983).

MOULLADE et al. (1988) observed a significant faunal break in deep-water agglutinated foraminifers coinciding with the K/T-boundary in the North Atlantic Plantagenet formation. In the sites studied, however, the Paleocene portion of the sequence revealed only few and poor foraminiferal assemblages. Similarly at DSDP Site 543, biostratigraphic control across the upper Maastrichtian to Paleocene interval is poor. Hence, the available data is still ambiguous as to whether or not the evolution of the deep sea benthos had been strongly affected by the K/T-boundary event.

A remarkable pattern has been observed in the community structure of benthic foraminifera in the Gubbio section of Central Italy (KUHNT, submitted). The morphogroup of benthic foraminifera interpreted as opportunistic by KAMINSKI et al. (1988b) was observed to increase in relative abundance in the two samples directly overlying the K/T boundary clay. The morphogroup which characterizes stable environments and shows limited capability for dispersal displays a
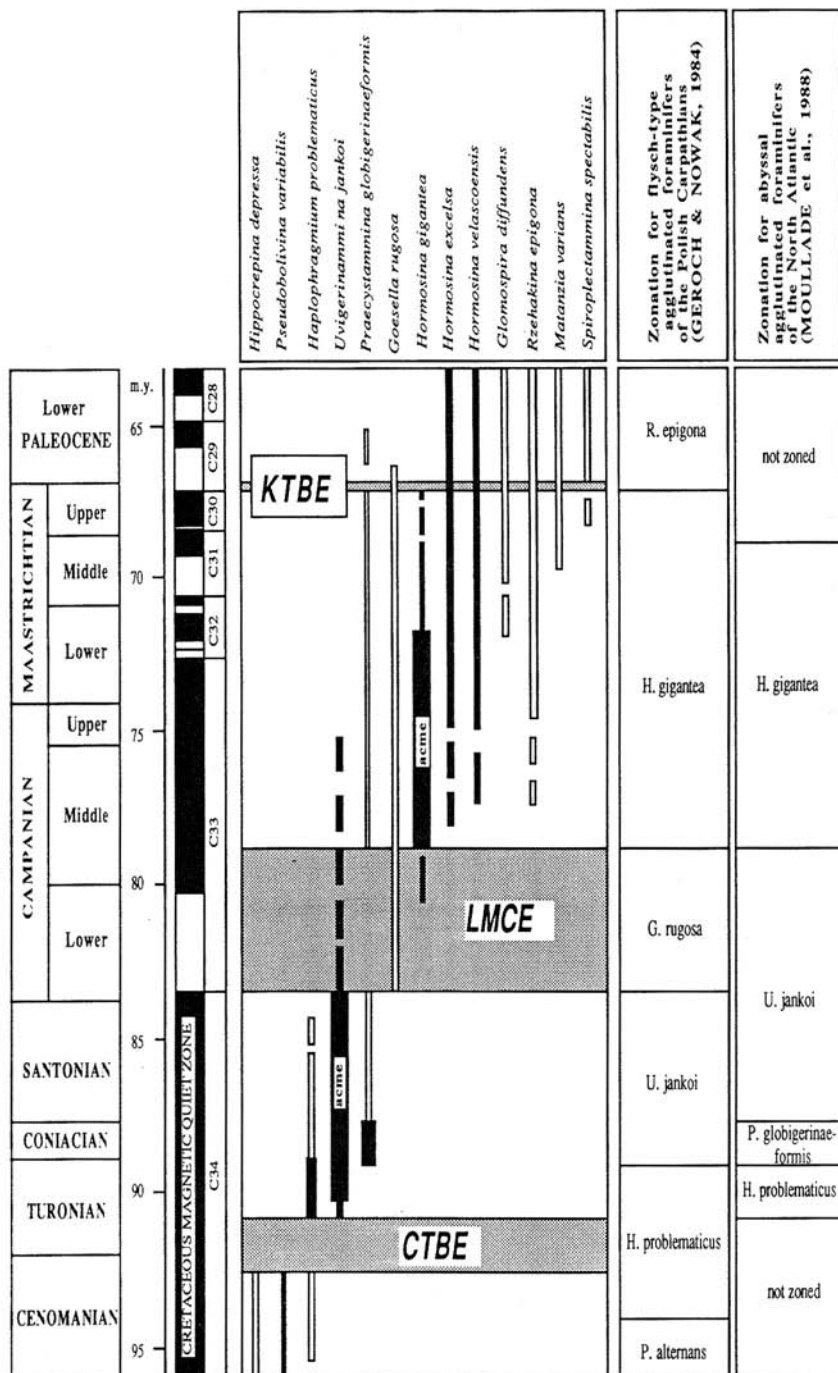
Fig. 4. Biostratigraphy of agglutinated deep water foraminifers in the North Atlantic and its marginal seas. Ranges of most important marker species in the abyssal North Atlantic is shown in black bars. Extended ranges and additional marker species of tethyan »flysch-type« and slope assemblages are added in blank bars. Time-scale and magnetic reversal scale is adapted from HAQ et al. (1987).

dramatic decrease from the top of the Cretaceous to the base of the Paleocene. This pattern of changes in community structure may be interpreted as evidence for mass mortality and subsequent recolonization

among DWAF at the end of the Cretaceous, but whether this mass mortality was due to actual physical disturbance or the collapse of the marine trophic structure remains to be resolved.

5. Biostratigraphy

Several species of agglutinated foraminifers appear to be stratigraphically useful and have correlative first or last occurrence levels in several basins of the Alpine-Carpathian Mountain belt (GEROCH, 1959; NEAGU, 1968, 1970; SANDULESCU, 1973; MORGIEL & OLSZEWSKA, 1981; GEROCH & NOWAK, 1984; GEROCH & KOSZARSKI, 1988). For several of these taxa similar stratigraphic ranges have recently been observed in the Gibraltar Arch area (KUHNT, 1987), in the North Atlantic (MOULLADE et al., 1988), in the Umbrian Apennines and the Betic Cordillera (KUHNT, submitted), and in Trinidad (KAMINSKI et al., 1988a).

Species like *Hippocrepina depressa, Plectorecurvoides irregularis, Trochammina abrupta, Recurvoides imperfectus, Haplophragmoides gigas minor* have their last occurrences near the Cenomanian/Turonian boundary. Their extinction was possibly caused by oxygen-depletion of the deep-sea during the paleoceanographic event at the Cenomanian/Turonian boundary (CTBE).

The characteristic well oxygenated red clay or limestone facies above the Cenomanian/Turonian boundary contains *Haplophragmium problematicum* as an indicator. The total range of *H. problematicum* is given as Lower Cenomanian to lowermost Campanian (NEAGU, 1970; KUHNT, submitted). Its partial range and optimum occurrence characterizes the Turonian *Haplophragmium problematicum* Zone of GEROCH & NOWAK (1984) (= the *H. lueckei* Zone of MOULLADE et al., 1988).

The species *Uvigerinammina jankoi* and *Hormosina gigantea* are perhaps the most distinctive Upper Cretaceous species in North Atlantic and Tethyan flysch-type assemblages, and are used as stratigraphic marker species in every zonal scheme. The first occurrence of *U. jankoi* is noted immediately above the benthic-free interval of the Cenomanian/Turonian boundary event. The highest occurrence of *U. jankoi* is denoted from the Middle/Upper Campanian of the Indian Harbour well (Labrador Margin), as determined by palynomorphs (BARSS et al., 1979). The report of this species from the Upper Maastrichtian of the Labrador Margin (MILLER et al., 1982; GRADSTEIN & BERGGREN, 1981) is probably based on insufficient biostratigraphic calibration. The species *H. gigantea* is restricted to the Middle/Upper Campanian and Maastrichtian (MOULLADE et al., 1988). The first occurrence of this species is a reliable indicator of the Middle Campanian in flysch- and deep sea environments below the CCD.

The last occurrence of *Praecystammina globigerinaeformis* is useful for determining a datum level close to the Coniacian/Santonian boundary in abyssal assemblages of DSDP Site 603 and ODP Site 641 (MOULLADE et al., 1988), but this species ranges into younger levels at bathyal depths and in the tropical abyssal DSDP Hole 543A (HEMLEBEN & TRÖSTER, 1984). The genera *Paratrochamminoides, Haplophragmoides, Karreriella* and *Pseudobolivina* may also have regional stratigraphic importance in the Upper Cretaceous but more detailed taxonomic work is required on these species.

Several species have their first occurrence in the interval between the Lower/Middle Campanian and the K/T-boundary (e.g. *Rzehakina inclusa, R. epigona, Hormosina velascoensis, Glomospira diffundens*). It still remains to be tested, whether or not these first occurrences are coeval benthic foraminiferal events (at the resolution provided by planktonic foraminiferal zonations) in different basins.

The zonation of GEROCH & NOWAK (1984) also includes a lower Campanian *Goesella rugosa* Zone. However, the utility of *Goesella rugosa* to determine the Santonian/Campanian boundary (and of *Matanzia varians* as an indicator of Middle Maastrichtian and younger strata) is limited to slope assemblages. In sediments deposited below the CCD these mainly calcareous agglutinated species are absent.

A major faunal turnover at the Cretaceous/Tertiary boundary is reflected by the first occurrence of many new species in the early Paleocene. Characteristic new Danian species are: *Budashevaella* cf. *multicamerata, Clavulinoides amorpha, Clavulinoides globulifera, Clavulinoides paleocenica, Conotrochammina whangai, Dorothia indentata, Eggerella trochoides, Phenacophragma beckmanni, Reticulophragmium* spp., *Reticulophragmoides jarvisi, Spiroplectammina spectabilis* (acme), *Spiroplectammina excolata, Trochammina ruthven murrayi,* and *Trochammina subtrullisatus.*

In summary, in the Western Mediterranean and the North Atlantic, major faunal turnovers in deep-water benthic agglutinated foraminifers are shown to coincide with global paleoceanographic events at the Cenomanian/Turonian boundary, in the Lower/Middle Campanian and at the Cretaceous/Tertiary boundary. These »benthic events« could be regarded as interregional and isochronous, i.e. reliable datum horizons for the biochronology of deep-sea sediments.

6. Paleobiogeography

The paleobiogeography of benthic foraminifers in the Upper Cretaceous was undoubtedly affected by many factors, including global climate, regional tectonics, and paleocirculation patterns. The late Cretaceous was a period of transition between a circum-equatorial circulation in the Mesozoic to a more meridional circulation pattern in the Atlantic during the Cenozoic (BERGGREN & HOLLISTER, 1974). In comparison with the modern ocean, the latitudinal temperature gradient of the surface waters during the late Cretaceous was less pronounced (HAQ, 1981). Nevertheless, a temperature contrast existed between the tropics and high latitudes (BARRON 1985, 1987; KEMPER, 1986). The vertical temperature gradient of the ocean water was also low in the late Cretaceous, with surface water temperatures averaging 16° C and bottom water 10–12° C in the South Atlantic (SHACKLETON et al., 1984). The homogeneous water mass resulting from comparatively low thermal gradients has been suggested as a probable handicap for the development of discrete, paleobathymetrically confined benthic foraminiferal assemblages (TJALSMA & LOHMANN, 1983).

In addition to paleoclimatic factors, the paleobiogeography of benthic foraminifers in the Western Mediterranean and in the North Atlantic was influenced by regional tectonic effects, such as the relationship between depocenters and continental breakup or collision. The opening and closing of oceanic gateways may also have affected the migration of species into and out of silled basins.

Compared with planktonic and calcareous benthic foraminifers, relatively little is known about the paleobiogeography of deep water agglutinated foraminifers or their response to environmental changes in the Upper Cretaceous. Our data base now enables an interregional comparison of agglutinated species from western Tethyan and circum-North Atlantic regions (Table 1). Most of the 174 species we recognize are cosmopolitan, but some faunal provinciality is evident among deep-water agglutinated assemblages. Biogeographic variation is manifested by differences in species diversity, the presence of endemic species or disjunct stratigraphic ranges in different areas (e.g. for *Uvigerinammina jankoi* or *Praecystammina globigerinaeformis*) and in the relative proportion of certain genera or species groups.

The distribution of Maastrichtian DWAF assemblages in the Western Tethys and North Atlantic is shown in Fig. 1. These faunas traverse a wide range of latitudes. Differences in Tethyan and Boreal end member assemblages are more evident in the relative proportion of different groups but less striking in taxonomic composition (compare assemblage types 1 and 2 in Table 1). Seventy seven species have been observed in Trinidad, more than 100 species occur in different environments of the late Cretaceous bathyal sequences of the Western Mediterranean area (columns MES, PEN and GUB in Table 1). Campanian and Maastrichtian assemblages from exploration wells on the Labrador margin (column LAB in Table 1) contain seventy four species. Many of the calcareous ataxophragmiids are missing at this high-latitude location.

A latitude dependent distribution pattern is evident among rzehakinids. *Rzehakina epigona* is abundant and exhibits an optimum size development in Tethyan slope assemblages (e.g. Trinidad, Carpathians, Morocco), but it occurs only very rarely in similar environments on the Labrador margin. In the Tethyan realm, however, *Rzehakina epigona* occurs in high abundance only in slightly oxygen-deficient environments with a remarkable input of organic matter. In well-oxygenated environments with low detrital input like the Western Mediterranean Scaglia assemblages or the abyssal assemblages of the North Atlantic Plantagenet Formation, *Rzehakina epigona* is very rare or even absent. This leads to the suggestion, that the distribution of *Rzehakina epigona* may also be controlled by the availability of nutrients derived from organic matter.

7. Conclusion

In the Upper Cretaceous North Atlantic and its marginal seas several different deep-water agglutinated foraminiferal (DWAF) biofacies can be distinguished. The community structure of DWAF is mainly influenced by paleobathymetry, oxygenation of bottom waters, detrital input, substrate disturbance, and availability of nutrients and calcium carbonate. Two different biofacies, related to different oxygenation of bottom waters have been observed in Upper Cretaceous DWAF: (1) highly diverse assemblages generally evolved under well oxygenated bottom waters, whereas (2) low diverse assemblages, dominated by »primitve« ammodiscacea indicate oxygen-deficient bottom water conditions. In the biogeographical distribution of DWAF in the North Atlantic a latitudinal gradient can be observed, although the majority of Upper Cretaceous DWAF were cosmopolitan. The evolution of DWAF was influenced by three paleoceanographic events: (1) at the Cenomanian/Turonian boundary, (2) in the Lower/Middle Campanian, and (3) at the Cretaceous/Tertiary Boundary. The important faunal changes depicted at these levels (»benthic events«), could be regarded as in-

ter-regional and isochronous, i.e. reliable datum horizons for the biochronology of deep-sea sediments deposited below the CCD. Thus, detailed studies of the spatial and temporal distribution of late Mesozoic DWAF provides a valuable information about the deep-sea paleoenvironments of the North Atlantic and the Western Tethys, which can contribute to a better understanding of the paleoceanographic evolution of these basins.

Taxonomic Remarks

The taxonomic framework used in this study is based on those established by KAMINSKI et al. (1988a) for Maastrichtian to Paleogene bathyal agglutinated assemblages in Trinidad, MOULLADE et al. (1988) for Upper Cretaceous abyssal assemblages of the North Atlantic and KUHNT (sub-

mitted) for »Scaglia-type« assemblages from Mediterranean pelagic limestones. An updated taxonomic description of late Cretaceous and Paleocene deep-water agglutinated foraminifers is in press in the proceedings of the third International Workshop on Agglutinated Foraminifera (KUHNT & KAMINSKI, submitted).

Acknowledgements

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