

# Cretaceous of the Western Tethys

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# Upper Cretaceous Deep-Water Agglutinated Benthic Foraminiferal Assemblages from the Western Mediterranean and Adjacent Areas

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With 6 Text-Figures

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**Abstract:** We investigated the biostratigraphic and paleoenvironmental distribution of Upper Cretaceous deep-water agglutinated benthic foraminiferal assemblages from 10 selected areas in the Western Mediterranean and adjacent areas in the North Atlantic and in the Alpine/Carpathian foldbelt. This distribution pattern, compared with paleoenvironmental data (e.g. paleobathymetry, oxygenation of the bottom waters, amount of terrigenous input and substrate disturbance) allows us to distinguish 12 general types of assemblages in which deep-water agglutinated taxa occur.

Assemblages consisting purely of agglutinated foraminifers

1. Flysch-type, high diversity (*Paratrochamminoides* Faunas)
2. Flysch-type, low diversity ("*Rhabdammina*" Faunas)
3. Low-latitude slope assemblages (*Rzehakina* Faunas)
4. "Low-oxygen" assemblages (*Glomospirella* Faunas)
5. High-latitude slope assemblages (*Glomospira* Faunas)
6. Abyssal assemblages ("*Krashennikow*"-type Faunas)

Mixed assemblages with a minor planktonic component

7. Mixed assemblages of slope basins
8. Mixed assemblages of the lower slope
9. Abyssal mixed assemblages

Plankton-dominated deep-water assemblages

10. "Scaglia-type" assemblages of Western Mediterranean deep-water limestones
11. Plankton-dominated assemblages of slope marls
12. Plankton-dominated assemblages in hemipelagic layers of turbiditic sequences

Low latitude slope faunas, present on the North African margins and in the Betic Cordillera of Southern Spain contain common calcareous ataxophragmids. In contrast, high latitude slope assemblages, recorded on the Labrador Margin, lack calcareous elements and are dominated by ammodiscids and litiolids. Flysch type (Type A) assemblages lack calcareous elements. This type includes assemblages dominated by coarsely agglutinated forms in proximal turbiditic environments and highly diversified assemblages in distal environments. Deep-water limestone assemblages include flysch-type forms, but also some slope forms and small smooth-walled agglutinates which can be compared to abyssal taxa. Abyssal multicolored or red clays of the North Atlantic, Pacific and Indian Ocean were populated by thin, smooth-walled varieties and are taxonomically distinct from others. Similar assemblages have been observed in the Rumanian Eastern Carpathians.

Biostratigraphic turnover in the taxonomic content of assemblages is observed in the Lower Turonian, mid-Campanian and in the late Maastrichtian to early Paleocene. These datum levels correspond to inter-regional and time-constant paleoceanographic events, which probably also affected the deep-water benthic biota. This allows us to use deep-water agglutinated foraminifers (DWAFF) for biostratigraphy in the Western Mediterranean and to extend the geographic utility of currently used zonal schemes which have been established in the Carpathian and Alpine areas.

**Kurzfassung:** Biostratigraphie und Environment-Abhängigkeit sandschaliger benthischer Tiefwasser-Foraminiferen der Oberkreide wurden in 10 ausgewählten Gebieten des Westmediterraneanraumes sowie angrenzender alpiner und atlantischer Tiefseebereiche 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.

Ausschließlich aus agglutinierenden Formen bestehende Faunen:

1. Flysch-Faunen hoher Diversität (*Paratrochamminoides*-Faunen)
2. Flysch-Faunen niedriger Diversität ("*Rhabdammina*"-Faunen)
3. Slope-Faunen niedriger Breiten (*Rzehakina*-Faunen)
4. Vergesellschaftungen ungünstiger Sauerstoffverhältnisse (*Glomospirella*-Faunen)
5. Slope-Faunen hoher Breiten (*Glomospira*-Faunen)
6. Abyssale Faunen ("*Krashennikov*"-Faunen)

Gemischt kalkschalige und agglutinierende Benthosfaunen mit geringem Planktonanteil:

7. Gemischte Faunen in Kontinentalrand-Becken
8. Gemischte Faunen des tieferen Kontinentalhanges
9. Abyssale gemischte Faunen

Plankton-dominierte Tiefwasser-Vergesellschaftungen:

10. "Scaglia-Faunen" der rötlichen pelagischen Oberkreidekalke des Westmediterran-Raumes
11. Plankton-dominierte Faunen in Kontinentalhang-Mergeln und Kalk/Mergel-Rhythmiten
12. Plankton-dominierte Faunen in hemipelagischen Abschnitten von Turbiditserien

Kontinentalhang-Vergesellschaftungen niedriger Breiten, die in den Kontinentalhang-Sedimenten Nordafrikas und des südspanischen Betikums auftreten, führen (im Gegensatz zu entsprechenden Faunen in hohen Breiten) reichlich kalkig agglutinierende Ataxophragmiden. FLYSCH-Vergesellschaftungen der westmediterranen FLYSCH-Einheiten enthalten keine kalkschalige Formen; sie werden von charakteristischen, grobkörnig agglutinierenden Formen in proximalen turbiditischen Environments dominiert, während in distalen turbiditischen Environments hochdiverse Vergesellschaftungen beobachtet wurden. Die Vergesellschaftungen der pelagischen Scaglia-Fazies enthalten Elemente der FLYSCH-Vergesellschaftungen, daneben aber auch Kontinentalhang-Formen und winzige glattschalige Formen, die Beziehungen zu distalen abyssalen Faunen aufweisen. Derartige abyssale Faunen spezieller taxonomischer Zusammensetzung wurden sonst nur in den bunten Tiefseetonen des Nordatlantik, Pazifik und Indik und in roten Tiefseetonen der rumänischen Ostkarpathen beobachtet.

Die biostratigraphische Gliederung der Tiefseesedimente des Westmediterraneanraumes mit Hilfe dieser Faunengruppe läßt sich weitgehend mit den Zonierungen, die in den FLYSCHZonen der Karpathen entwickelt wurden, korrelieren. Wichtige Faunenschnitte können im basalen Turon, im mittleren Campan und an der Kreide/Tertiär-Grenze beobachtet werden. Diese Zeitstufen sind durch überregionale, zeitgleiche paläoozeanographische Events charakterisiert, die wahrscheinlich auch die Evolution des Tiefsee-Benthos beeinflußt haben. Die Korrelation der Entwicklung agglutinierender Tiefsee-Foraminiferen mit diesen globalen, zeitkonstanten Events läßt die biostratigraphische Brauchbarkeit dieser Faunengruppe auch für überregionale Korrelation in einem neuen Licht erscheinen.

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## 1. Introduction

The sample base for this study is material from 10 localities in various depositional and paleogeographic settings in the Western Mediterranean.

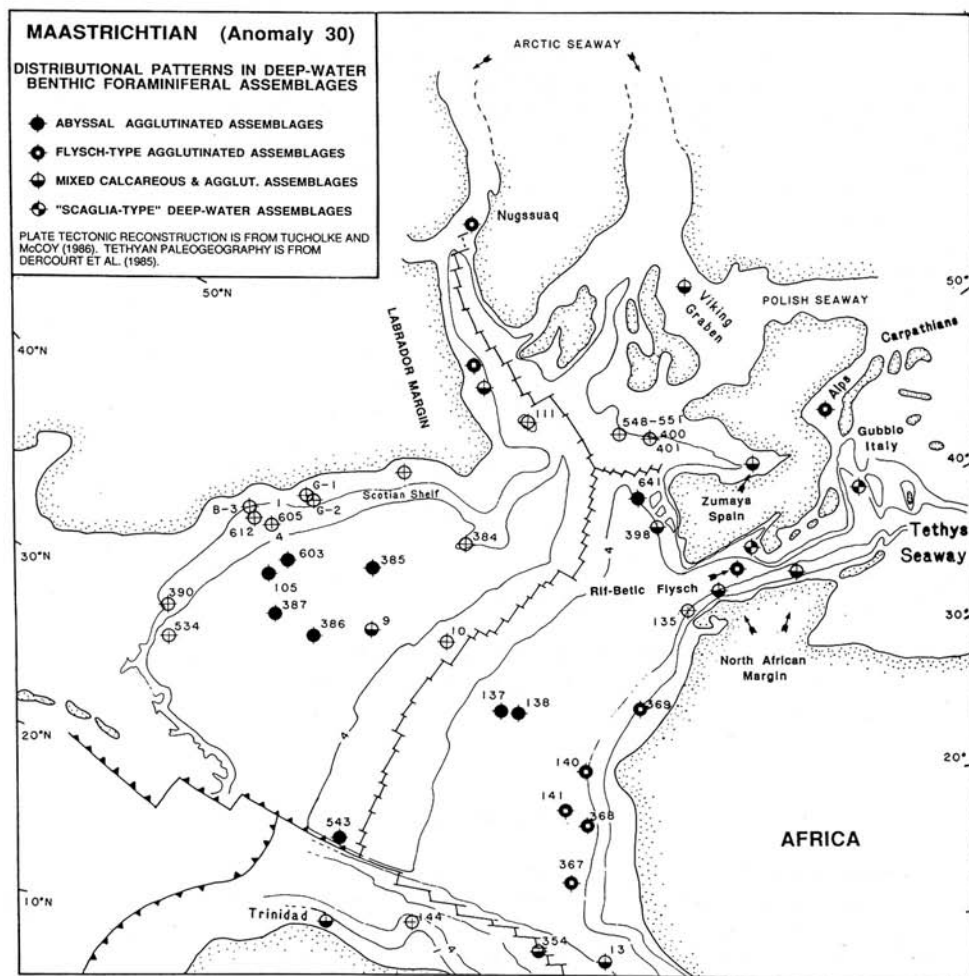
1-2. Subbetic and Penibetic zones of the southern Iberian paleomargin (southern Spain). The paleoenvironment of these zones is characterized by bathyal water depths well above the CCD, little fine-grained clastic input, and well oxygenated bottom waters. The typical sediments are red pelagic marls and limestones.

3-6. North African paleomargin (Tellian Units in Northern Morocco and Algeria): We have compared assemblages derived from the upper slope,

continental margin basin and deep bathyal to abyssal zones at the distal part of the margin. Here oxygen-deficient bottom-water conditions prevail which can probably be attributed to a high input of fine-grained terrigenous sediments.

7. Almarchal Unit of the Campo de Gibraltar flysch domain (Southern Spain). An Upper Cretaceous fine-grained calciturbidite sequence was deposited in this paleogeographic zone within a deep bathyal environment.

8-9. Rif-Betic Flysch (remnants of the Gibraltar-Tethyan seaway in Southern Spain and Northern Morocco): Deep bathyal to abyssal water depths (deposition below the CCD), oxygen levels at the seafloor and detrital overprint varied, depending on the relative position of the sections in



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

relation to local fan systems. Two principally different paleogeographic domains can be distinguished: the Mauretanian and Numidian deep-water clastic fan systems and the Massylian distal pelagic deep-water realm.

10. Italy (Gubbio section, Umbrian Apennines): Bathyal water depths well above the CCD, sediment-starved, well-oxygenated; the typical sediments are red pelagic "Scaglia"-limestones.

The ranges and relative abundances of characteristic taxa have been compared to assemblages from various localities around the North Atlantic and in the Alpine-Carpathian mountain belt (Text-Fig. 1), including the Zumaya Section of Northern Spain, the high latitude locality of the Indian Harbour well on the Labrador Margin, slope environments in Trinidad, flysch deposits in the Romanian Eastern Carpathians, and the abyssal DSDP/ODP Sites 137, 141, 367, 368, 543, 603, and 641 in the North Atlantic.

## 2. Characteristic Deep-Water Benthic Foraminiferal Assemblages

Twelve different deep-water agglutinated benthic foraminiferal (DWAF) assemblages of Upper Cretaceous age from the Western Mediterranean and North Atlantic have been distinguished by comparing the environmental data and taxonomical composition of agglutinated assemblages. Main environmental features of these assemblages are as follows. The complete taxonomic composition of some examples of these assemblages is given in Text-Fig. 2.

### Assemblages consisting purely of agglutinated foraminifers

#### 1. Flysch type, high diversity (*Paratrochamminoides* Faunas)

General features:	Low faunal density, comparatively high diversity
Characteristic taxa:	<i>Paratrochamminoides</i> spp. <i>Rhizammina</i> <i>Uvigerinammina jankoi</i> (Lower Campanian and older) <i>Subreophax scalaris</i> <i>Hormosina excelsa</i> (small variety) <i>Hormosina ovulum</i>
Sediment:	Red carbonate-free claystones between coarse-grained calciturbidites and debris-flows, well oxygenated bottom water conditions
Examples:	Flysch Units of the Moroccan Rif: Turonian-Santonian argillites of the Massylian Units, Turonian-Maastrichtian of the Mauretanian Units, Maastrichtian of the Numidian Talaa Lakrah Unit, DSDP Sites 367, 368, 141

#### 2. Flysch type, low diversity ("*Rhabdammina*" Faunas)

General features:	Assemblages mainly consisting of large, coarsely agglutinated forms, faunal density can be high, diversity is low, single species often dominate
Characteristic taxa:	<i>Dendrophrya excelsa</i> <i>Rhizammina</i> <i>Paratrochamminoides</i>

*Aschemonella carpathica**Hormosina gigantea**Reophax duplex*

## Sediment:

Gray-green bioturbated carbonate-free claystones intercalated in a succession of fine-grained calciturbidites and mud-turbidites, less oxygenated bottom water conditions

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Text-Fig. 2. Biogeographic and stratigraphic distribution of Upper Cretaceous benthic agglutinated deep-water foraminiferal species in the Western Mediterranean and adjacent areas. The following localities have been included into this study:

1. Sierra de Las Cabras section in the Western Subbetic Zone of the southern Iberian paleomargin (Southern Spain). Mixed calcareous and agglutinated assemblages from pelagic marls with high plankton/benthos ratio.
2. Hacho de Montejaque section (Penibetic Zone, Southern Spain). Turonian-Campanian "Scaglia-type" assemblages from HCl-residues and Campanian/Maastrichtian mixed assemblages from washing residues.
3. Prerif Zone (Northern Morocco), which formed in the late Mesozoic the upper part of the North African paleomargin. Mixed assemblages from pelagic marls with high plankton/benthos ratio.
4. Mesorif Zone (Northern Morocco), Maastrichtian of the M83 section. Mixed assemblages from pelagic marls with low plankton/benthos ratio.
5. Loukkos Zone (Northern Morocco), Campanian-Maastrichtian of the Souk el Had area. Exclusively agglutinated assemblages from greenish marls and claystones.
6. Tanger Unit (Northern Morocco), Campanian-Maastrichtian of the Tangier area (hemipelagic marls and greenish claystones, fine-grained calciturbidite sequences). Agglutinated assemblages (*Rzehakina* and "*Rhabdammina*" faunas).
7. Almarchal Unit of the Campo de Gibraltar flysch domain (Southern Spain). Campanian/Maastrichtian agglutinated assemblages of a fine-grained calciturbidite sequence in a deep bathyal environment.
8. Distal Tellian and Massylian Upper Cretaceous deep-water (abyssal) argillites of the Rif-Betic Seaway (Tangier area).
9. Deep-sea clays intercalated in Mauretanian and Numidian deep-water turbiditic sequences (Campanian/Maastrichtian of the Beni Ider and Talaa Lakrah units, Northern Morocco).
10. Gubbio section, Umbrian Apennines (Italy). HCl-residues from red pelagic "Scaglia"-limestones, deposited in a sediment-starved, well-oxygenated, bathyal environment well above the CCD: "Scaglia-type" agglutinated assemblages.

Assemblages from various localities around the North Atlantic and from the Alpine-Carpathian mountain belt are added for comparison: The Zumaya section of Northern Spain (11), a high latitude locality of the Indian Harbour well on the Labrador Margin (12), slope environments in Trinidad (13), flysch deposits in the Romanian Eastern Carpathians (14), DSDP Sites 141, 367, 368 with flysch-type assemblages (15), DSDP Site 543 with abyssal mixed assemblages (16), and DSDP/ODP Sites 137, 603, and 641 with abyssal agglutinated assemblages (17).

LOCALITY					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
AGE	T	C	S	C	M	Ca-M	T-Ca	Ca-M	Ca-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	T-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	Ca-M	T-M
<i>Ammobaculites agglutinans</i>					---											X						
<i>Ammobaculites aubertae</i>					---											X						
<i>Ammobaculites jarvisi</i>					---			X							X	X	X					
<i>Ammobaculites sp.3</i>					---										X	X	X					
<i>Ammobaculites sp.4</i>					---											X						
<i>Ammodiscus asperellus</i>					---															X	X	
<i>Ammodiscus cretaceus</i>	---	---	---	---	---		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Ammodiscus glabratus</i>					---		X								X	X	X			X		
<i>Ammodiscus infimus</i>	---	---	---	---	---			X										X				
<i>Ammodiscus pennyi</i>					---			X						X				X		X		X
<i>Ammodiscus pennyi cf.</i>					---		X											X				
<i>Ammodiscus peruvianus</i>					---			X		X	X				X	X	X			X		
<i>Ammodiscus planus</i>					---	X	X	X				X			X	X	X			X		
<i>Ammodiscus sp.1</i>					---									X					X			
<i>Ammolagena clavata</i>					---											X	X					
<i>Ammosphaer. pseudopauciloculata</i>		---	---	---	---		X	X						X	X	X	X	X	X			
<i>Arenobulimina dorbigny</i>					---										X	X	X				X	
<i>Aschemonella carpathica</i>					---						X			X	X			X	X			
<i>Aschemonella ex gr. grandis</i>					---		X	X						X		X	X	X	X			
<i>Bathysiphon spp.</i>	---	---	---	---	---			X		X	X	X	X		X	X	X	X	X			
<i>Bolivinospis parvissimus</i>					---															X	X	
<i>Budashevaella trinitatis</i>					---											X	X			X		
<i>Clavulinoides aspera</i>					---												X				X	
<i>Clavulinoides eggeri</i>					---		X								X							
<i>Clavulinoides subparisiensis</i>					---	X	X	X							X			X			X	
<i>Cribrostomoides sp. 1</i>					---		X							X								
<i>Cribrostomoides trinitatis</i>					-		X		X						X	X	X	X	X			
<i>Dendrophrya ex gr. excelsa</i>	---	---	---	---	---			X	X	X	X	X	X		X		X	X	X			
<i>Dendrophrya latissima</i>					---						X					X	X	X	X			
<i>Dorothia crassa trochoides</i>					---	X		X	X		X				X		X	X			X	
<i>Dorothia oxycona</i>	---	---	---	---	---	X	X	X	X						X	X	X	X	X	X		X
<i>Dorothia retusa</i>					---		X	X	X						X	X	X					
<i>Dorothia sp.1 (coarse)</i>					---											X						
<i>Gaudryina ex gr. cretacea</i>					---		X	X	X	X					X	X	X	X				
<i>Gaudryina pyramidata</i>					---	X	X	X	X						X		X	X			X	
<i>Gaudryina sp. 1</i>					---											X						
<i>Glomospira charoides</i>	---	---	---	---	---		X	X	X		X	X	X	X	X	X	X		X	X	X	X
<i>Glomospira diffundens</i>					---			X								X	X	X	X	X	X	
<i>Glomospira gordialis</i>	---	---	---	---	---		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Glomospira irregularis</i>	---	---	---	---	---	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Glomospira serpens</i>					---			X	X	X	X			X	X		X	X			X	
<i>Glomospirella gaultina</i>	---	---	---	---	---		X	X	X	X	X	X	X	X	X	X			X	X	X	X
<i>Glomospirella grzybowski</i>					---			X							X				X	X		



LOCALITY	AGE					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	T	C	S	C	M	Ca-M	T-Ca	Ca-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	T-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	Ca-M	T-M	
<i>Goesella rugosa</i>				---	---	X	X		X						X			X				
<i>Haplophragmium problematicus</i>	---	---	-				X							X				X				X
<i>Haplophragmoides bulloides</i>	---	---	---	---	---													X				X
<i>Haplophragmoides concavus</i> cf.	---	---	---	---	---		X		X		X		X									X
<i>Haplophragmoides eggeri</i>				---	---				X										X			
<i>Haplophragmoides fraudulentus</i>				---	---																X	X
<i>Haplophragmoides glabra</i> cf.				---	---											X	X					
<i>Haplophragmoides herbichi</i>	---	---	-															X				
<i>Haplophragmoides horridus</i>				---	---													X				
<i>Haplophragmoides kirki</i>				---	---											X						
<i>Haplophragmoides linki</i> cf.				---	---																X	X
<i>Haplophragmoides menitens</i>				---	---																X	X
<i>Haplophragmoides multicamerus</i>				---	---																	X
<i>Haplophragmoides multiformis</i>				---	---																	X
<i>Haplophragmoides perexplicatus</i> s.l.				---	---																X	X
<i>Haplophragmoides pseudokirki</i>				---	---																	X
<i>Haplophragmoides retroseptus</i>				---	---				X							X	X			X		
<i>Haplophragmoides</i> sp.1				---	---		X							X								X
<i>Haplophragm. suborbicularis</i> ex gr.				---	---									X		X	X					
<i>Haplophragmoides walteri</i> cf.				---	---		X		X	X	X	X	X	X	X	X	X				X	X
<i>Hormosina crassa</i>	---	---	---	---	---		X				X							X	X	X	X	X
<i>Hormosina excelsa</i>		-	-	-	---							X	X			X		X	X	X	X	X
<i>Hormosina gigantea</i>				---	---		X		X	X	X	X				X		X	X	X	X	X
<i>Hormosina ovuloides</i>	-	-	-	---	---		X	X	X	X	X	X					X	X	X	X	X	X
<i>Hormosina ovulum</i>	-	-	-	---	---	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X
<i>Hormosina trinitatensis</i>				---	---													X				
<i>Hormosina velascoensis</i>				---	---		X		X		X	X		X	X	X	X	X	X	X	X	
<i>Hormosinella distans</i>				---	---		X							X								X
<i>Hormosinella</i> sp. 141				-	-															X		
<i>Hyperammina dilatata</i>	---	---	---	---	---	X	X	X	X	X	X	X			X	X	X		X	X		X
<i>Hyperammina elongata</i>	---	---	---	---	---	X	X	X	X			X		X		X	X	X	X	X	X	X
<i>Hyperammina subdiscreta</i>	---	---	---	---	---	X								X					X	X	X	X
<i>Kalamopsis dubia</i>				---	---				X										X	X		
<i>Kalamopsis grzybowskii</i>				-	---	X	X						X	X	X	X	X	X	X	X	X	X
<i>Karrerella conversa</i>	---	---	---	---	---	X	X	X				X	X	X		X	X	X	X	X	X	X
<i>Karrerella horrida</i>				---	---								X			X	X		X			X
<i>Labrospira inflata</i>				---	---																X	X
<i>Labrospira pacifica</i>				---	---												X				X	X
<i>Labrospira</i> sp.1				---	---											X						
<i>Lagenammina</i> sp.1				---	---												X		X			
<i>Lituotuba lituiformis</i>	-	-	---	---	---	X		X				X		X	X	X	X		X			
<i>Matanzia varians</i>				---	---				X					X	X	X	X	X				
<i>Paratrochamminoides acervulatus</i>				---	---			X			X		X		X		X		X	X	X	X

LOCALITY																							
AGE	T	C	S	C	M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	Ca-M	T-Ca	Ca-M	Ca-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	T-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	T-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	Ca-M	T-M
Paratrochammin. heteromorphus							X	X				X		X	X	X			X				
Paratrochamminoides intricatus s.l.	----	----	----	----	----											X						X	X
Paratrochamminoides irregularis									X		X	X			X		X	X	X	X		X	X
Paratrochammin. semipellucidus s.l.	----	----	----	----	----										X							X	X
Paratrochamminoides sp.1							X								X								
Paratrochamminoides sp.2							X								X						X		
Paratrochamminoides sp.3							X								X						X		
Paratrochamminoides spp.	----	----	----	----	----		X	X			X	X	X	X	X	X			X	X	X	X	X
Phenacophragma elegans					-													X					
Plectorecurvoidea/Recurvoidea spp.	----	----	----	----	----	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Plectorecurvoidea parvus					-																	X	
Plectorecurvoidea rotundus					-																	X	
Praecystamina globigerinaeformis	----	----	----	----	----		X								X								X
Praecyst.(?) cf. globigerinaeformis	----	----	----	----	----		X								X						X	X	X
Psammospaera fusca	-	-	-	----	----						X	X	X	X			X		X		X		
Psammospaera scruposa	-	-	-	----	----			X			X	X		X		X	X	X				X	
Pseudobolivina cuneata	----	----	----	----	----																X	X	X
Pseudobolivina lagenaria	----	----	----	----	----		X								X						X	X	X
Pseudobolivina munda	----	----	----	----	----		X								X						X	X	X
Pseudobolivina sp.1	----	----	----	----	----																X		X
Pseudobolivina sp.2	----	----	----	----	----																X		X
Pseudobolivina sp.3				----	----		X								X								
Pseudobolivina sp.4				----	----		X																
Pseudobolivina spp.				----	----												X	X				X	
Recurvoidea anormis				----	----			X									X		X		X		
Recurvoidea deflexiformis				----	----			X									X	X			X		
Recurvoidea gerochi				----	----												X	X			X		X
Recurvoidea subturbinatus cf.				----	----												X		X		X		X
Recurvoidea walteri				----	----			X									X		X		X		X
Reophax aff. dentaliniformis	----	----	----	----	----												X		X		X		X
Reophax duplex				----	----			X			X	X	X			X	X	X	X	X			
Reophax globosus				----	----						X	X	X				X	X			X		
Reophax pilulifer				----	----			X			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 subnodulosus cf.				-	-		X		X						X								
Rhabdammina spp.	----	----	----	----	----	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Rhizammina algaeformis cf.	-	-	-	-	-		X								X							X	X
Rhizammina grzybowskii				----	----													X					
Rhizammina indivisa	----	----	----	----	----	X	X	X	X			X	X	X	X	X	X	X			X	X	X

LOCALITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17					
AGE	T	C	S	C	M	Ca-M	T-Ca	Ca-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	T-M	Ca-M	Ca-M	Ca-M	T-Ca	Ca-M	Ca-M	T-M	
<i>Rzehakina epigona</i>				-	---		X		X	X	X	X		X	X	X	X					
<i>Rzehakina fissistomata</i>				-	---			X	X	X								X	X			
<i>Rzehakina inclusa</i>				---	---			X		X	X							X	X			
<i>Rzehakina minima</i>				-	---													X				
<i>Saccamina grzybowskii</i>	---	---	---	---	---		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Saccamina placenta</i>				-	---		X		X		X	X	X	X	X	X						
<i>Saccamina placenta cf.</i>	---	---	---	---	---		X	X			X	X								X		
<i>Saccamina sphaerica</i>				---	---		X														X	X
<i>Saccorhiza ramosa cf.</i>				---	---									X								
<i>Sillicosigmolina perplexa</i>				-	---															X		
<i>Spaerammina gerochi</i>				---	---													X		X		
<i>Spirolectammina dentata aff.</i>	-	-	---	---	---	X	X		X	X				X	X	X	X	X			X	
<i>Spirolectammina israelskyi</i>				---	---		X		X					X								
<i>Spirolectammina israelskyi cf.</i>				---	---																X	
<i>Spirolectammina laevis</i>	-	-	---	---	---	X		X						X							X	
<i>Spirolectammina navarroana</i>				---	---			X							X	X						
<i>Spirolectammina spectabilis aff.</i>				---	---			X						X	X							
<i>Spirolectammina subhaeringensis</i>	-	---	---	---	---	X		X			X							X			X	
<i>Spirolectinata (?) sp.1</i>				-	---									X								
<i>Subreophax guttifer</i>	---	---	---	---	---		X							X								X
<i>Subreophax pseudoscalaris</i>				-	---									X	X	X				X		
<i>Subreophax scalaris</i>	---	---	---	---	---	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
<i>Subreophax sp.1</i>				---	---									X						X		
<i>Subreophax splendidus</i>				---	---					X				X	X			X	X			
<i>Thurammina sp.</i>	---	---	---	---	---					X	X					X		X				
<i>Tolypammina sp. 1</i>				---	---	X								X								
<i>Tolypammina sp. 2</i>				---	---	X								X								
<i>Tolypammina sp. 3</i>				-	---									X								
<i>Trochammina altiformis</i>	---	---	---	---	---										X	X			X			X
<i>Trochammina bulloidiformis</i>				---	---													X	X			X
<i>Trochammina deformis</i>				---	---	X				X				X	X				X			
<i>Trochammina globigeriniformis ex gr.</i>				---	---						X			X	X				X	X		
<i>Trochammina gyroidinaeformis</i>				---	---															X	X	
<i>Trochammina sp.1 (coarse)</i>				---	---			X													X	X
<i>Trochammina spp.</i>	---	---	---	---	---	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Trochamminoides dubius</i>				---	---	X			X	X				X	X			X	X	X		
<i>Trochamminoides dubius cf.</i>				---	---		X							X						X		
<i>Trochamminoides proteus</i>				---	---			X						X				X	X	X		
<i>Trochamminoides proteus cf.</i>				---	---		X							X	X					X	X	
<i>Trochamminoides subcoronatus</i>				---	---										X	X				X		
<i>Turritellia sp.</i>				-	---									X							X	
<i>Uvigerinamina jankoi</i>	---	---	---	---	---		X				X			X				X	X	X	X	X
<i>Verneuilina cretacea</i>				---	---		X							X							X	
<i>Verneuilinoides polystrophus</i>				---	---		X							X				X				

Examples: Campanian-Maastrichtian of the Almarchal Unit (Campo de Gibraltar), Campanian-Maastrichtian of the Tanger Unit (Rif, Morocco)

### 3. Slope type (*Rzehakina* Faunas, "low oxygen" assemblages)

General features: Low diversity, species with a finely agglutinated, silicified wall dominate

Characteristic taxa: *Rzehakina epigona*  
*Glomospirella gaultina*  
*Recurvoides*  
*Paratrochamminoides irregularis*  
*Glomospira serpens*  
*Hormosina velascoensis*

Sediment: Green-black laminated or bioturbated claystones, poorly oxygenated bottom water conditions

Examples: Campanian-Maastrichtian of the Tellian Bab Taza and Loukkos Units (Rif, Morocco)

### 4. High latitude slope assemblages

General features: Low to medium diversity, flysch-type agglutinated taxa dominate

Characteristic taxa: *Glomospira charoides*  
*Cribostrumoides trinitatensis*  
*Bathysiphon*  
*Rhabdammina*  
*Recurvoides walteri*  
*Hormosina ovulum*  
*Karrieriella horrida*  
*Uvigerinammina jankoi*

Sediment: Greenish gray claystones, slightly oxygen-deficient bottom-water conditions

Examples: Campanian-Paleocene of the Indian Harbour well (Labrador Margin)

### 5. Abyssal assemblages under well-oxygenated bottom water conditions ("Krascheninnikov-type")

General features: High diverse agglutinated fauna, consisting of tiny, finely agglutinated species. These assemblages correspond to the abyssal agglutinated faunas first described from the Pacific and Indian Ocean (KRASHENINNIKOV 1973, 1974)

Characteristic taxa: *Rhizammina*  
*Uvigerinammina jankoi*  
*Hormosina gigantea*  
*Haplophragmium problematicum*  
*Pseudobolivina munda* and *lagenaria*  
*Karrieriella conversa*  
*Praecystammina globigerinaeformis*  
*Haplophragmoides fraudulentus, multiformis, menitens*  
*Labrospira inflata, pacifica*

Sediment: Brown, varicolored zeolitic claystones, well oxygenated bottom-water conditions, slow pelagic sedimentation

Examples: Turonian-Maastrichtian of DSDP/ODP Sites 137, 603, 641

### 6. Impoverished abyssal assemblages under oxygen-deficient bottom water conditions (biofacies B, *Glomospirella* Faunas)

General features: A low-diversity agglutinated assemblage, consisting of often poorly preserved "primitive" tests, commonly associated with rich radiolarian assemblages

Characteristic taxa: *Glomospirella gaultina*  
*Glomospira gordialis, irregularis*  
*Ammodiscus*  
*Rhizammina*  
*Haplophragmoides concavus*  
*Hormosina*

Sediment: Greenish to dark-grey zeolitic claystones, poorly oxygenated bottom water conditions

Examples: Lower Turonian and Lower/Middle Campanian of DSDP Site 603, Lower Turonian of ODP Site 641, Paleocene of DSDP Site 543

Mixed assemblages with a minor planktonic component

### 7. Mixed assemblages of slope basins

General features: Highly diverse assemblages with large numbers of calcareous benthic foraminifers and calcareous agglutinating ataxophragmids

Characteristic taxa: *Matanzia varians*  
*Recurvoides walteri, anormis*  
*Rzehakina epigona, inclusa*  
*Dorothia oxycona, retusa, crassa*  
*Haplophragmoides retroseptus*  
*Spiroplectammina dentata*  
*Goesella rugosa*

Sediment: Grey-greenish marls and claystones, less oxygenated bottom water conditions

Examples: Campanian-Paleocene of the Mesorif Zone (Rif, Morocco), Campanian-Paleocene of Trinidad, Paleocene of Zumaya (Spain)

### 8. Mixed assemblages of the lower slope

General features: Agglutinated assemblages with only small numbers of calcareous benthic foraminifers and calcareous agglutinating ataxophragmids

Characteristic taxa: *Dendrophrya excelsa*  
*Rhizammina*  
*Recurvoides*  
*Paratrochamminoides*  
*Rzehakina epigona*  
*Aschemonella carpathica*

- Sediment: Light- and dark-gray "hemipelagites" consisting of fine-grained calciturbidites, mud-turbidites, and strongly bioturbated autochthonous layers, less oxygenated bottom-water conditions
- Examples: Campanian-Maastrichtian of the Tellian Bab Taza and Tanger units (Rif, Morocco), Campanian of the Almarchal Unit (Campo de Gibraltar)

### 9. Abyssal mixed assemblages

- General features: Assemblages with large numbers of calcareous benthic foraminifers and calcareous agglutinating ataxophragmids occur in addition to a highly diverse agglutinated fauna, consisting of tiny, finely agglutinated species. Deposition close to the CCD
- Characteristic taxa: brown clay assemblages:  
*Rhizammina*  
*Haplophragmoides perexplicatus*, *menitens*, *molestus*  
*Subreophax scalaris*  
*Bolivinopsis parvissimus*  
*Labrospira inflata*, *pacifica*  
 calcareous agglutinated assemblages:  
*Spiroplectammina subhaeringensis*  
*Verneuilina cretacea*  
*Tritaxia aspera*  
*Dorothia crassa*  
*Gaudryina pyramidata*  
*Arenobulimina orbigny*
- Sediment: Brown zeolitic clays and light gray marly intercalations, well oxygenated bottom water conditions
- Examples: Campanian-Maastrichtian of DSDP Site 543

### Plankton-dominated deep-water assemblages

### 10. "Scaglia-type" assemblages of Western Mediterranean deep-water limestones

- General features: Well diversified assemblages with large numbers of rhizamminids and tiny, finely agglutinated species
- Characteristic taxa: *Rhizammina*  
*Uvigerinammina jankoi*  
*Subreophax scalaris*  
*Tolypammina*, and *Komoki*-like forms  
*Karrieriella conversa*  
*Trochamminoides*  
*Spiroplectammina*  
*Matanzia varians*  
*Aschemonella carpathica*  
*Ammosphaeroidina pseudopauciloculata*  
*Praecystammina globigerinaeformis*  
*Pseudobolivina cf. munda*, *lagenaria*  
*Haplophragmium problematicus*

- Sediment: White, yellow, rose colored to reddish biomicritic limestones and marly limestones, well oxygenated bottom water conditions
- Examples: Turonian-Campanian of the Penibetic Zone (Southern Spain), Turonian-earliest Paleocene of the Gubbio sequence (Umbrian Apennines, Italy)

### 11. Plankton-dominated assemblages of slope marls

- General features: Highly diverse assemblages with large numbers of calcareous benthic foraminifers and calcareous agglutinating ataxophragmids.
- Characteristic taxa: *Dorothyia oxycona*, *crassa*, *retusa*  
*Gaudryina pyramidata*  
*Spiroplectammina dentata*  
*Paratrochamminoides*  
*Glomospira gordialis*, *irregularis*
- Sediment: Gray marls or marl-limestone couples, moderately oxygenated bottom water conditions
- Examples: Campanian-Maastrichtian of the Prerif Zone (Northern Morocco), Campanian-Maastrichtian of the Subbetic and Penibetic Zones (Southern Spain)

### 12. Plankton-dominated assemblages in hemipelagic layers of turbiditic sequences

- General features: Diverse assemblages with large numbers of calcareous benthic foraminifers and calcareous agglutinating ataxophragmids
- Characteristic taxa: *Dendrophrya excelsa*  
*Spiroplectammina dentata*, *subhaeringensis*  
*Recurvoides*  
*Dorothyia oxycona*, *crassa*  
*Goesella rugosa*
- Sediment: Greenish or reddish calcareous marls, well oxygenated bottom water conditions
- Examples: Campanian-Maastrichtian of the Zumaya section (Northern Spain)

## 3. Paleoecology and Paleoceanography

### 3.1 Detrital Input and Community Structure

Detrital input and substrate disturbance are important sedimentary factors affecting 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 astrophid-dominated assemblage directly above the coarse layer of a turbidite to a more diverse assemblage further up in the hemipelagite was 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 was consequently attributed to turbidite intensity.

Recent studies, including data from experimental studies using spade cores and recolonization trays (SCHRÖDER 1986, KAMINSKI 1988, KAMINSKI et al. 1988b), have interpreted concentrations of "primitive" tubular species as a result of hydrodynamic sorting. In these studies an epifaunal habitat has been demonstrated for the modern *Dendrophrya*, in contrast to an infaunal habitat of rectilinear species of the genus *Reophax*. If erosion by a turbidity current effects mainly the flocculent surface sediment, epifaunal species would preferably be entrained by downslope currents and one would expect to see concentrations of *Dendrophrya* in the turbiditic T<sub>d</sub> or T<sub>e</sub> layer of the Bouma Sequence. Corresponding field observations were possible in the Maastrichtian Numidian Flysch of the Talaa Lakrah Unit in the Moroccan Rif (Text-Fig. 3), where redeposited assemblages found in the fine-grained turbiditic T<sub>e</sub> layers, can be distinguished from the autochthonous reddish sub-CCD sedimentation by its carbonate content and its light-gray color. These redeposited assemblages, presumably from a deep-distal slope environment, are made up by tubular agglutinated species of the genus *Rhabdammina* or *Dendrophrya*, accompanied by pelagic planktonic foraminifers (e. g. *Globotruncana falsostuarti*). In contrast, the autochthonous agglutinated assemblages of the red-clay facies are highly diverse and contain only few tubular species (typical *Paratrochamminoides* assemblages).

A generalized model about the effect of substrate disturbance on the structure of modern DWAf communities has been developed by KAMINSKI (1988). In tranquil areas covered by fine-grained pelagic sediment, which provide stable environments for benthic organisms, the agglutinated fauna is dominated by species of Komokiacea and Astorhizidae. 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 diverse and contains a large proportion of species which utilize fine-grained material for test construction. Disturbed environments are characterized by a coarse-grained substrate, consisting of coarse detrital quartz and/or carbonate sand and reworked planktonic and benthic foraminiferal tests. The in situ-agglutinated fauna commonly displays lower 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 Astorhizidae and a number of litiolids and trochamminids. These groups are epifaunal, and constitute the morphogroup of surface-dwelling herbivores, detritivores and omnivores (JONES & CHARNOCK 1985). The infaunal genus *Reophax*, including *Reophax dentaliniformis* which was interpreted by KAMINSKI (1985) as an opportunistic form, especially dominates after brief periods of disturbance ("benthic storms").

Upper Cretaceous deep-water agglutinated benthic communities exhibit surprising analogies with this distribution pattern and community structures 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 reveal the characterizing features of dominating rhizamminids and a large proportion of species which utilize fine-grained material in the construction of their test. Assemblages of the

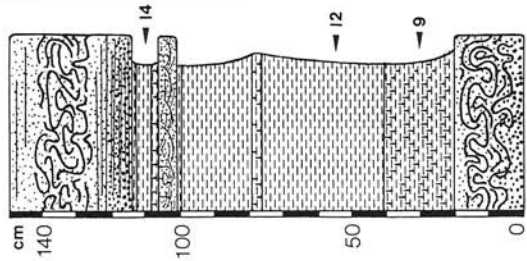




Autochthonous and redeposited foraminiferal assemblages



TALAA LAKRAH UNIT  
(NUMIDIAN FLYSCH)  
MAASTRICHTIAN



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.

### 3.2 Bottom-Water Anoxia and Paleooceanographic Events

The oxygenation of bottom water appears to be an important factor for the composition of deep-water agglutinated foraminiferal assemblages. During the mid- to late Cretaceous and Paleocene the world oceans underwent a period characterized by several periods of oxygen depletion in the deep oceanic realm. These periods of oxygen depletion (or oceanic anoxic events of authors) are characterized by benthic-free zones or distinct "low-oxygen" benthic foraminiferal assemblages and appear to coincide with significant faunal changes also observed in the deep-water agglutinated foraminifers. Three major global paleooceanographic events have been distinguished during the Upper Cretaceous:

#### 1. Cenomanian/Turonian Boundary Event (CTBE)

The CTBE is characterized by a predominating biosiliceous sedimentation and shows distinct and marked anoxic facies in the deep-sea (HERBIN et al. 1986, KUHNT et al. 1986, THUROW et al. 1982 and in press). The event is accompanied by important taxonomic changes in deep-water benthic foraminifers (GEROCH & NOWAK 1984, KUHNT 1987, MOULLADE et al. in press). In the deep-water limestones of the Western Mediterranean and in the North Atlantic Plantagenet Formation the CTB is devoid of benthic foraminifers and overlying beds are characterized by rare and low-diverse agglutinated assemblages (mainly indeterminable "tubes" and species of the family Ammodiscidae). The HCl-residues consist almost completely of radiolarians and (secondarily) silicified planktonic foraminifers. In recent oceans the oxygen-minimum zone on continental slopes below high productivity surface waters appears rather barren of in situ foraminiferal fauna (ZOBEL 1973). This may be a possible model for the rare occurrence and low diversity of agglutinants in the beds overlying the CTB, which exhibit important certification and slightly more reducing environments than the sequence upsection.

The re-occurrence of benthic foraminifers occurred in the early to Middle Turonian, and diversified benthic assemblages can be observed beginning in the Middle-Upper Turonian (*P. helvetica* and *M. schneegansi* Zones),

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Text-Fig. 3. Redeposition of agglutinated assemblages from deep-distal sources. Maastrichtian of the Talaa Lakrah Unit (Numidian Flysch), Rif, Northern Morocco.

with characteristic *Haplophragmium problematicus* - *Uvigerinamina jankoi* assemblages.

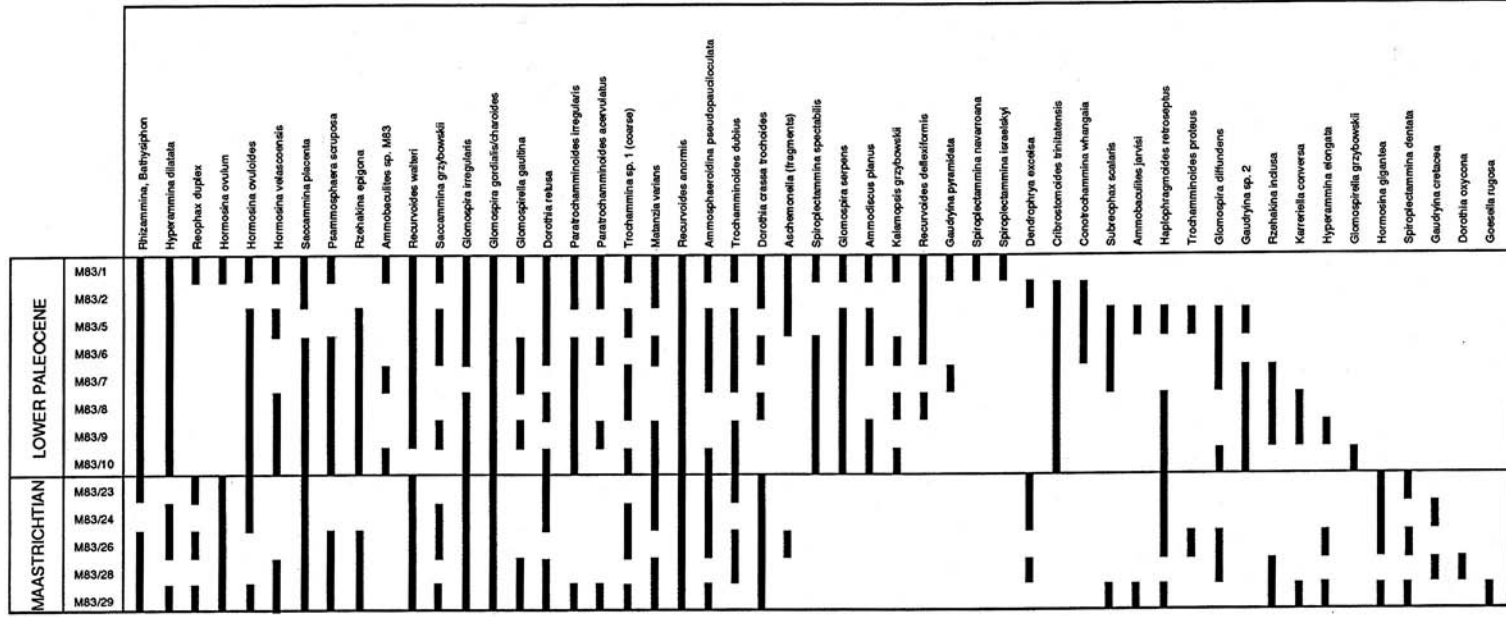
## 2. A Lower/Middle Campanian Event (LMCE)

This event is characterized by the intercalation of a biosiliceous facies in the Tethyan flysch basins (NEAGU 1968, HERM 1962, BUTT 1981, KUHN 1987). A radiolarian biofacies with a peculiar taxonomic composition of the radiolarian assemblages prevails across this interval and has also been observed in the zeolitic clays (sub-CCD deposits of the Plantagenet Formation) of the North Atlantic Ocean (MOULLADE et al. in press, THUROW in press). In both cases this biosiliceous event coincides with a major faunal change in agglutinated foraminifers: The *Uvigerinamina jankoi* assemblage, which dominates the Turonian-Santonian sequences, is replaced by a *Hormosina gigantea* assemblage which characterizes Upper Campanian and Maastrichtian biofacies in the flysch series as well as in the zeolitic claystones deposited below the CCD. In the pelagic limestone sequences of the Gubbio area and the Penibetic Zone, no prominent biosiliceous signal has been observed in the Lower Campanian. However, a turnover in the composition of agglutinated foraminiferal assemblages is likewise observed at that locality.

## 3. The Cretaceous/Paleocene Boundary Event (KTBE)

At the end of the Cretaceous period (66.4 Ma), hundreds of species of oceanic calcareous phyto- and zooplankton suddenly became extinct. According to the scenario of ALAVAREZ et al. (1980), the catastrophic impact of an asteroid-sized bolide produced short-term climatic changes which resulted in the collapse of the shallow-water marine trophic structure. Stable oxygen and carbon isotopes provide evidence of temperature change and greatly reduced oceanic primary productivity coincident with the K/T boundary clay and during the first few hundred thousand years of the Paleocene (HSÜ & MCKENZIE 1985, ARTHUR et al. 1987, KAMINSKI & MALMGREN in press). However, the KTB also exhibits in several localities a dark laminated boundary clay, indicating oxygen deficiency at the ocean floor (HSÜ 1986). The effects of the K/T boundary event on deep marine benthic organisms are more poorly understood. Deep water benthic foraminiferal species were certainly 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) or extinction occurred not suddenly but over a longer period of time (WEBB 1973, DAILEY 1983). We studied the taxonomic composition of DWAF assemblages in a continuous section in a slope sequence of the North African paleomargin (Section M83, Mesorif Zone, compare KUHN 1987). The stratigraphic distribution of 51 agglutinated taxa across the K/T boundary is recorded in this section (Text-Fig. 4). Thirteen of these species appear for the first time in the Lower Paleocene. Only 5 species have their last occurrence near the boundary and for 3 of these 5 species a last occurrence has been recorded already within the Upper Maastrichtian.

Recent research on the population dynamics of modern species of benthic foraminifera (KAMINSKI et al. 1988b) provides new insight into the problem



Text-Fig. 4. Range chart of DWAf across the K/T boundary in a slope section of the North African Margin (Section M83, Mesorif Zone, Northern Morocco).

of detecting possible mass mortality among benthic foraminifers. In an experiment using recolonization trays placed in the Panama basin, KAMINSKI et al. (1988b) were able to identify which morphogroups of benthic foraminifera are opportunistic and which groups show limited capability for dispersal. A remarkable pattern in the community structure of benthic foraminifera has been observed by KUHNT (submitted) in the Gubbio section of Central Italy. 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 displays limited capability for dispersal displays a dramatic decrease from the top of the Cretaceous to the base of the Paleocene. This pattern can be interpreted as evidence for mass mortality among benthic foraminifers across the K/T boundary.

MOULLADE et al. (in press) observed a significant faunal break in deep-water agglutinated foraminifers coinciding with the K/T boundary in the North Atlantic Plantagenet Formation. However, in the sites studied, the Paleocene portion of the sequence revealed only few and poor foraminiferal assemblages, and a confirmation of these findings requires additional study.

The available data is still ambiguous as to whether or not the deep-sea benthos had been strongly affected by the K/T boundary event. This information is crucial to discriminate between the different proposed models to explain the cause of this major event.

#### 4. Paleobathymetry

The paleobathymetric distribution of Upper Cretaceous DWAF assemblages can be reconstructed for the Maastrichtian time slice from a transect on the thrusted North African Margin in the Telliian Units of the Moroccan Rif (KUHNT in press). These data are compared to DSDP/ODP sites on the Northwest African Margin, Galicia Margin and North American Margin (compare Text-Fig. 1).

Analysis of the taxonomic composition of benthic foraminiferal assemblages and comparison with general faunal trends such as plankton/benthos ratios, diversity and abundance of agglutinated species led to the evaluation of characteristic foraminiferal biofacies. These trends have been used to define five bathymetric zones along a composite transect of the Upper Cretaceous North African and Iberian continental margins:

1. Upper Slope Assemblages (200-500 m water depth): Besides first flysch-type agglutinants (e. g. *Glomospira*) calcareous agglutinating forms like *Matanzia*, *Verneuilina*, *Gaudryina*, *Dorothia*, and *Spiroplectamina* are common (corresponding to the *Marssonella* association of HAIG 1979). Generally, this assemblage shows optimal benthos diversity. The plankton/benthos ratio is above 9.

2. Middle Slope Assemblages (500-1500 m water depth): Flysch-type forms (e. g. *Glomospira*, *Ammodiscus*, *Hormosina*, *Paratrochamminoides*, *Rhabdammina*) become an important constituent of the agglutinants, and calcareous ataxophragmids of the "*Marssonella* association" are still common. The amount of calcareous forms, especially planktonics, is quite variable (from almost zero to 99 %) due to effects of a local carbonate lysocline and/or redeposition.

In an intermediate bathymetric zone a *Rzehakina-Rhabdammina-Reusella* assemblage has been observed between the typical middle slope and the lower slope assemblages: Flysch-type agglutinants dominate. The plankton/benthos ratio is quite inconstant. The amount of planktonic foraminifera can be very low especially in assemblages with a high dominance of the *Rhabdammina* group.

3. Lower Slope Assemblage (1500-→2500 m water depth): *Rhabdammina* assemblage, flysch-type agglutinated assemblages with high dominance of tube-like morphotypes (e. g. *Rhabdammina*, *Dendrophrya*). Planktonic foraminifera are very rare or absent, often fragmented and/or corroded and are restricted to forms with a high dissolution-resistance.

4. Abyssal Assemblage ("Flysch-type", occurring in regions with significant detrital input): *Recurvoides-Paratrochamminoides* assemblage without any autochthonous calcareous foraminifera (deposition below CCD). The diversity of agglutinated forms is higher in comparison to slope assemblages.

5. Abyssal *Labrospira-Praecystammina* Assemblages ("Krashennikov-type"): A purely agglutinated assemblage consisting mainly of small smooth-walled forms which is typical for late Cretaceous deep oceanic basins with low detrital input. The diversity of this assemblage is generally lower than that of flysch-type assemblages.

Similar paleobathymetric distribution patterns, typical for Upper Cretaceous low-latitude areas, have been observed in Trinidad and the Caribbean Sea (HEMLEBEN & TRÖSTER 1984, KAMINSKI et al. 1988a), and on the Baltimore Canyon transect (NYONG 1983, NYONG & OLSSON 1984).

Paleobathymetric patterns in northern assemblages (e. g. Labrador Margin) differ from low-latitude assemblages by the lack of a shallow "*Marsionella* association" of calcareous ataxiophragmids. Shallow Maastrichtian assemblages contain abundant coarse tubular species and litiolids with only very rare calcareous ataxophragmids. Deeper assemblages contain more abundant *Glomospira*, *Hormosina*, *Paratrochamminoides*, *Ammosphaeroidina*, *Praecystammina* and finely agglutinated litiolids (*Cribrostomoides*, *Haplophragmoides* and *Labrospira*). Campanian deep assemblages contain abundant *Uvigerinammina*.

## 5. Biostratigraphy

Several species of agglutinated foraminifera 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, SANDLESCU 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 (KUHN 1987), in the North Atlantic (MOULLADE et al. in press), in the Umbrian Apennines and the Betic Cordillera (KUHN in press) and in Trinidad (KAMINSKI et al. 1988a).

Several species (e. g. *Hippocrepina depressa*, *Plectrorecurvoides irregularis*, *Trochammina abrupta*, *Recurvoides imperfectus*, *Haplophragmoides gigas minor*) have their last occurrences near the Cenomanian/Turonian boundary. Their extinction is most probably 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 CTBE contains *Haplophragmium problematicum* as an indicator.

The total range of *H. problematicus* is given as Lower Cenomanian to lowest Campanian (NEAGU 1970, KUHNT in press). Its partial range and optimum occurrence characterize the Turonian Haplophragmium problematicus Zone (= *A. problematicus* Zone of GEROCH & NOWAK 1984 and the *H. lueckeii* Zone of MOULLADE et al. in press).

The species *Uvigerinamina 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 from Middle-Upper Campanian of the Indian Harbor well on the Labrador Margin. 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. The first occurrence of this species is a reliable indicator of the Middle Campanian in flysch and deep-sea environments.

The last occurrence of *Praecystamina globigerinaeformis* is useful for determining a datum level close to the Coniacian/Santonian boundary in abyssal assemblages, but this species ranges into younger levels at bathyal depths.

One of the most interesting Upper Cretaceous lineages is the evolution of the typical *Hormosina excelsa* from ancestors, which may belong to the *Hyperamina dilatata* group in the Coniacian/Santonian. With respect to size, the evolution of this form parallels that of the *H. ovulum*-*H. gigantea* group. Upper Cretaceous specimens are typically small, but near the top of its stratigraphic range in the Upper Maastrichtian to Paleocene, a size increase is observed.

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

GEROCH & NOWAK (1984) defined a Lower Campanian *G. rugosa* Zone in the Polish Carpathians. 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. Moreover, we have not observed *G. rugosa* on the western North Atlantic margin. These mainly calcareous agglutinated species are absent in sediments deposited below the CCD.

The genera *Paratrochamminoides*, *Haplophragmoides*, *Karrerella* and *Pseudobolivina* may also have regional stratigraphic importance in the Upper Cretaceous, but more detailed taxonomic work is required on these species.

A major faunal turnover at the Cretaceous/Tertiary boundary is reflected by the first occurrence of many new species in the early Paleocene in Trinidad (Text-Fig. 4). Characteristic new species in the Danian are: *Budastevaella* cf. *multicamerata*, *Clavulinoides amorphus*, *Clavulinoides globulifera*, *Clavulinoides paleocenica*, *Conotrochammina whangai*, *Dorothia indentata*, *Eggerella trochoides*, *Haplophragmoides lamella*, *Karrerella tenuis*, *Phenacophragma beckmanni*, *Reticulophragmium* spp., *Reticulophragmoides jarvisi*, *Spiroplectamina spectabilis* (acme), *Spiroplectamina excolata*, *Trochammina ruthven murrayi*.

Interestingly enough, in the Western Mediterranean and the North Atlantic major faunal turnovers in deep-water benthic agglutinated foraminifers 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 inter-regional and isochronous, i. e. reliable datum horizons for the biochronology of deep-sea sediments.

## 6. Benthic Foraminifers and the Subsidence History of Western Mediterranean Margins

The burial history of the sedimentary wedges along the North African and Southern European margins in the Western Mediterranean is strongly influenced by the tectonic history of the region. The geologic record on the North African Margin shows four phases of sedimentation during the Cretaceous (KUHNT & OBERT, this volume), which probably have influenced the entire Cretaceous Rif-Betic seaway and its paleomargins.

1. Distension and subsidence of the margins in the Lower Cretaceous.
2. A first transpressional phase with uplift and slight metamorphism in the Albian to early Cenomanian, which affected the northerly ("Haut Telliën") paleogeographic zones of the North African continental margin.
3. A late Cretaceous stage of subsidence (Cenomanian-Santonian).
4. A second compressional phase starting with the Campanian and reflected by the formation of submarine fans with turbiditic sequences, sedimentary klippe, and olistostrome complexes.

The temporal distribution of Upper Cretaceous deep-water agglutinated foraminiferal assemblages reflects this complex subsidence and sedimentation pattern. This relation can be demonstrated by two examples (Text-Figs. 5 and 6): the Upper Cretaceous of the Tanger Unit in the Moroccan Rif (North African Margin) and that of the Penibetic Zone in Southern Spain (European Margin of Iberia or the Alboran Block). In the Penibetic Zone (Text-Fig. 5), a shift from Albian-Cenomanian agglutinated assemblages, which are dominated by calcareous ataxophragmids towards "Scaglia-type" assemblages (KUHNT submitted) occurred during a Cenomanian-Turonian phase of strong subsidence, accompanied by a global sea-level rise. Since the late Campanian, when in the local paleotectonic pattern compressive movements and first uplift can be distinguished, ataxophragmid-dominated agglutinated assemblages re-occur in the Hacho de Montejaque section. In the Tanger Unit of the Moroccan Rif (Text-Fig. 6), well diversified flysch-

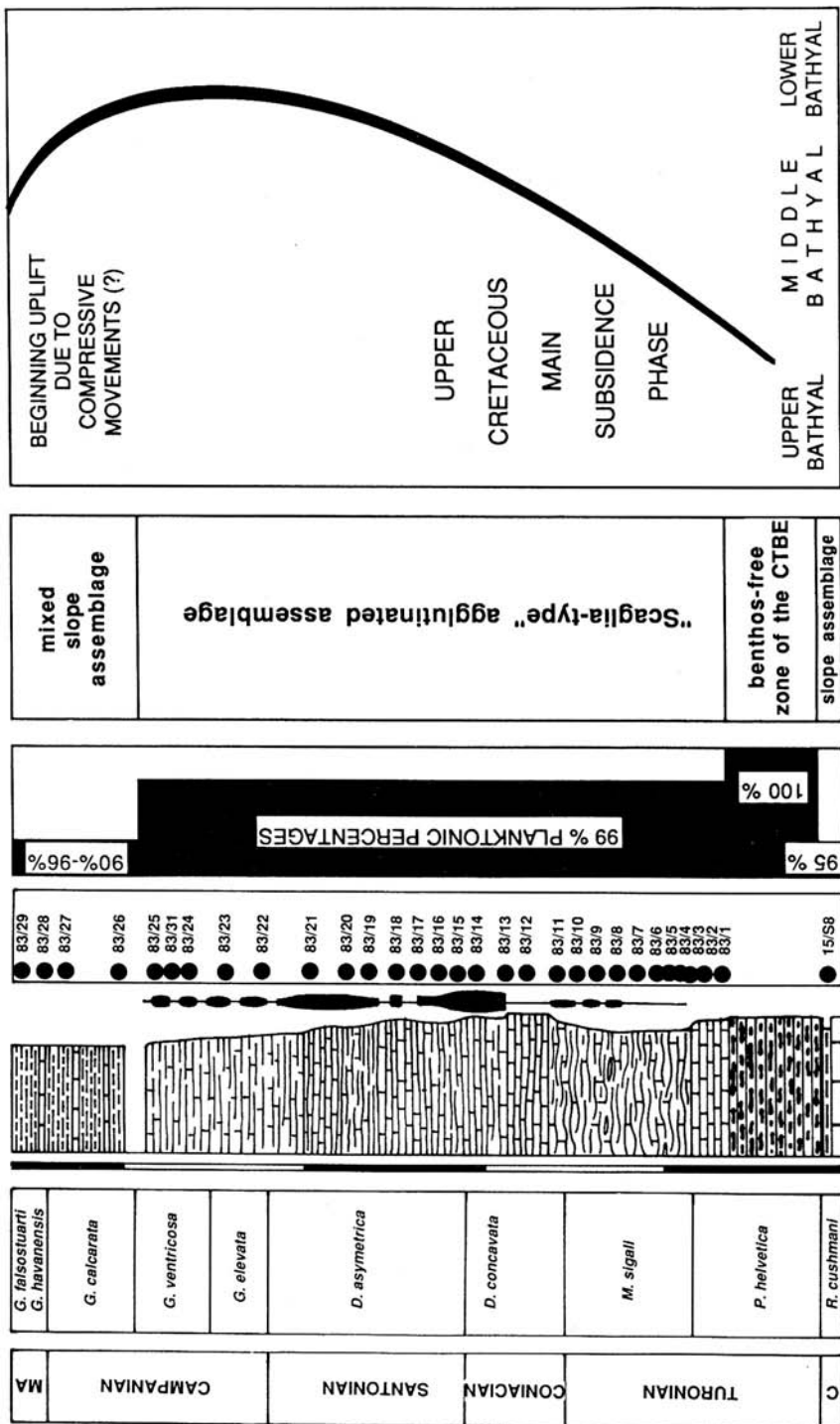
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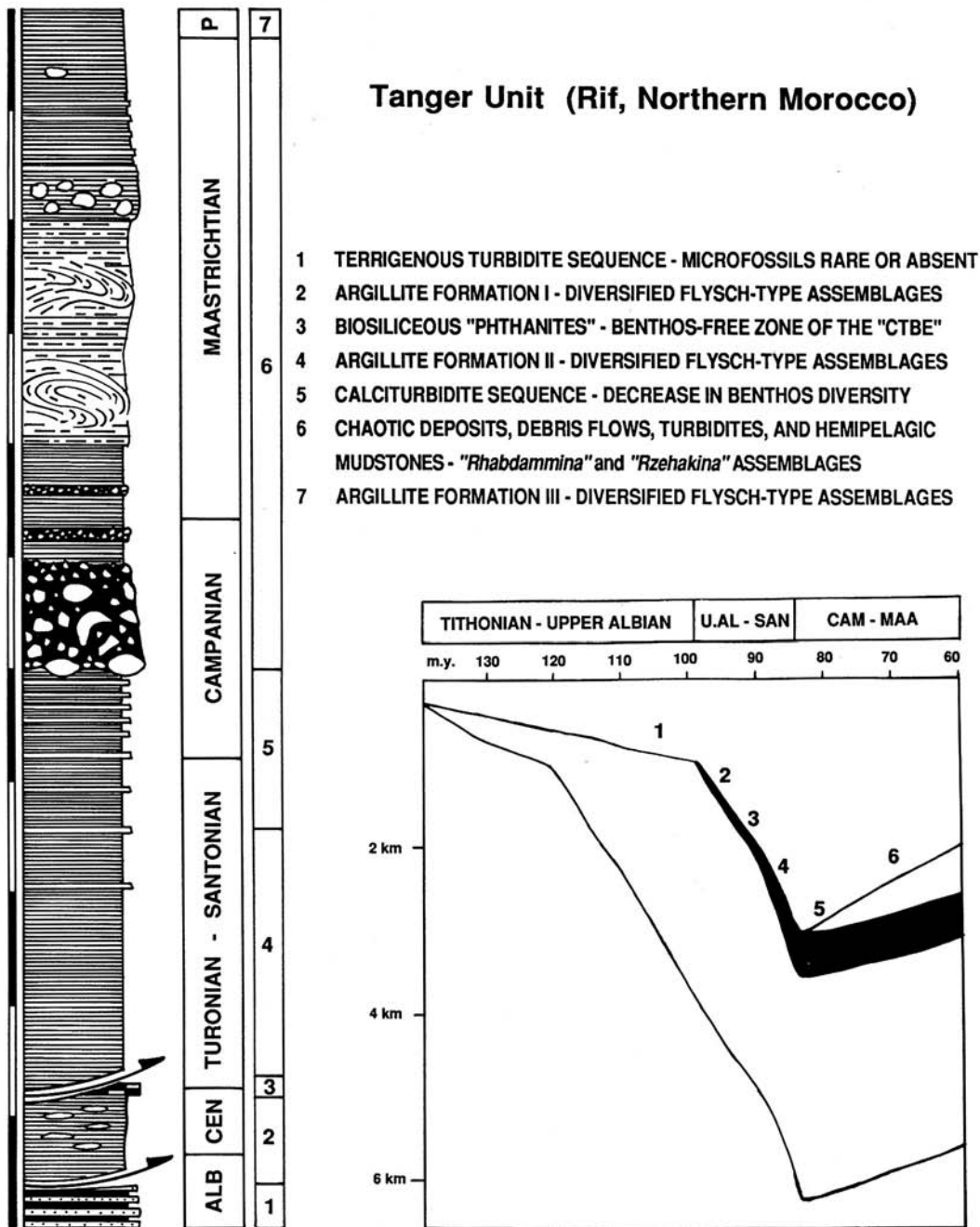
Text-Fig. 5. Cretaceous subsidence history and foraminiferal biofacies in the Hacho de Montejaque section (Penibetic Zone, Southern Spain).

Text-Fig. 6. Upper Cretaceous to Paleogene in the Tanger Unit (Rif, Northern Morocco): Synthetic section, burial history (corrections for sea-level history and compactions are taken into account) and benthic foraminiferal biofacies.



Hacho de Montejaque Section  
(Penibetic Zone, Spain)





Text-Fig. 6

type agglutinated assemblages, which characterize Albian to Santonian beds, were replaced by low-diversity *Rhabdammina* and/or *Rzehakina* faunas during the Campanian. These assemblages reflect the enhanced detrital input, the sedimentary filling of basins and probable tectonic uplift of certain regions during the Campanian-Maastrichtian compressive paleotectonic phase.

## 7. Conclusion

Deep-water agglutinated foraminifers (DWA) provide valuable information about late Cretaceous slope and deep oceanic paleoenvironments in the Western Mediterranean area. Their community structure is mainly influenced by paleobathymetry, oxygenation of bottom waters, detrital input, substrate disturbance, and availability of calcium carbonate. 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 evolution of DWA is strongly 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 at these levels ("benthic events"), coeval with global paleoceanographic events, could be regarded as inter-regional and isochronous, i.e. reliable datum horizons for the biochronology of deep-sea sediments deposited below the CCD on more than a regional scale.

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