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Autor(en): **Nyong, Eyo E.**

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# Campanian to lower Maastrichtian paleobiogeography of the western North Atlantic region

By EYO E. NYONG<sup>1)</sup>

## ABSTRACT

Planktic foraminiferal evidence suggests that two major paleobiogeoprovinces can be recognized in the western North Atlantic region during the Campanian to lower Maastrichtian. Planktic foraminiferal composition and distribution support the views expressed by earlier workers who maintained that surface water circulation within the North Atlantic Ocean was dominated by the gulf stream gyre, resulting in a widespread Tethyan faunal province throughout most of the region. The development of a transitional biogeoprovince is noted in the northernmost parts of the western North Atlantic in the present study while the development of a Boreal biogeoprovince probably awaited further opening of the Norwegian–Greenland and Labrador Seas and subsequent connection between the Arctic and North Atlantic Oceans. It is observed that foraminiferal dissolution at depth can seriously affect paleobiogeographic interpretation.

## ZUSAMMENFASSUNG

Das Auftreten planktischer Foraminiferen lässt vermuten, dass es zwischen Campanian und unterem Maastrichtian zwei paläobiogeographische Hauptverbreitungsgebiete gab. Die Zusammensetzung und die Verteilung der planktischen Foraminiferen bestätigen die Ansichten früherer Autoren, dass die Oberflächenzirkulation im Nordatlantik durch den Golfstrom bestimmt wurde. Dies wiederum hatte eine weite Verbreitung der Tethys-Fauna in den meisten Gebieten zur Folge. Die vorliegende Arbeit befasst sich mit der Entwicklung der biogeographischen Übergangsgebiete im nördlichsten Teil des Nordwestatlantiks. Die Entwicklung einer echten borealen Biogeoprovinz erfolgte erst nach einer weiteren Öffnung der Norwegischen, Grönland- und Labrador-See, welche eine Verbindung zwischen Arktis und Nordatlantik schuf. Die paläogeographischen Interpretationen werden durch die Auflösung von Foraminiferen in grösseren Tiefen stark beeinflusst.

## Introduction

Much paleoecological research has focussed on changes in the biogeography of species. However, due to lack of detailed biostratigraphic studies, most of the analysis have involved late Tertiary sediments. In the past few decades, the advent of deep-sea drilling has allowed a significant refinement of Cretaceous biostratigraphy, subsequently it has been shown that Cretaceous planktic foraminifers are not entirely cosmopolitan and that zoogeographic variation across latitudinal boundaries exist

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<sup>1)</sup> Department of Geological Sciences, Rutgers University, New Brunswick, New Jersey 08903, USA.  
Present address: Department of Geology, University of Calabar, Calabar, Nigeria.

(DOUGLAS 1972). The first major contributions to foraminiferal biogeography can be traced to DOUGLAS & SLITER (1966), DAVIDS (1966) and to the work of BANDY (1967), when he first drew attention to a "keeled line" which indicated the occurrence of planktic foraminifera of tropical character further north than Recent tropical species distribution in sediments of Europe and North America.

A review of pertinent literature on foraminiferal biogeography shows that most of the benthic genera and species considered to be Tethyan (warm water) indicators in the Jurassic can also be used to determine tethyan boundaries during the Cretaceous, especially the early Cretaceous. During the mid-Cretaceous, planktic foraminifera underwent rapid expansion and diversification with the advent of globotruncanids, hedbergellids, rotaliporids and related forms. By late Cretaceous times planktic foraminifera had become well established and abundant. In recent years, planktic foraminifera have been shown to be useful indicators of biogeographic provincialization and paleocirculation in late Cretaceous seas (OLSSON 1964, 1977; DOUGLAS & SLITER 1966; DAVIDS 1966; SLITER 1976; SCHEIBNEROVA 1971, 1972, 1973; BERGGREN & HOLLISTER 1974). The main North Atlantic basin (Fig. 1) was part of the circum-equatorial Tethys Ocean from the mid-Jurassic until the late Cretaceous when the South Atlantic with its connection to the southern ocean opened wide enough to allow exchange of surface

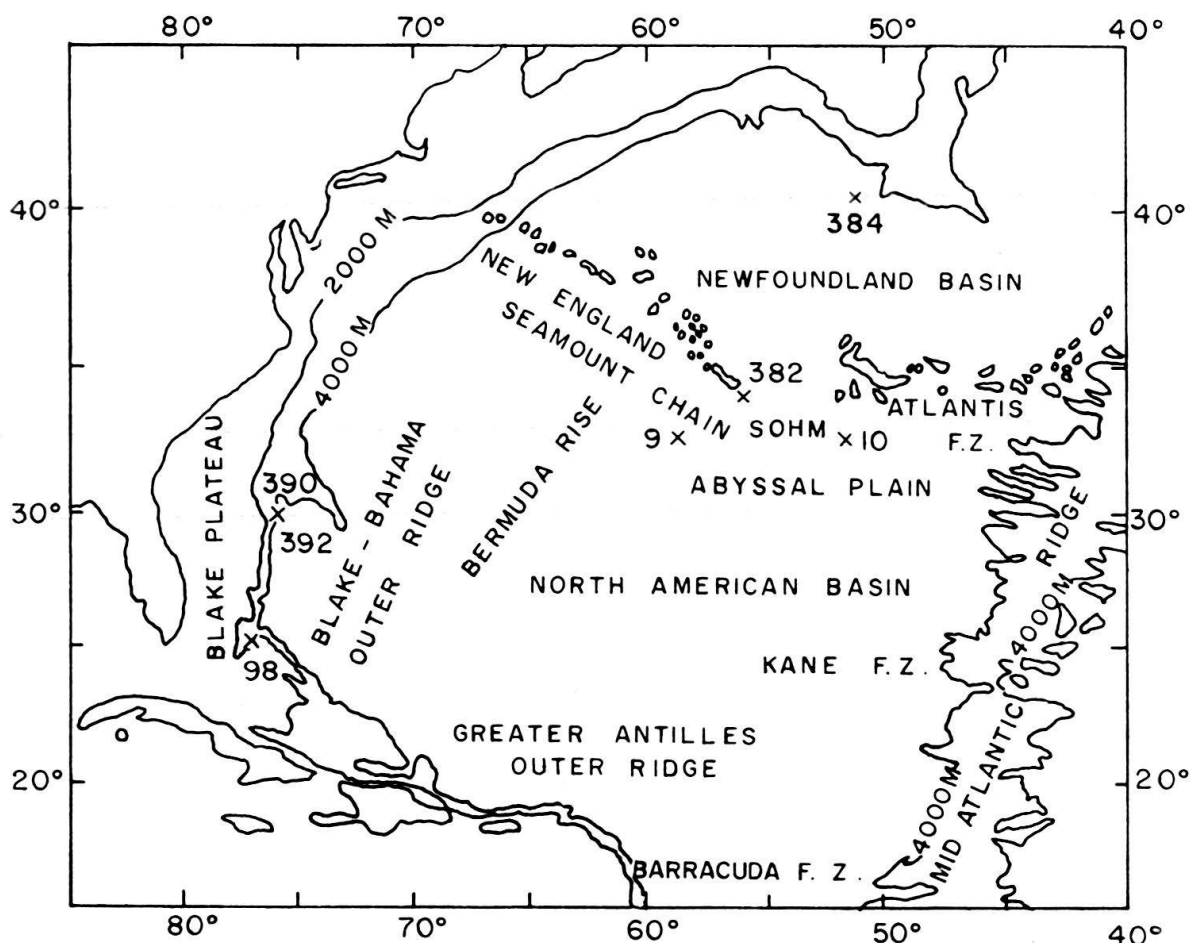


Fig. 1. Map showing location of the western North Atlantic Ocean and associated structural elements.

and possibly deep water masses with the North Atlantic (THIEDE 1979). Continued spreading of the North–South Atlantic seafloor resulted in further development of circulation patterns in the late Cretaceous (BERGGREN & HOLLISTER 1974). Distribution and composition of planktic foraminifers suggest that the gulf stream gyre dominated North Atlantic circulation with northward branches into the Labrador Sea around Greenland and northeastwards towards the arctic region, through late Cretaceous and early Tertiary times (DAVIDS 1966; BERGGREN & HOLLISTER 1974).

At present, it is generally assumed that Cretaceous planktic foraminifers had distributional patterns similar to Recent forms in that the planktic foraminifers with small unornamented tests and globular chambers lived in cold temperate waters and those with ornamented tests associated with greater diversity lived in tropical and subtropical waters (BE & TOLDERLUND 1971; FRERICHS 1982). DOUGLAS & SLITER (1966) noted that in the late Campanian, 5 genera and 6 species were present in temperate areas, compared to 10 genera and 25 species in Tethyan areas. DAVIDS (1966) also noted that Tethyan assemblages were more diverse than temperate assemblages. This situation is analogous to present day diversity patterns between tropical and temperate regions. In addition to being less diverse, late Cretaceous temperate faunas contain greater proportions of globigerinid forms (BERGGREN & HOLLISTER 1974) while Tethyan assemblages contain more globotruncanids and rugoglobigerinids (DAVIDS 1966).

DOUGLAS & SLITER (1966) identified as Tethyan, the Campanian species *Globotruncana calcarata* CUSHMAN. The heterohelicidae, notably *Pseudotextularia* and *Racemi-guembelina* are also regarded by them as Tethyan. DAVIDS (1966) in a study of Maastrichtian faunas demonstrated that *Globotruncana calciformis* DE LAPPARENT, *G. conica* WHITE and *Praeglobotruncana citae* BOLLI were diagnostic Tethyan species. OLSSON (1964) regarded *Hedbergella monmouthensis* (OLSSON) as a late Cretaceous temperate species. BERGGREN (1962) had reported abundant specimens of this species from Scandinavia, a region that was well within the temperate realm in the late Cretaceous. The diversity, abundance and distribution of these species and related taxa within the western North Atlantic region, provide evidence for zoogeographic provincialization in the Campanian to lower Maastrichtian.

OLSSON (1964, 1977) in discussing the late Cretaceous planktic foraminiferal faunas of the coastal plain of New Jersey and Mesozoic faunas of the western Atlantic, noted a decrease in Tethyan influence over these regions during the Campanian and Maastrichtian. He recorded a planktic composition which tends to suggest an interplay of cold and warm water masses in this region. The common Tethyan indicator species recorded by Olsson included *Globotruncana linneana* (D'ORBIGNY), *G. fornicata* PLUMMER, *G. cretacea* (D'ORBIGNY), *G. subrugosa* GANDOLFI, *G. elevata* (BROTZEN) and *G. calcarata*. SCHEIBNEROVA (1971) recognized in the Mesozoic, a Tethyan (Mediterranean, tropical/subtropical), Boreal (temperate, cool, polar), and Austral (equivalent to the Boreal of the northern hemisphere) biogeographic provinces. She also recognized an additional transitional (situated between Tethyan and boreal/austral biogeographic provinces) biogeographic province in the late Cretaceous. She considered these provinces to be circumglobal in distribution. However, BERGGREN & HOLLISTER (1974) in a review of work on the history of the North Atlantic did not find evidence for delineation of a Boreal faunal province in the North Atlantic during the late Cretaceous. Similar findings have been reported from the early Senonian of western Europe (BAILEY & HART

1979) and from Cenomanian–lower Senonian of Bornholm (DOUGLAS & RANKIN 1969). DOUGLAS (1972) indicated a northward extension of the Tethyan faunal realm to 50° N. Latitude and suggested the possible presence of a Boreal province north of this latitude during late Cretaceous times. It is apparent that there is no clear consensus of opinion among various workers as to the northern extent of the Tethyan faunal province and the presence or absence of a Boreal faunal province in the North Atlantic region during this period. The planktic foraminiferal distribution observed in this study sheds some light on the problem, as more data from the Deep Sea Drilling Project (DSDP) has become available.

#### *Planktic foraminiferal diversity and distribution*

This study is based upon a summary of observed distribution of planktic foraminifers recovered from DSDP holes located in the western North Atlantic region. Sample coverage ranges from about 50° N. Latitude (Site III Orphan Knoll) to 9° N. Latitude (Site 144 on the Demerara Rise). The location of the DSDP holes used in the study is shown in Figure 2. Planktic foraminifers make up 75–98% of the total foraminiferal population at all sites investigated excluding hole 9A where the percentage was

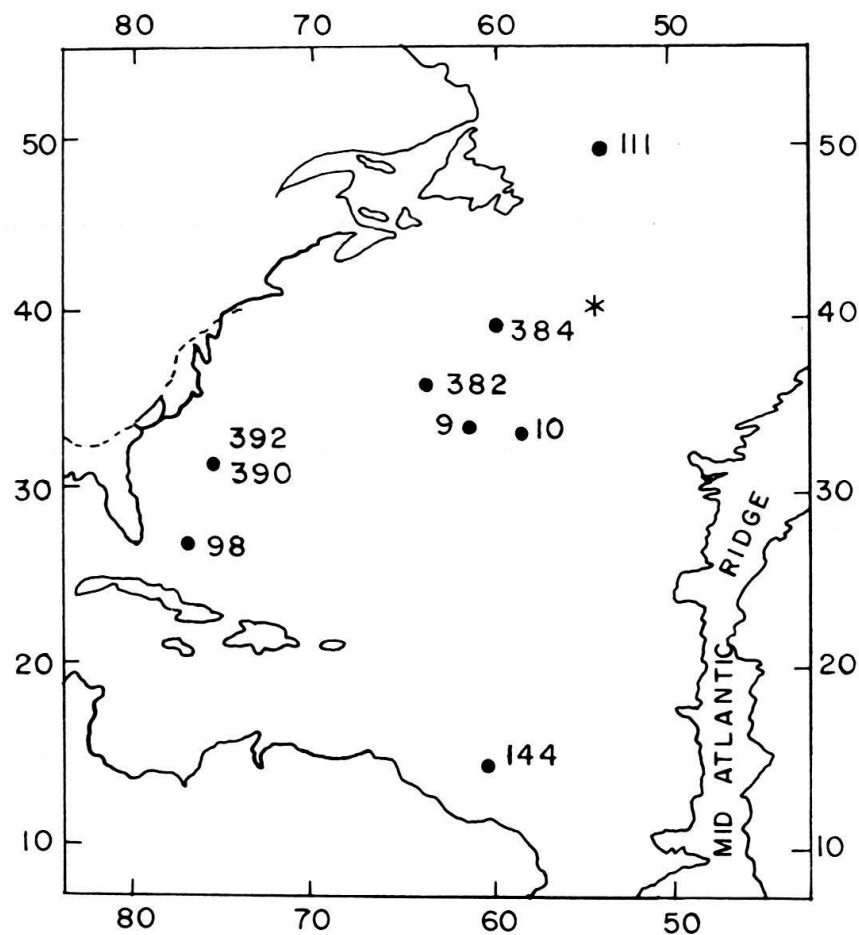


Fig. 2. Outline map of the western North Atlantic showing location of DSDP sites considered in this study (\*data from McNULTY 1979).

Table 1: *Distribution of planktic foraminifers at DSDP sites in the western North Atlantic, from lower to higher latitudes.*

Planktic Foraminiferal Species	DSDP SITES (Western North Atlantic)							
	144	98	390A	392A	10	9A	382	III A
<i>Globotruncana arca</i>								
<i>G. fornicata</i>								
<i>G. ventricosa</i>								
<i>G. tricarinata</i>								
<i>G. stuartiformis</i>								
<i>G. elevata</i>								
<i>G. linneana</i>								
<i>G. calciformis</i>								
<i>G. conica</i>								
<i>G. rosetta</i>								
<i>G. contusa</i>								
<i>G. calcarata</i>								
<i>G. lapparenti</i>								
<i>G. subspinosa</i>								
<i>G. stephensoni</i>								
<i>Rugoglobigerina rugosa</i>								
<i>Archeoglobigerina</i> sp.								
<i>Praeglobotruncana citae</i>								
<i>Hedbergella monmouthensis</i>								
<i>H. holmdelensis</i>								
<i>Heterohelix globulosa</i>								
<i>H. pulchra</i>								
<i>H. striata</i>								
<i>H. punctulata</i>								
<i>H. ultimata</i>								
<i>Pseudotextularia elegans</i>								
<i>Pseudoguembelina costulata</i>								
<i>P. excolata</i>								
<i>Racemguembelina fructicosa</i>								
<i>Guembelitra cretacea</i>								
<i>Planoglobulina multicamerata</i>								
<i>P. grabrata</i>								
<i>Globigerinelloides messinae</i>								
<i>G. volutus</i>								
<i>G. subcarinatus</i>								
<i>Globigerinelloides</i> sp.								
<i>Schackoina multispinata</i>								
<i>Schackoina</i> sp.								

Common ———

Rare - - - -

less than forty. The observed planktic foraminiferal composition at each location is shown in Table 1. The foraminiferal report from site 384 (McNULTY 1979) was also utilized for the analysis, the recurrent planktic foraminiferal species from the lower Maastrichtian at this site is listed in the appendix. In general, single and double-keeled globotruncanids, heterohelicids including species of *Racemiguembelina*, *Pseudotextularia*, *Planoglobulina*, *Pseudoguembelina* and *Heterohelix* are abundant in the lower latitude sites. These forms persist into sites located at latitude 40° N and beyond, but tend to decrease in their relative abundance and diversity. Species of *Archeoglobigerina*, *Rugoglobigerina* and *Hedbergella* although present in the other sites tend to become significant components of the planktic foraminiferal assemblage in the higher latitude sites (40° N and higher).

Geographic variation in diversity is not pronounced especially when considered in terms of number of species present (Fig. 3). However, shifts in the relative number of species of each genus represented and in the overall proportions of constituent species are discernable. For example, some species of the genus *Globotruncana* are absent in the section from hole IIIA, while others occur in few numbers; whereas species of *Rugoglobigerina*, *Archeoglobigerina*, *Hedbergella* and *Heterohelix* are well represented in sections from this location. In general, 8 to 10 genera represented by about 16 to 24

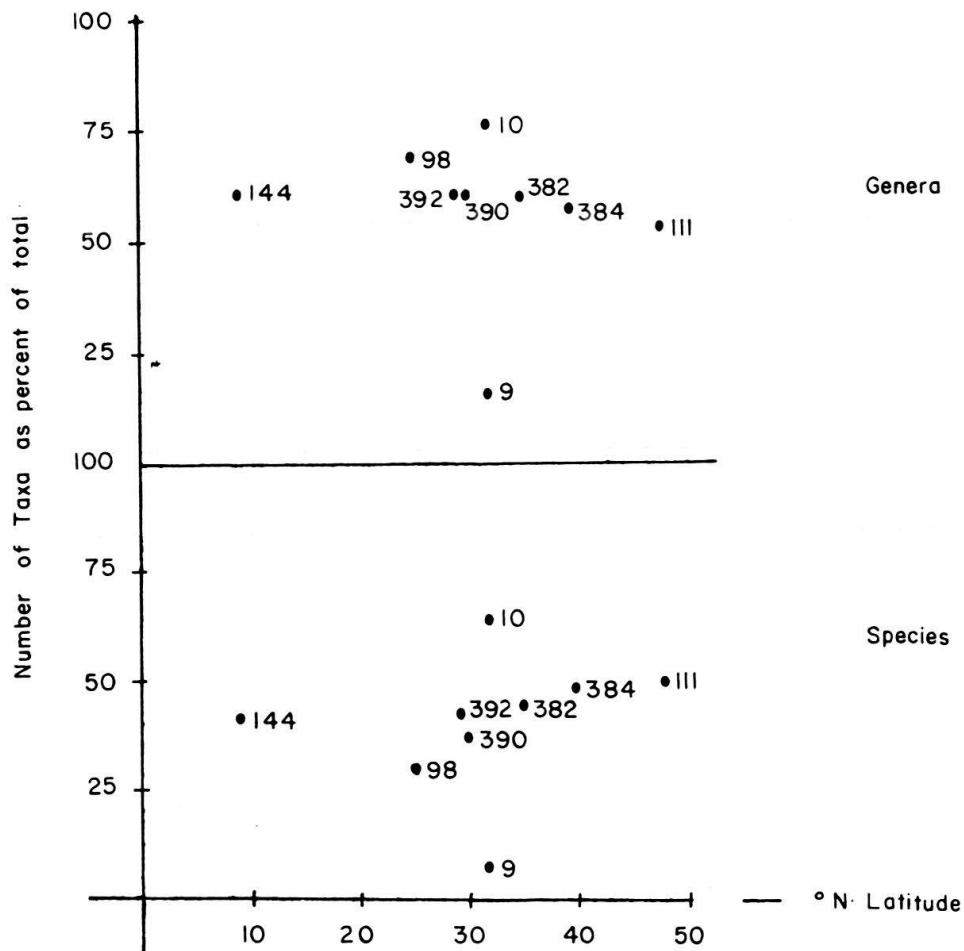


Fig. 3. Diversity trend of species and genera at respective DSDP sites from low to high latitude.



species are noted from sites below latitude 40° N, whereas about 8 or less genera represented by less than 20 species characterize samples from sites above latitude 40° N. Only 2 genera represented by a total of 3 species were recovered from hole 9A. Sediment from this interval is dominantly zeolitic clays with less than 1% CaCO<sub>3</sub> content (PETERSON et al. 1970), with a rich radiolarian assemblage. These zeolitic clays were deposited at paleodepths greater than 3000 m (TUCHOLKE & VOGT 1979; NYONG & OLSSON 1984). The planktic foraminiferal composition at this interval probably reflects extensive dissolution at depth.

### Discussion

It is generally accepted that the solubility of calcite (CaCO<sub>3</sub>, the shell material of planktic foraminifers) increases with depth (BERGER 1979), and that below the calcium compensation depth (CCD), deep sea sediments are relatively carbonate-free (less than 10% CaCO<sub>3</sub>). Any interpretation of the distribution of planktic foraminifers in deep-sea sediments must therefore take into consideration the position of the CCD relative to depth of deposition at the time of sedimentation in the basin under consideration. Unfortunately, most interpretation of the paleobiogeography of the North Atlantic region predate the wide acceptance of the concept of a CCD and do not reflect recent advances in the timing of the opening and subsequent connection of the Arctic and North Atlantic Oceans.

SLITER (1976) recognized the Tethyan, Transitional and Austral biogeoprovinces in his study of Campanian to lower Maastrichtian deep sea cores from the southwestern Atlantic. The distribution of late Cretaceous planktic foraminifers within these three biogeoprovinces in the southern hemisphere as observed by SLITER (1976) is shown in Table 2 and affords comparison to the distribution observed in the present study from the western North Atlantic (Table 1).

Benthic foraminiferal analysis (NYONG & OLSSON 1984) and sedimentological studies (TUCHOLKE & VOGT 1979) show that the Campanian to lower Maastrichtian sediments of hole 9A were deposited at or below CCD. A significant loss of planktic foraminifers must be expected at this site due to carbonate dissolution at the CCD. This would account for the poor planktic foraminifera recovery at this site. The planktic foraminiferal assemblage shown in Table 1 for hole 9A are therefore considered in this study as not being representative of the total foraminiferal community that inhabited the surface waters in this region during late Cretaceous times. SCHEIBNEROVA (1973) interpreted the planktic assemblage at this site as being "non-tropical" in character and suggested the existence of a "cold wall" of the gulf stream current in the vicinity of site 9 such as exists at present. This view is not substantiated in the present study. GRADSTEIN et al. (1975) identified from the Campanian–Maastrichtian interval of the Scotian shelf and Grand Banks, *Globotruncana angusticarenata* GANDOLFI, *G. stuarti* (DE LAPPARENT), *G. gansseri* BOLLI, *Rugoglobigerina rugosa* (PLUMMER) and *Praeglobotruncana citae* (BOLLI), a few species of hedbergellids and simple globigerinelloid forms were also reported, suggesting some temperate influence in the region. This report is in agreement with that of WILLIAMS et al. (1974) who reported abundant and diverse globotruncanid assemblage from the Scotian shelf, but indicated that a temperate influence was present during the Campanian in this region on the basis of pres-



Table 2: Provincial distribution of planktic foraminifers in the southern hemisphere (after SLITER 1976).

SPECIES	PROVINCE		
	TETHYAN	TRANSITIONAL	AUSTRAL
Rugoglobigerina pilula			
R. pustulata			
R. rotundata			---
Heterohelix glabrans			
H. globulosa			
H. pulchra			
Globigerinelloides multispinatus			---
Globotruncana arca			---
Globotruncanella havanensis			---
Hedbergella holmdelensis			
H. monmouthensis			
Planoglobulina carseyae			
Schackoia multispinata			
Abathomphalus intermedia			---
A. mayaroensis			---
Guembelitria cretacea			---
Globotruncana marginata			---
Heterohelix striata			---
Rugoglobigerina macrocephala			---
R. rugosa			
Globotruncana contusa			
G. elevata			
G. fornicata			
G. linneiana			
G. mariei			
G. stuarti			
G. stuartiformis			
G. ventricosa			
Gublerina cuvillieri			
Pseudotextularia elegans			
Racemiguembelina fructicosa			
Globotruncana aegyptiaca			
Pseudoguembelina spp.		---	
Rugotruncana subcircumnodifer		---	
Globotruncana calcarata		---	
G. gansseri			
Plummerita spp.			
Rugoglobigerina scotti			
Trinitella spp.			

--- Rare

ence of species of *Hedbergella* and *Archaeoglobigerina*. In the Baltimore canyon area, the interpretation of planktic foraminiferal composition and distribution has been similar to the Scotian shelf and Grand Banks. POAG (1980) working in the Baltimore canyon region identified in the Campanian–Maastrichtian, fauna similar to those reported by OLSSON (1964) from the coastal plain areas of New Jersey. Specimens of *Abathomphalus*, *Plummerita*, *Globotruncana calciformis*, *G. falsostuarti* SIGAL and *Praeglobotruncana citae* were not present, rather species of *Hedbergella* were found to be frequent in sections from the coastal plain area (OLSSON 1964) suggestive of a temperate influence.

The absence of certain Tethyan (warm water) species from the deep-sea assemblages presented in this study and from the Campanian to lower Maastrichtian sections of various wells in the coastal plain of New Jersey (OLSSON 1964, 1977), Baltimore canyon region (POAG 1980), the Scotian shelf and Grand Banks (WILLIAMS et al. 1974; GRADSTEIN et al. 1975) can be explained as follows:

1. That planktic foraminifers inhabit various depth segments of the upper water column has been established (SLITER 1972; DOUGLAS & SAVIN 1973). This depth stratification of planktic foraminifers has been confirmed by oxygen and carbon isotopic studies (DOUGLAS & SAVIN 1975, 1978; SAITO & VAN DONK 1974). Shallow dwelling planktic foraminiferal tests are generally first to dissolve at depth, while deeper dwelling forms may be excluded from shelf regions such as the Baltimore Canyon and coastal plain areas as their depth habitat cuts across the shelf; e.g. *Praeglobotruncana citae* which is absent in the coastal plain sections of New Jersey (OLSSON 1964) and in the Baltimore canyon area (POAG 1980) are present downdip in deeper parts of the basin, such as at site 10 (Table 1).
2. A gradual introduction of “cold” surface water may have been initiated through the Labrador sea and Greenland areas. The flow of such water mass could have been limited to continental margins by the influence of the dominant gulf stream current system (Fig. 4), thus introducing the temperate forms observed in the coastal plain and adjacent continental margins, while causing the exclusion of certain Tethyan indicator species.

Considering the abundance and diversity of globotruncanids at the DSDP sites investigated in this study (excluding site 9) and the associated species of *Pseudotextularia* and *Pseudoguembelina*, it can be suggested that the gulf stream gyre helped to sustain the distribution of Tethyan fauna throughout most of the western North Atlantic (Fig. 4) during the Campanian to lower Maastrichtian times. On the whole, there is a slight drop in generic diversity between 40° N and 50° N latitude (Fig. 3) which is not accompanied by a drop in species diversity. This situation is strikingly different from the observed diversity trends between tropical (Tethyan) and temperate (Boreal/Austral) biogeoprovinces in present day oceans. The foraminiferal composition, abundance and diversity trends therefore, do not warrant the delineation of a Boreal biogeoprovince in the western North Atlantic in the present study. The “cold wall” suggested by SCHEIBNEROVA (1973) in the area of site 9 probably occurred further north and possibly at a later stage in the evolution of the North Atlantic ocean.

However, the exclusion of some Tethyan fauna and increase in abundance and diversity of globigerine forms, when considered along with the reduced but persistent globotruncanid assemblage does warrant definition of a transitional biogeoprovince in

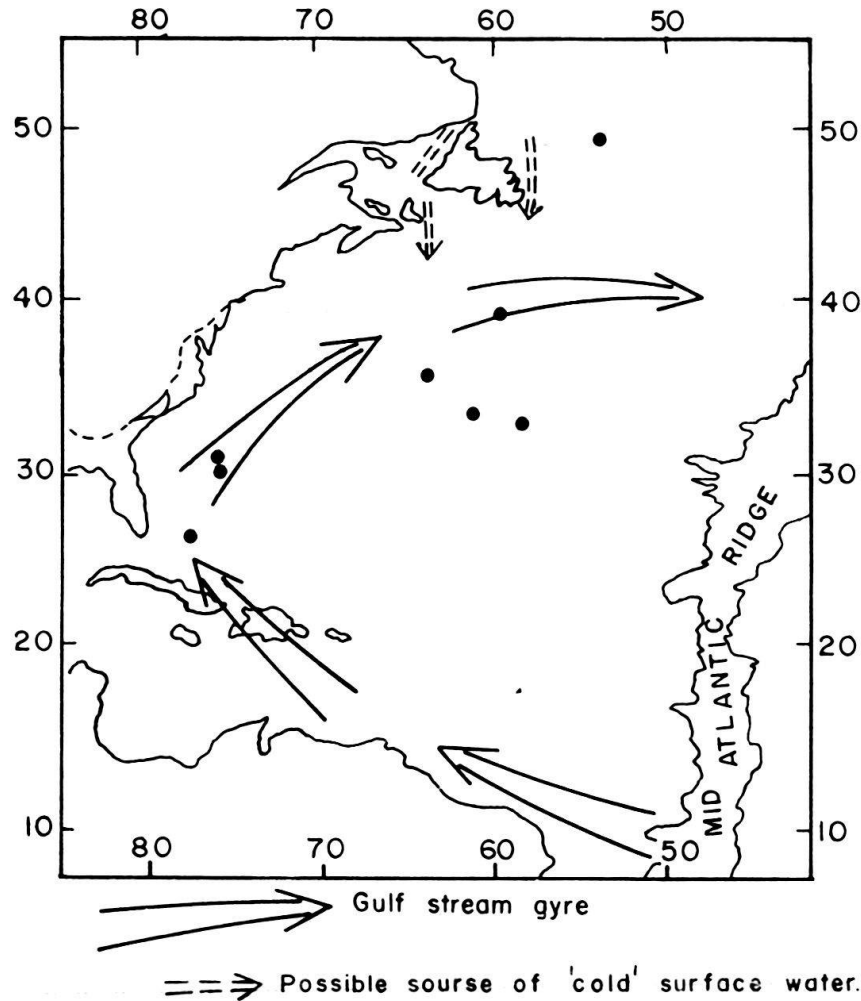


Fig. 4. Campanian to lower Maastrichtian circulation in the western North Atlantic.

the northernmost parts of the western Atlantic. This biogeographic province is considered the equivalent of the transitional biogeoprovince defined in the southern hemisphere by SLITER (1976), and the temperate biogeoprovince of DAVIDS (1966). The reduced globotruncanid assemblage observed at site 384 (MCNULTY 1979), shown in the appendix, suggests a waning of Tethyan influence in the region during the late Cretaceous. At site III (Orphan Knoll), this reduction in proportion of globotruncanids is accompanied by abundance of *Hedbergella monmouthensis* and *H. holmdelensis* OLSSON, suggestive of a cooler water mass. A gradual change from warmer to cooler water mass is therefore present in this vicinity. The boundary between the Tethyan and transitional biogeoprovinces can be located between sites 384 and III (Fig. 5). Within this area, a drop in generic diversity of planktic foraminifers is discernable (Fig. 3). The absence of a corresponding drop in species diversity could be due to selective dissolution of certain species occurring at most sites investigated. The development of a true Boreal biogeoprovince in the North Atlantic region probably occurred after the opening of the Norwegian–Greenland and Labrador Seas which provided a pathway for exchange of surface waters between the cooler Arctic and warmer Atlantic Oceans. Such exchange may have been possible in late Paleocene to Eocene times (THIEDE 1979).

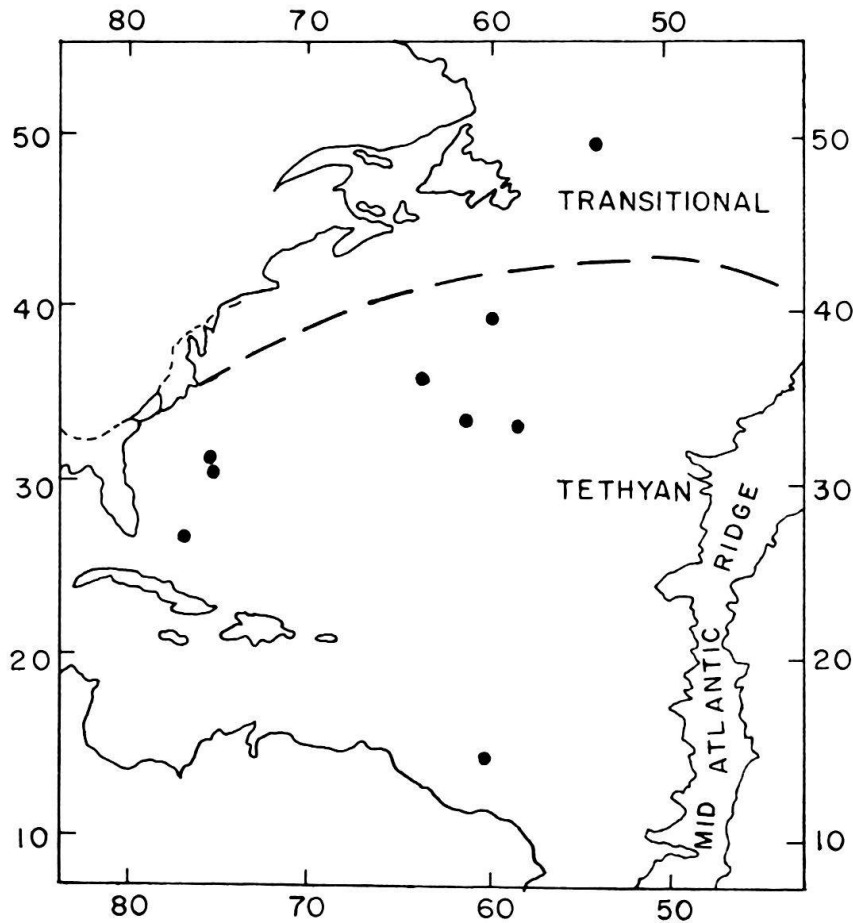


Fig. 5. Biogeoprovinces of the western North Atlantic in the Campanian to lower Maastrichtian.

### Summary and conclusions

Although distributional patterns of Recent planktic foraminifers can be used to infer past zoogeographic provincialization, the paleodepth and position of the CCD within the basin under investigation must be understood, as dissolution of foraminifers at the CCD could seriously affect subsequent paleobiogeographic interpretation.

The composition, distribution and diversity trends of planktic foraminifers in the western North Atlantic during Campanian to lower Maastrichtian allow the delineation of both a dominant Tethyan and a comparatively restricted transitional faunal province in this region during the period. The Tethyan biogeoprovince is characterized by single and double keeled globotruncanids including such species as *Globotruncana arca*, *G. fornicata*, *G. ventricosa* (WHITE), *G. tricarinata* (QUEREAU), *G. stuartiformis* DALBIEZ, *G. elevata*, *G. linneana*, *G. conica*, *G. contusa* and *G. calcarata* as the abundant forms. Heterohelcid taxa are also abundant and are represented by species of *Racemi-guembelina*, *Pseudotextularia*, *Planoglobulina*, *Pseudoguembelina* and *Heterohelix*. In general, 8 to 10 genera comprising 16 to 24 species characterize the Tethyan province in this region. The transitional biogeoprovince is characterized by a decrease in diversity and abundance of globotruncanid and heterohelcid taxa and the occurrence in significant numbers of species of *Rugoglobigerina*, *Archeoglobigerina* and *Hedbergella*.

Within the transitional biogeoprovince, planktic foraminiferal composition is reduced to about 8 or less genera represented by less than 20 species.

No evidence is found for the presence of a Boreal biogeoprovince in the region during the Campanian to lower Maastrichtian. The boundary between the Tethyan and transitional biogeoprovinces in the western North Atlantic is a gradational one and is here approximately located at about 40° N latitude (Fig. 5).

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## Appendix

Reccurent planktic foraminiferal species within the lower Maastrichtian *Globotruncana arca* Zone (CITA & GARTNER 1971), as observed by McNULTY (1979), from DSDP site 384.

*Heterohelix glabrans* (CUSHMAN)  
*H. globulosa* (EHRENBERG)  
*H. pulchra* (BROTZEN)  
*H. striata* (EHRENBERG)  
*Globigerinelloides multispina* (LALICKER)  
*G. subcarinatus* (BRONNIMANN)  
*Globotruncana arca* (CUSHMAN)  
*G. contusa* (CUSHMAN)  
*G. elevata* (BROTZEN)  
*G. fornicata* PLUMMER

*G. havanensis* (VOORWIJK)  
*G. lapparenti* BROTZEN  
*G. stuarti* (DE LAPPARENT)  
*Pseudoguembelina costulata* (CUSHMAN)  
*P. elegans* (RHEZAK)  
*P. excolata* (CUSHMAN)  
*P. intermedia* DE KLASZ  
*Rugoglobigerina pennyi* BRONNIMANN  
*Ventilabrella multicamerata* DE KLASZ



