Neogene foraminifera from the Eastern Rabat area (Morocco): stratigraphy, palaeobathymetry and palaeoecology

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Abstract - A study of planktonic and benthic foraminifera from 17 marl samples of the upper Late Miocene to the Early Pliocene from the Eastern Rabat area (Morocco) was carried out. The benthic fauna is analyzed quantitatively and sorted by a cluster analysis. The resulting faunal assemblages, together with the Planktonic/Benthic-ratio and the species richness, are attached to three different environments: an Ammodiscus beccarii-assemblage of the inner shelf (inner neritic); a Hantzawaia boueanum-assemblage of the middle shelf (middle neritic); and a Planulina ariminensis-assemblage of the upper slope (upper bathyal). In their temporal succession they represent a transgression-regression sequence.

INTRODUCTION

In this study, 17 marl samples with foraminifera from two sections were investigated. The samples were taken by Dr. Frits Hendriks and Mr. Arno Strouhal in the summer of 1990 within the scope of the DFG-project 'Landschaftsentwicklung Rabat (Morphogenese, Pedogenese, Ökodynamik in der Region Rabat') The exact location of the investigated sections is shown in Fig. 1.

The object of this study is to show the ecologic and bathymetric development of the deposition area by the aid of benthic foraminifera. The biostratigraphic control is using planktonic foraminifera.

DESCRIPTION OF SECTIONS AND LITHOSTRATIGRAPHIC UNITS

The names of the following rock units were taken from Wemli (1988). They are not mentioned in Figs 2 and 3 because of lack of space.

**Section A (Ain Allal Ben Mehdi)**

The first 1.4 m of the section is built up by laminated, slightly sandy marls. They are designated as "Marnes de Salé". Information about the lower parts has not been recorded. The overlying unit, called "Marnes grises sableuses", has a thickness of 4.6 m. The laminated marls are strongly bioturbated. Some hard calcareous horizons are intercalated. Furthermore, glauconite-rich, bioturbated sandy marls with a thickness of 5 m are following up to the end of the section. They are named "Sables verts glauconieux". Within this unit, a continuous coarsening upward is present. Above the investigated part of the section, the glauconitic sands are cross-stratified and contain gastropods and pelecypods.

**Section B (O. Akrech)**

Above the "basement", which is designated as "Substratum paléozoïque", lies an interstratification of orange to yellow calcareous marls and marly, bioturric limestones, which is marlier in the upper part. Directly at the base, the limestones are gravel-bearing and can be classified as a basal conglomerate. This unit, called "Sables jaunes biodétritiques", has a thickness of 5.6 m. The overlying 0.4 m thick conglomeratic bank forms the interface between the "Sables jaunes biodétritiques" and the overlying "Marnes de Salé". It is called "Banc à coraux" and contains hermatypic corals, which also occur separately in the directly overlying marls. These "Marnes de Salé" are laminated and become slightly sandier in the upper part. Their thickness in this place is 28 m. They are superposed unconformably by cross-bedded, conglomeratic limestones ("Dalle moghrebienne").
The "Sables jaunes biodétritiques" and the "Marnes de Salé" up to sample B 8 represent the Messinian stage. From sample B 9 onwards, the "Marnes de Salé" are of Zanclean age. "Marnes grises sableuses" and "Sables verts glauconieux" also represent the Zanclean stage.

METHODS OF ANALYSIS

Originally, the samples were for investigating only clay minerals and heavy minerals; therefore, little sample material was available. There were only 50-100 g per sample. However, because of the abundance of faunas, sufficient foraminifera could be identified.

First, the material was prepared with hydrogen peroxide and washed through a sieve of 100 μm. After drying, the residue was distributed evenly on a common black picking tray. To determine the P/B-ratio, a minimum of 300 specimens or, in very poor or corroded samples, all specimens were counted. After this, the residue was sieved over a 250 μm-sieve. From the > 250 μm-fraction, a sufficient amount of planktonic foraminifera was picked for the biostratigraphic control. Then, at least 300 benthic specimens were selected. Therefore, some equally distributed fields on the black picking tray were selected and scanned. From samples containing less than 300 benthic foraminifera >250 mm, all specimens were selected.

The restriction on the >250 μm-fraction at the investigation of benthic foraminifera has a lot of advantages: The determination of species is much easier, and the amount of displaced specimens is reduced. The loss of species restricted to smaller fractions seems to be negligible, since for both the living fauna and the dead ones, the faunal boundaries of the fractions greater than 63 μm and 250 μm occur at the same depth (Lutze and Coulbourn, 1984). In the opinion of other authors (Schröder et al., 1987; Bolotovskoy and Bolotovskoy, 1989), the smaller fractions have to be taken into consideration. However, only the "Marnes de Salé" and "Marnes grises sableuses" samples contain significant proportions of smaller species of Bolivina, Brizalina or Trifarina. Their proportions are about 30-40 percent, but many specimens are partly dissolved, therefore including the smaller fractions would not give more exact results.

To limit the species to be determined and to eliminate rare ones only species whose minimum content was 1 percent in at least one sample were determined. Species represented by only one specimen in a sample were not determined.

BIOSTRATIGRAPHY

For the biostratigraphic classification of the investigated sections by planktonic foraminifera, the zonation of Wernli (1988), erected for the northern Morocco, was used. For a better comparison, the zones according to Blow (1969) and the absolute ages according to Haq et al., 1987, are shown (Figs 2 and 3). The subdivision of the zones according to Wernli (1988) is based upon the following guide fossils:
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Globorotalia puncticulata
Globorotalia margaritae evoluta
Globorotalia marginata margaritae
Globorotalia primitiva (FA = first appearance)

Because Globorotalia conomoloea was recorded only in the Early Pliocene, a differentiation of m6a and m6aβ within the dutertrei and humerosa-subzone (m6a) was not possible. Fig. 2 shows the appearance of the guide species and other species with a more guiding character. The following species were found:

Globigerina nepenthes Todd Plate 1, fig. 1
Globorotalia acostaensis Blow Plate 1, fig. 2
Globorotalia conomoloea Kennett Plate 1, fig. 3
Globorotalia dutertrei (D’Orbigny) Plate 1, fig. 5
Globorotalia humerosa Takanayagi & Saito Plate 1, fig. 6
Globorotalia limbata (Fornasini) Plate 1, fig. 10
Globorotalia margaritae margaritae Bolli & Bermudez Plate 1, fig. 7
Globorotalia margaritae evoluta Cita Plate 1, fig. 8
Globorotalia menardii (Parker, Jones & Brady) Plate 1, fig. 9
Globorotalia merotumida Blow & Banner Plate 2, fig. 1
Globorotalia pleiotumida Blow & Banner Plate 2, fig. 2
Globorotalia primitiva Cita Plate 1, fig. 4
Globorotalia suterae Catalano & Sprovieri Plate 2, fig. 3
Globorotalia cf. theyeri Fleisher Plate 2, fig. 4

In addition to the species described by Wernli (1988), a species very similar to Globorotalia theyeri Fleisher appears. According to Kennett and Srinivasan (1983). G. theyeri appears from the zone N 19 of Blow (1969). Unfortunately, no guide fossils could be recorded in the samples B4-5 and A 6-9. The reason for this is the nearshore environment during the sedimentation time. This results in a low percentage of planktonic foraminifera. In these samples only noncarinated planktonic foraminifera occurred. The age of the related lithostratigraphic units is shown by Wernli (1988) with dutertrei et humerosa-subzone (m6a, upper Late Miocene) for the "Sables jaunes biodétritiques" (samples B 4-5) and with puncticulata-zone (p1b, upper Early Pliocene) for the "Sables verts glauconieux" (samples A 6-9). The determined ages of the investigated samples correspond with the data of Wernli (1988).

The following species were found frequently, but were not guide species during the period investigated:

Globigerinoides bollii Blow
Globigerinoides obtusus extremus Bolli & Bermudez
Globigerinoides obtusus obtusus Bolli
Globigerinoides ruber (D’Orbigny)
Globigerinoides trilobus (Reuss)
Globoquadrina altispira altispira (Cushman & Jarvis)
Globorotalia obesa Bolli
Hastigerina aequilateralis (Brady)
Hastigerina pelagica (D’Orbigny)
Orbulina biloba D’Orbigny
Orbulina universa D’Orbigny
Sphaeroidinellopsis seminulina seminulina (Schwager)

ECOLOGIC ASPECTS OF THE IMPORTANT BENTHIC FORAMINIFERA

Most of the planktic foraminifera were also found in the Mediterranean. Therefore, the figures in AGIP (1982) were helpful for determination. Here, only those species that are either frequent or of special ecologic or bathymetric interest are mentioned. The distribution of the more frequent species (portions > 5%) is shown in Fig. 3. The percentages of all determined benthic species are shown in appendix 2.

The classification of ecological zones (respectively deposition areas) was made by the subdivision according to Bremer et al. (1980), Van Morkhoven et al. (1984) and Murray (1991) respectively:

Bremer et al.
Van Morkhoven et al.
Murray

inner shelf
upper shelf
upper slope
lower slope

inner neritic 0 - 30m
middle neritic 30-100m
lower neritic 100-200m
upper bathyal 200-600m
middle bathyal 600-1000m
lower bathyal >1000m
inner shelf 0-100m
outer shelf 100-200m
upper slope 200-2000m
lower slope 2000-4000m

upper neritic 0-20m
middle neritic 20-100m
lower neritic 100-200m
upper bathyal 200-600m
middle bathyal 600-1000m
lower bathyal >1000m

Inner Shelf (Inner Neritic)

Ammonia beccarii (Linné), Plate 2, fig. 5.

A. beccarii is very frequent in the lower part of the "Sables jaunes biodétritiques" (76%) and relative-
ly frequent in the upper part, and in the "Sables verts glauconieux" as well. Species of the genus *Ammonia* are typical dwellers of shallow waters (Murray, 1973, 1991; Poag, 1981). They can survive under extreme conditions. So, they withstand changing temperatures between 0 to 35 °C and salinity changes from <1 to >90%. However, for reproduction they need temperatures between 17 to 32 °C and salinities from 15 to 40‰. Recently, the biggest populations (proportional and absolute) were found in mid-latitudes where precipitation exceeds evaporation and nearshore salinities are lower than normal. Larger, heavy calcareous, ornamented specimens are more characteristic of

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**Fig. 2.** Biostratigraphic zonation, occurrence of guide fossils, and P/B ratio of the investigated sections.
Plate 1  Planktonic foraminifera (Length of scale bar 100mm, all figs. same scale)

fig. 1. Globigerina nepenthica TODD, sample B 11   fig. 2. Globorotalia acoastensts BLOW, a: sample B 10, b, c: sample B 6
fig. 3. Globorotalia conomioea KENNETT, a, b: same specimen, sample B 10  fig. 4. Globorotalia primitiva CITTA, a, b: same specimen, sample B 10, c: sample A 1
fig. 5. Globorotalia dutertrei (D'ORBIGNY), b, c: same specimen, sample A 1
fig. 6. Globorotalia humerosa TAKAYANAGI & SAITO, b, c: same specimen, sample A 1  fig. 7. Globorotalia margaritae margaritae BOLL & BERMUDEZ, a: sample A 5, b, c: same specimen, sample A 1
fig. 8. Globorotalia margaritae evoluta CITTA, a: sample A 4, b: sample A 5  fig. 9. Globorotalia menardii (PARKER, JONES & BRADY), a, b: same specimen, sample B 8, c: sample B 10
fig. 10. Globorotalia limbata [FORNASINI], a, b: same specimen, sample B 8
colder, stressful or hypersaline conditions. On the other hand, smaller and thinly calcareous specimens are pointing to hyposalinity and abundant food supply (Walton and Sloan, 1990). They are most common in 0-50 m of water depth, rather than on the inner shelf (Murray, 1991). In the Adriatic sea, the proportion of A. beccarii decreases strongly from 100 m downwards (Haake, 1977). Off the coast of West Africa, this species occurs down to 50 m of water depth (Lutze, 1980).

Species commonly found in hyposaline environments like Ammonia tepida (Cushman), Ammonia beccarii forma tepida of Walton and Sloan, 1990, are not present in the investigated samples. Therefore, the found specimens together with the other species, represent a normal marine environment.

**Middle Shelf (Middle Neritic)**

*Quinqueloculina* sp., Plate 3, fig. 3.

The occurrence of *Quinqueloculina* is restricted to the lower part of the "Sables verts glauconieux". However, in this stratum they are relatively frequent. Because of their bad preservation, a specific assignment was not possible.

*Cibicidoides lobatulus* (Walter & Jacob), Plate 2, fig. 8.

*C. lobatulus* is relatively frequent on the top of the "Sables verts glauconieux". In addition, smaller proportions with a maximum of 1 percent occur in some samples of the "Marnes de Salé" and the "Marnes gris sableuses", which were probably displaced. *C. lobatulus* lives as an epiphyte or fixed on solid substrates (Murray, 1973). It is tolerant against increased salinity (Van der Zwaan, 1982). Off Morokko, it occurs rarely up to a water depth of 80 m (Mathieu, 1971), off West Africa up to 500 m (Lutze, 1980).

*Cibicidoides subhaidingeri* (Parr), Plate 2, fig. 9.

*C. subhaidingeri* is frequent in the upper part of the "Sables jaunes biodétritiques", while fewer specimens are found in the "Marnes gris sableuses". According to Van Morkhoven *et al.* (1986), its distribution covers the outer neritic and the bathyal (100-2000 m).

*Elphidium cf. alvareztanum* (D’Orbigny), Plate 2, fig. 6

*Elphidium crispum* (Linne), Plate 2, fig. 7.

*Elphidium fichtelitana* (D’Orbigny), Plate 3, fig. 2.

The occurrence of the *Elphidium* species (15 % maximum) is restricted to the "Sables jaunes biodétritiques" and to the "Sables verts glauconieux". The determined *Elphidium* species live in a shallow marine environment; they are living vegetation-bound and have a great tolerance to increased salinities (Van der Zwaan, 1982). *E. crispum* lives off Northwest Africa from a water depth of 38 to 75 m (Lutze, 1980; Lutze and Coulbourn, 1984). Carinated *Elphidium* species prefer to live on sand or vegetation with temperate to warm marine conditions on the inner shelf (Murray 1991).

*Hanzawaia boueana* (D’Orbigny), Plate 3, fig. 1.

*H. boueana* is the dominating species in the "Sables verts glauconieux" and in the upper part of the "Sables jaunes biodétritiques". It is mainly a species of the outer neritic and the upper bathyal (Berggren and Haq, 1976).

**Remarks** - The specimens are very similar to *Florites boueaurum* (D’Orbigny) figured by Berggren and Haq (1976), AGIP (1982) and to *Nonionina boueana* D’Orbigny (after Brady, 1884, v.IX, pl. CIX, figs. 12a-b) in Hansen and Rögl (1980) but not to *Hanzawaia boueana* (D’Orbigny) of Papp and Schmid (1985, pl. 35, figs 2-5), which differs by its large pores and its more asymmetrical coiling.

*Hanzawaia cf. concentrica* (Cushman)

*H. concentrica* is restricted to the upper part of the "Sables jaunes biodétritiques". Its proportional occurrence in this part is 4 percent. *H. concentrica* is common on the inner and middle shelf, but additionally occurs in bays and estuaries (Pog, 1981). Its recent distribution reaches from water depths of 30 to 300 m off Northwest Africa, sometimes even in greater water depths (Lutze and Coulbourn, 1984, Haake *et al.*, 1982), in the Gulf of Mexico up to approximately 200 m (Pflum and Frenichs, 1976).

The genus *Hanzawaia* prefers oxygen-rich conditions (Snyder *et al.*, 1988).
Plate 2 figs 1-4. Planktonic foraminifera figs 5-9. Benthic foraminifera of the inner shelf (inner neritic) and the middle shelf (middle neritic) (Length of scale bars 100 mm, all planktonic foraminifera same scale)

fig. 1. Globorotalia merotumida BLOW & BANNER, b, c: same specimen, sample B 7 fig. 2. Globorotalia plesiotumida BLOW & BANNER, sample B 7 fig. 3. Globorotalia suterae CATALANO & SPROVIERI, b, c: same specimen, sample B 7 fig. 4. Globorotalia cf. theyeri FLEISHER, b, c: same specimen, sample A 5 fig. 5. Ammonia beccari (LINNÉ), sample A 9 fig. 6. Elphidium cf. alvarezaum (D'ORBIGNY), sample A 9 fig. 7. Elphidium crispum (LINNÉ), sample A 9 fig. 8. Cibicides lobatulus (WALKER & JAKOB), sample A 9 fig. 9. Cibicides subhaidingeri (PARR), b, c: same specimen, sample A 4
Upper Slope (Upper Bathyal)

*Anomalinae helictrus* (Costa), Plate 3, fig. 4.

*A. helictrus* occurs relatively frequently in the "Marnes de Salé" and in the "Marnes grises sableuses", very rare in samples of the "Sables verts glauconieux". It occurs specifically in the middle and lower bathyal deposits (Berggren and Haq, 1976).

*Bigerina nodosaria* D'Orbigny

*B. nodosaria* occurs rarely in the samples of the "Sables verts glauconieux". The shallowest living occurrence is approximately 90 m (Lutze, 1980; Lutze and Coulbourn, 1984), or approximately 60 m (Mathieu, 1971). The genus *Bigerina* is found most frequently on the shelf under temperate, marine conditions (Murray, 1991).

*Buliminia aculeata* D'Orbigny, Plate 3, fig. 7.

With a maximum content of 4 %, *B. aculeata* is restricted to the "Marnes de Salé" and the "Marnes grises sableuses". *B. aculeata* is a mud dweller with a high tolerance for higher salinities and oxygen deficiency; it might prefer abundant nutrient (Van der Zwaan, 1982). It is found most frequently in the middle and upper bathyal, while its generally shallowest occurrence is in the upper part of the upper epibathyal (Van Morkhoven et al., 1986; Poag, 1981), or between 200 and 350 m (Berggren and Haq, 1976; Lutze and Coulbourn, 1984). The living occurrence off Northwest Africa is starting at water depths of approximately 500 m (Lutze, 1980, Haake et al., 1982), equally in the Gulf of Mexico (Pflum and Frerichs, 1976).

**Remarks** - Some of the identified specimens show similarities to *Buliminia echinata* D'Orbigny (e.g., pl. 3, fig 7a) but the typical characteristics are not very marked.

*Buliminia costata* D'Orbigny, Plate 3, fig. 6.

*B. costata* occurs rarely in the "Marnes de Salé" and in the "Marnes grises sableuses". It is a mud dweller with low tolerance to increased salinities and more frequent in periods of oxygen deficiency and nutrient abundance (Van der Zwaan, 1982). Its recent occurrence off Northwest Africa starts in water depth of 140 m (Haake et al., 1982).

*Cibicidoides dutemplei* (D'Orbigny), Plate 3, fig. 5.

This form is frequent in the "Marnes grises sableuses". It is rarely found in the "Marnes de Salé". As a mud dweller with low tolerance to oxygen deficiency or increased salinity (Van der Zwaan, 1982), it occurs in deposits of the outer neritic and in the upper bathyal depth levels (Van Morkhoven et al., 1986).

**Remarks** - The figured specimens show an extremely elevated ventral side. Specimens with a slighter elevated ventral side according to the figures of Papp and Schmid (1985), Van Morkhoven et al. (1986) and Van der Zwaan (1982) are also very frequent. The species is called *Heterolepa dutemplei* (D'Orbigny) by Papp and Schmid (1985).

*Cibicidoides incrassatus* (Fichtel and Moll), Plate 3, fig. 8.

This species occurs rarely in nearly all samples of the "Marnes de Salé" and of the "Marnes grises sableuses". Its distribution covers mainly the outer neritic and the upper bathyal (100-600 m), but it rarely occurs in the middle and lower bathyal depth (Van Morkhoven et al., 1986).

*Cibicidoides pachyderma* (Rzehak), Plate 3, fig. 10.

*C. pachyderma* is relatively frequent in "Marnes de Salé" and in "Marnes grises sableuses" samples. It occurs predominantly in the upper bathyal (Van Morkhoven et al., 1986).

*Cibicidoides cf. pseudoungerianus* (Cushman) This taxon occurs rarely in few samples of the "Marnes de Salé. *C. pseudoungerianus* is taken to be *C. pachyderma* by Van Morkhoven et al. (1986). The similar C. sp. A of Poag (1981) is restricted to the shelf and the upper slope. *C. pseudoungerianus* occurs off Northwest Africa from water depths of 90 m (Lutze and Coulbourn 1984), or from 75 m (Lutze 1980). According to Haake et al. (1982) they live in water depth from 300 m onwards. According to Pflum and Frerichs (1976), in the Gulf of Mexico they are restricted to bathyal depths (200-2000 m).

*Cibicidoides ungerianus* (D'Orbigny), Plate 3, fig. 11.

In the "Marnes de Salé", this species occurs frequently. Sporadic specimens are to be found in the "Marnes grises sableuses" and in the lower part of the "Sables verts glauconieux". This is a mud dweller of the open marine, with no tolerance to oxygen deficiency or to increased salinities (Van der Zwaan, 1982). Van Morkhoven et al. (1986) refer to it as *C. pachyderma*. 
Plate 3

figs 1-3. Benthic foraminifera of the middle shelf (middle neritic)
figs 4-12. Benthic foraminifera of the upper slope (upper bathyal) (Length of scale bars 100 mm)
fig. 1. *Hanzawaia boueana* (D'ORBIGNY), sample A 7
fig. 2. *Elphidium fichtelarum* (D'ORBIGNY), sample A 9
fig. 3. Quinqueloculina sp., a, b: same specimen, sample A 6
fig. 4. *Anomaloides helcinus* (COSTA), b, c: same specimen, sample B 10
fig. 5. *Cibicidoides ditremplet* (D'ORBIGNY), b, c: same specimen, sample A 1
fig. 6. *Bulimina costata* D'ORBIGNY, sample A 8
fig. 7. *Bulimina aculeata* D'ORBIGNY, sample A 1
fig. 8. *Cibicidoides incrassatus* (FICHETEL & MOLL), b, c: same specimen, sample B 8
fig. 9. *Globocassidulina subglobosa* (BRADY), sample B 10
fig. 10. *Cibicidoides pochyiema* (RZEHARK), b, c: same specimen, sample A 1
fig. 11. *Cibicidoides ungerianus* (D'ORBIGNY), b, c: same specimen, sample B 8
Fig. 3. Distribution of the most frequent benthic species and species richness of the investigated sections
**Globocassidulina subglobosa** (Brady), Plate 3, fig. 9.

*G. subglobosa* occurs rarely in the "Marnes de Salé" and more frequently in the lower part of the "Marnes grises sableuses". It covers a widespread bathymetric range. However, it mainly occurs in the bathyal depth (Berggren and Haq, 1976). Living specimens are to be found from water depths of 510 m off Northwest Africa (Lutze and Coulbourn, 1984), or from approximately 25 m (Lutze, 1980).

**Lenticulina rotulata** (Lamarck), Plate 4, fig. 2 and other *Lenticulina*

The occurrence of *Lenticulina* is restricted mainly to the "Marnes de Salé" and the "Marnes grises sableuses". *Lenticulina* prefers cool, marine conditions on the outer shelf and bathyal depths (Murray, 1991). Additionally, they prefer a high oxygen water content.

**Martinottiella communis** (D'Orbigny), Plate 4, fig. 5.

*M. communis* occurs in all samples of the "Marnes de Salé" and the "Marnes grises sableuses" and is represented from 1 to 6 percent. It occurs off Northwest Africa from 487 m (Lutze and Coulbourn 1984), in the Gulf of Mexico from water depths of approximately 100 m (Pflum and Frerichs, 1976). *Martinottiella* prefers cool water and marine conditions (Murray, 1991).

**Melonis barleeanus** (Williamson), Plate 4, fig. 6.

*M. barleeanus* occurs rarely but continuously in the "Marnes de Salé" and in the "Marnes grises sableuses". *M. barleeanus* is interpreted by Berggren and Haq (1976) as a reliable indicator of middle and upper bathyal depth. The recent occurrence starts off Northwest Africa at 1000 m water depth (Haake et al., 1982), otherwise from approximately 300 m (Berggren et al. 1976).

**Melonis pompilioides** (Fichtel & Moll), Plate 4, fig. 7.

*M. pompilioides* occurs at the top of the "Marnes de Salé" and in the "Marnes grises sableuses". *M. barleeanus* is interpreted by Berggren and Haq (1976) as a reliable indicator of middle and upper bathyal depth. The recent occurrence starts off Northwest Africa at 1000 m water depth (Haake et al., 1982), otherwise from approximately 300 m (Berggren et al. 1976).

**Oridorsalis tener** (Brady)

*O. tener* occurs occasionally in the "Marnes de Salé" and in the "Marnes grises sableuses". Its living occurrence in the Gulf of Mexico starts in the middle bathyal (from 500 m water depth, Pflum and Frerichs 1976). *Oridorsalis* prefers cool water and normal marine conditions (Murray, 1991).
Planulina ariminensis (D'Orbigny). Plate 4, fig. 11.

*P. ariminensis* is the dominant species of the "Marnes de Salé" and of the "Marnes grises sableuses". It reaches a maximum of 36 percent. Its main occurrence reaches from the outer neritic down to about 800 m (Van Morkhoven *et al.*, 1986). But it is most frequently represented in depths between 200 and 300 m (Berggren and Haq 1976). On the inner shelf, it is rare (Poag 1981). Off Northwest Africa, it occurs from water depths of 200 m (Lutze and Coulbourn, 1984), or from 400 m (Lutze, 1980). According to Haake *et al.* (1982), it is found from depths of 300 to 900 m water depth, and according to Pflum and Frerichs (1976) from depths between 150 and 1000 m.

Pullenia bulloides (D'Orbigny)

*P. bulloides* occurs continuously with low percentages in the "Marnes de Salé" and in several samples of the "Marnes grises sableuses". Its main occurrence is in the middle and lower bathyal (Berggren and Haq, 1976). Off Northwest Africa, living specimens occur from water depth of 607 m (Lutze and Coulbourn, 1984), off the Southeastern USA from the upper bathyal (Todd, 1979). Frequently, its occurrence starts at approximately 300 m, sporadically between water depths of 100 and 150 m (Berggren *et al.*, 1976; Pflum and Frerichs, 1976).

Pullenia quinqueloba (Reuss)

*P. quinqueloba*, relatively rarely found in this study, occurs in the "Marnes de Salé". Its occurrence is mainly bathyal (Berggren and Haq, 1976). Off Northwest Africa, their living occurrence begins at water depths of 150 m (Lutze and Coulbourn, 1984), and in the Gulf of Mexico at water depths of approximately 50 m (Pflum and Frerichs, 1976). The species of the genus *Pullenia* prefers cool water (Murray, 1991).

Siphonina reticulata (Czjzek), Plate 4, fig. 12.

*S. reticulata* is frequently found in samples of the "Marnes de Salé". Berggren and Haq (1976) described this species together with *Siphonina planocon vexa*, which is characteristic of the middle bathyal and even greater depths.

Sphaeroldina bulloides (D'Orbigny), Plate 4, fig. 8.

*S. bulloides* is to be found regularly in several samples of the "Marnes grises sableuses". Its occurrence covers mainly the upper and middle bathyal; their shallowest occurrence is the middle neritic, where they are distinctively rare (Van Morkhoven *et al.*, 1976). According to Berggren and Haq (1976), its minimal depth is below 150 m. Off Northwest Africa, living specimens occur from water depth of 130 m (Lutze and Coulbourn, 1984), in the Gulf of Mexico from approximately 100 m (Pflum and Frerichs, 1976).

Textularia abbreviata (D'Orbigny), Plate 4, fig. 13.

*T. abbreviata* occurs with percentages up to 7 percent in the "Marnes grises sableuses", in the "Marnes de Salé", they are scarce.

Textularia *cf.* barrettii Parker & Jones

*Textularia* *cf.* sagittula Dedfrance

Both species occur isolated in the "Marnes de Salé". *Textularia* occurs in a widespread area from water depths of 0 to 500 m (Murray, 1991). Recently, *T. barrettii* is frequent in the upper part of the continental slope off the Southeastern USA, it is scarce on the outer shelf (Todd 1979). The living occurrence of *T. sagittula* off Northwest Africa reaches from water depths of 50 to 300 m (Haake *et al.*, 1972), or from 90 to 500 m (Lutze, 1980). Off Casablanca, *T. sagittula* is numerously found between water depth of 60 and 80 m (Mathieu, 1971).

Uvigerina *cf.* peregrina Cushman

*U. cf. peregrina* is scarce in two samples of the "Marnes de Salé" and the "Marnes grises sableuses". According to Van der Zwaan (1982), *U. peregrina* is a mud dweller which is most frequent under stable marine conditions. It has no great tolerance to oxygen depletion or increased salinity. Its distribution covers the outer shelf and the upper slope (Poag, 1981).

Uvigerina longistriata Periconig, Plate 4, fig. 10.

It is a dweller of the upper bathyal zone (Boersma, 1984). Its content reaches no more than 6 percent in the "Marnes de Salé" and in the "Marnes grises sableuses".

Uvigerina rutilla Cushman & Todd, Plate 4, fig. 9.

This bathyal species (Boersma, 1984) has its maximum frequency in the lower part of the "Marnes de Salé" with 14 percent content.

Living Uvigerinids occur off Northwest Africa from water depths of 80 m (Haake *et al.*, 1982). They prefer cooler temperate water (Murray, 1991). Furthermore, some relatively rare species occur in the investigated samples, all of them characteristic for greater water depths (bathyal and deeper).
Plate 4 Benthic foraminifera of the upper slope (upper bathyal) [Length of scale bars 100 mm]

fig. 1. Gyrodinoides neoeldanii (BROTZEN), a, b: same specimen, sample A 1
fig. 2. Lenticulina rotulata (LAMARCK), a, b: same specimen, sample B 8
fig. 3. Heterolepa dertorenensis (RUSCELLI), a, b: same specimen, sample B 8
fig. 4. Karreiella brodyi (CUSHMAN), sample A 1
fig. 5. Martinitiella communis (D'ORBIGNY), sample B 8
fig. 6. Melonis barleeanus (WILLIAMS), a, b: same specimen, sample A 4
fig. 7. Melonis pompiolitides (PICHTEL & MOLL), a, b: same specimen, sample A 1
fig. 8. Sphaeroidina bulliolides D'ORBIGNY, sample A 1
fig. 9. Uvigerina nutina CUSHMAN & TODD, sample B 8
fig. 10. Uvigerina longistrata PERCONS, sample B 8
fig. 11. Planulina artensensis D'ORBIGNY, a, b: same specimen, sample A 1
fig. 12. Siphonina reticulata (CZJEK), a, b: same specimen, sample B 9
fig. 13. Textularia abbreviata D'ORBIGNY, a, b: same specimen, sample A 3
These species are: *Chilostomella avoidea*, *Cibicidoides cicatricosus*, *Cibicidoides* cf. *grosseperforatus*, *Cylindroclavulina bradyi*, *Laticarinina pauperata*, *Saracenella italica*, *Vulvulina* cf. *pennatula*. The bathymetric references for above are: Lutze and Coulbourn (1984), Murray (1991) and Van Morkhoven et al. (1986).

**CLUSTER ANALYSIS**

The cluster analysis is a frequently applied method in micropalaeontology to create groups inside similar or not easily distinguishable datasets (Mello and Buzas, 1968; Lutze and Coulbourn, 1984; Snyder et al., 1988). Sample-clusters (Q-mode) or species-clusters (R-mode) can be constructed. Sample-clusters represent different biotopes or thanatotopes, whereas species-clusters represent different biofacies or thanatofacies. In the present study, sample-clusters were constructed to record different conditions of environment and deposition (which are represented by different thanatotopes). For the available computer program, the number of objects (samples) has to be greater than or equal to the number of characteristics (proportional occurrence according to each single species in the samples). Because of the presence of 74 classified species of benthic foraminifera, and a total of 17 samples, only the species with a minimum percentage of 10 percent in at least one sample were taken for the cluster analysis. Therefore, the number of species was reduced to 15.

The cluster analysis was practised by the "single linkage"-method. By this method, "runaways" in a set of objects were easy to perceive (Backhaus et al., 1990). The result (Fig. 4) shows two clusters and one single sample by a distance of 1500. The first cluster contains the samples A-1 to A-5, and B-6 to B-11. The second cluster contains the samples A-6 to A-9, and the sample B-5. In sample B-4, the percentage of one single species amounts to 76 percent. Therefore the distance to the other clusters is too large for this species to be attached to one of them. The constructed clusters represent 3 different thanatotopes, which can be attached to inner neritic, middle neritic and upper bathyal environments (see Results).

**PROPORTIONAL OCCURRENCE OF PLANKTONIC FORAMINIFERA (P/B-RATIO)**

The ratio of planktonic and benthic foraminifera in a sample allows inferences about the palaeo-water depth. This is based essentially on the fact that the density of planktonic foraminifera is highest in the open ocean. In comparison, the productivity of benthic foraminifera is higher on the shelf than in the deep ocean. Reduced salinity and increased turbidity of sea water are responsible for the reduced density of planktonic foraminifera in nearshore environments (Funnell, 1967). To avoid errors in the interpretation of fossil sediments, the possibility of dissolving, displacement and admixtures of older deposits have to be considered. Gibson (1989) described the issue of the proportional occurrence of the planktonic foraminifera as a three segment "line": a slow increase in the percentage of planktonic specimen with increasing depth on the inner shelf or at coastal areas, where slightly reduced salinity and increased turbidity is present in the water mass. A very rapid increase in the percentage with increasing water depth begins on the outer shelf, where open ocean water mass conditions dominate. A relatively slow proportional increase in the high percentages then occurs in the deep oceanic areas. Even though results differ in wide ranges, a minimum depth can be given.

The results of the present study show great differences in the proportional occurrence of planktonic foraminifera (Fig. 2); e.g., the percentage of the earlier samples (B4-5) shows approximately 1-2 % of planktonic foraminifera. This increases rapidly to 77 % (B6) and decreases continuously to 58 % at the top of section B. Section A starts at 57 % and decreases slightly fluctuating to 32 % in sample A 5. From this point on, the planktonic foraminiferal occurrence decreases abruptly. In the latter samples (A 6-9), it amounts to 2 to 10 %. The trend of the curve is connected closely to the results of the cluster analysis; e.g., the samples of cluster 2 and the single sample B 4 contain small proportions of planktonic foraminifera, whereas the samples of cluster 1 show larger numbers.

Hence, according to Gibson (1989) a minimum water depth of 100 m for the earlier samples and a minimum of 50 m for the later samples of cluster 1 can be given. However, if one considers average results, e.g., from the North Eastern Gulf of Mexico, for the estimation of the palaeo-water depth, the results are 500 m, or 200 m. These seem to be the actual results, especially in relation to the benthic faunas. By using the proportional occurrence of planktonic foraminifera, the only explanation for cluster 2 and the single sample B4 is that they were deposited in relatively shallow waters.

**SPECIES RICHNESS AND DISPLACED FORAMINIFERA**

The species richness in a sample or in trends inside of a section can indicate the depositional environment. However, final conclusions can only be made in combination with other methods. In principle, only marginal marine environments can
Neogene foraminifera from the Eastern Rabat area (Morocco): stratigraphy, palaeobathymetry and palaeoecology

Fig. 4. Dendrogram of the cluster analysis

be distinguished from normal marine environments (Murray, 1973, 1991). Therefore, the Fisher $\alpha$-Index from the diagram of Murray (1991) was taken. According to Murray (1991), "values < 5 generally indicate brackish or hypersaline marginal marine environments but may also indicate normal marine environments with a high dominance of single species. Where $\alpha > 7$ normal marine shelf to slope or hypersaline shelf are indicated."

The values increased in the lower part of section B from 5 to more than 20 and stayed at a level of approximately 17. In section A the values fluctuated strongly, but decreased in general. The values of the several samples can be taken from Fig. 3.

Displacement of benthic foraminifera can be demonstrated only in exceptional cases. In some samples, which are interpreted as upper slope deposits, some specimen of *Cibicides lobatulus* were found. Their occurrence never exceeded 1 percent and can be excluded from the interpretation.

RESULTS

From the presented data, three distinctly different assemblages of benthic foraminifera can be distinguished. Named by the dominant species, they are an *Ammonia beccarii*-assemblage, a *Hanzawaia boueana*-assemblage and a *Planulina ariminensis*-assemblage. They represent different palaeoecologic and palaeobathymetric conditions.

*Ammonia beccarii*-assemblage

This assemblage is present only in sample B4. The percentage of the dominant species *A. beccarii* amounts to 74 %. The proportional occurrence of planktonic foraminifera is approximately 1 %, the Fisher $\alpha$-index is 4.5. Together with the additional fauna (*C. lobatulus, E. crispum*), the inner shelf with normal marine conditions was a probable deposition area. This assemblage is restricted to the lower part of the "Sables jaunes biodétritiques".

*Hanzawaia boueana*-assemblage

This assemblage embraces the samples A 6-9 and B 5 (cluster 2). The percentage of *H. boueana* fluctuates between 24 and 55 %. Additional frequent species are: *Cibicides lobatulus, Cibicoides subhaidingertii, Elphidium crispum* and *Quinqueloculina* sp. The occurrence of planktonic foraminifera is between 2 and 10 %. The Fisher $\alpha$-index fluctuates between 3 and 13. Hence, the middle shelf (middle neritic) offers a deposition area with a water depth of approximately 100 m. The water had most likely normal salinity and was provided with sufficient oxygen. This assemblage occurs in the upper part of the "Sables jaunes biodétritiques" and in the "Sables verts glauconieux".

*Planulina ariminensis*-assemblage

This assemblage covers the samples A 1-5 and B 6-11 (cluster 1). It is the species- and specimen-richest of the three different faunal assemblages. The percentage of the dominant species *P. ariminensis* reaches from 6 to 36 %, with an average of 21 %. Additional frequent species are: *Anomalinoidea helicinus, Cibicoides dutemplei, Cibicoides incrassatus, Cibicoides pachyderma, Cibicidoides...*
M. GEBHARDT

des subhaldingeri, Cibicidoides ungerianus, Globocassidulina subglobosa, Gyroidioides neosal-
darii, Heterolepa dertonensis, Martinitiella communis, Melonis popmiotides, Siphonina reticulata, Sphaeroidina bulloides, Textularia abbreviata, Uvigerina longistriata and Uvigerina rutila. The occurrence of planktonic foraminifera decreases from 77 % in sample B 6 to 32 % in sample A 5. The Fisher α-index fluctuates between 13 and 22. Hence, this points to the upper slope (upper bathyal) with probable decreasing water depths of 500 to 200 m as the deposition area. This assem-
bblage covers the "Marnes de Salé" and the "Marnes grises sableuses", at which the water depth was distinctly shallower.

DISCUSSION

According to Boltovskoy (1983), one probable explanation for the richness of the benthic forami-
niferal fauna off Northwest Africa is the relatively high productivity, which results from a higher
nutrient supply. In the investigated samples of the Planulina arminiensis-assemblage occur several
genera like Heterolepa, Islandiella, Karrierella, Lenticulina, Martinitiella, Oridorsalis, Melonis and
Uvigerina, which prefer cooler water. This and the species- and specimen-rich fauna point to up-
welling during the deposition. In the lower, earlier part, the percentage of Lenticulina, which prefer water with a high oxygen content, is higher than in the upper, younger part. Contrary to this, the occurrence of species which have low tolerance to oxygen deficiency (Bulimina aculeata, Cibicidoides dutemplet) is higher here than in the lower part. This points to a slightly decreasing oxygen content, respectively to an increasing nutrient supply. Reason for this could be an increasing nutrient inflow of rivers from the continent during the tectonic lifting. This corresponds to the decreasing content of planktonic foraminifera during the deposition period. Altogether, there is a substan-
tial similarity to the bathyal fauna from the Guadalquivir-area, as described by Berggren and
Haq (1976). Resulting from the sequence of the samples in the sections, the inner shelf deposits in the beginning of the Miocene sedimentation are followed by rapid deepening of the deposition area. Even within the "Sables jaunes biodétritiques", the middle shelf was reached. With the "Marnes de Salé", which were deposited on the upper slope, the greatest water depth was set. The lifting of the area started with the deposition of the "Marnes grises sableuses", so that the "Sables verts glauconiteux" could be deposited on the middle shelf again. With the appearance of the different faunal assemblages and with the proportional occurrence of the planktonic foraminifera, shown in Figs 2 and 3, a trans-
gression in the upper Late Miocene and a regres-
sion in the Early Pliocene are represented. In contrast to this, Haq et al. (1987) are showing for the Miocene/Pliocene boundary a lowstand of the seal level. Because the habits of the investigated foraminifera could not have changed substantially for different periods, it is deduced that the relative deepening and lifting of the deposition area have to be of tectonic nature.

CONCLUSIONS

The investigated sections range from the upper Late Miocene (dutertretet humerosa-subzone, m8a)
into the Early Pliocene (puncticulata-zone (p1b) according to Wernli (1988)).

By the Planktonic/Benthic-ratio, the species richness and different benthic foraminiferal assem-
bblages, three distinct environments can be described:

an Ammonia beccarii-assemblage of the inner shelf (inner neritic);

a Hanzawaia boueana-assemblage of the middle shelf (middle neritic);

a Planulina arminiensis-assemblage of the upper slope (upper bathyal).

In their temporal succession they represent a transgression-regression sequence in the investi-
gated area.

The shown transgression-regression sequence seems to be induced by tectonics.

Acknowledgements - I thank everybody who helped me in this study: Dr. F. Hendriks and Mr. A. Strouhal for making the sample material available, Mr. B. Kleeberg and Mrs. H. Glowa helped with the plates, Prof. Dr. A. v. Hillebrandt critically reviewed the manuscript and Mrs. S. Pannebaker helped me with the English translation.

REFERENCES


Appendix 1

Faunal reference list (only benthic foraminifera)

1. Ammonia beccari (LINNÉ) = Nautilus beccari LINNÉ, 1758, Systema naturae, Ed. 10, Holmiae, tomus 1, p. 710, pl. 1, fig. 1a-c.


23. *Eggerella sp.*


44. Lenticulina vortex (FICHTEL & MOLL) = Nautilus vortex FICHEL & MOLL, 1798, Test. microsc., Wien, p.31, pl. 2.figs. a-c.


49. Melonis pompilloides (FICHTEL & MOLL) = Nautilus pompilloides FICHEL & MOLL, 1798, Test. microsc., Wien, p. 31, pl. 2.figs. a-c.

50. Orilorsalis tener (BRADY) = Truncatulina tenera BRADY, 1884,Challenger Rep., vol. 9, p. 665, pl. 95, figs. 11a-c.


52. Pleurostomella alternans SCHWAGER, 1866, Novara Exped. 1857-1859, Wien, Geol. Theft, Bd. 2, Abth. 2, p. 238, pl. 6, figs.79-80.


55. Quinqueloculina sp.

56. ?Rotorblinella sp.


58. ?Septotextularla sp.


68. Textularia cf. isabellensis DAVIS, 1941, Jour. Pal., Tulsa,vol. 15, p. 149, pl. 24, fig. 10.


70. Textularia sp.


74. Vulvulina cf. pennatula (BATSCH) = Nautilus pennatula BATSCH,1791, Conyel. Seesandes, Jena, University Press, pl. 4, fig. 13a-e.
## Appendix 2
### Proportional Occurrence of Species in the Samples
(only benthic foraminifera)

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The rest contains all species, which are represented with only one specimen in the sample.