2. Late Miocene-early Pliocene nannofossil biochronology and biogeography in the Vera Basin, SE Spain

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Abstract. — The modes of formation of the massive evaporites deposited in the deep Mediterranean basins during latest Miocene (~ 6.0—5.0 Ma), and thereby the question whether the Mediterranean was completely isolated from Atlantic Ocean waters during that time, have been the subject of much debate in recent years. The late Miocene-early Pliocene sediments of the Vera Basin in SE Spain have previously been interpreted as representative of a continuous and truly marine environment.
In this paper calcareous nannofossils have been investigated in the late Miocene-early Pliocene sequence of the Vera Basin and from eight Mediterranean and two Atlantic Ocean DSDP sites. An almost threefold increase (from 25–30% to 70–80% of the total assemblage) of one species, Dictyococcites minutus, represents a significant ecotone. This ecotone occurred prior to 6.6 Ma, but not before 9.5 Ma, in the Mediterranean. The results from the DSDP cores also reveal that D. minutus dominated the nannofossil assemblages continuously throughout late Miocene-early Pliocene times. This ecotone is not present during the latest part of the Miocene of the Vera Basin, but its presence in the early Pliocene indicates that this basin was temporarily isolated from the marine environment during the latest Miocene. The continuous occurrence of nannofossils during the isolated interval is interpreted as due to redeposition from primarily early and middle late Miocene sediments.

Two new species are described: Reticulofenestra baqui and Sphenolithus versonis, and one species is recombined: Reticulofenestra gelidus (GEITZENAUER) n. comb.

ACKNOWLEDGEMENTS

The manuscript was critically read by Professor I. HESSLAND and Dr. B. U. HAQ. I am also indebted to Drs. L. SJÖBERG and N.-A. MÖRNER for valuable discussions and comments. Dr. D. T. RICHARD improved the manuscript linguistically.

Financial support was provided by Stockholm University and the Swedish Natural Science Research Council.

INTRODUCTION

Recent studies in the Guadalquivir Basin of southern Spain have revealed that this region underwent a pronounced shallowing in late Miocene time and a renewed deepening in the early Pliocene (BENSON, 1972, 1976; BERGGREN and HAQ, 1975; BERGGREN et al., 1976). It is believed that the shallowing was tectonically induced, and that this movement continued well into late Miocene (Messinian) time. The vertical movement restricted the marine passage between the Atlantic Ocean and the Mediterranean. A total isolation of the Mediterranean has also been considered possible, resulting from the combined effects of the tectonic movement and an eustatic lowering of the sea level. The final connection is believed to have been the Betic Strait (VAN COUVERING et al., 1976; ADAMS et al., 1977).
This interpretation is opposed by some workers (Bizon et al., 1975; Montenat et al., 1976). They suggest that a normal marine passage existed continuously in the Betic Strait through late Miocene and early Pliocene times. This hypothesis is mainly based on data from the Cuevas del Almanzora section in the Vera Basin of SE Spain.

This question, whether the Mediterranean became isolated from the Atlantic Ocean at some time during the Messinian, is of prime importance in order to explain the origin of the massive evaporites that were deposited during the Messinian in the deep Mediterranean basins. These evaporites have an estimated volume of more than one million cubic kilometers (Ryan et al., 1973; Ryan, 1973; Hsü et al., 1977).

This study presents the results of qualitative and quantitative investigations of calcareous nannofossils from the Cuevas del Almanzora section in the Vera Basin and from some Mediterranean and Atlantic Ocean Deep Sea Drilling Project (DSDP) sites (fig. 1). The changing biogeographic patterns in the late Miocene-early Pliocene nannofossil assemblages, as they are recorded from the Vera Basin and the DSDP cores, provide important information towards the solution of the problem of continuity of a marine connection between the Atlantic Ocean and the Mediterranean. Certain characteristics in the biogeographic evolution of the nannofossil assemblages are interpreted as indicating that the Vera Basin was temporarily isolated from the marine environment during late Messinian time and that marine conditions were re-established in the earliest Pliocene.
STUDY MATERIAL

The material studied was collected during a field-trip after the Third Messinian Seminar in Malaga in September-October 1977. The collecting was made under guidance of C. Montenat, who has described the Cuevas del Almanzora section.

The lowermost sample was taken 1/2 m below sample number 74148 of Montenat et al. (1976, fig. 4) (fig. 2 in this paper); samples 1—7 were taken at every third meter, except sample 5 which was taken 1 m above sample 4. Sample 8 was taken about 1.5 m above number 74157. Samples 8—14 were taken at 1.5 m intervals and samples 14—20 at 2 m intervals. The DSDP samples used are listed in table 1.

METHODS

Each sample was "shaved" in order to avoid contamination from other parts of the section before smear-slides were made directly from the raw samples. Taxonomic determinations and frequency data were gathered from light microscope observations at 1000 × magnification.

Samples studied in the scanning electron microscope were treated with a sodium hexametaphosphate (2%) and hydrogen peroxide (10%) solution, which was saturated with respect to olcite in order to avoid dissolution of the calcitic nannofossils.

Approximately 500 fields were observed on each smear-slide along random traverses to determine the taxal representations. Random counts of at least 400 coccoliths were made in each smear-slide along a continuous traverse. According to Shaw (1964) this number provides a 95% probability that species occurring with relative abundances of 0.75% will be included in the counts.

The coccolith zones used follow the "standard calcareous nannoplankton zonation" proposed by Martini (1971). For the discussion of the absolute chronology of the Miocene-Pliocene boundary, coccolith zonal boundaries and datum levels two numerical time-scales are considered, those of Berggren and Van Couvering (1974) and Ryan et al. (1974), respectively.

PREVIOUS WORK

The sedimentary and biostratigraphic history of the Vera Basin has been outlined by several authors (i.e. Volk, 1966; Montenat et al., 1976). The Cuevas del Almanzora section in the Vera Basin is considered to represent (1) a continuous
marine environment throughout the Messinian, and (2) the first described continuous micropaleontological succession in the Western Mediterranean area that straddles the Miocene-Pliocene boundary (MONTENAT et al., 1976). For these reasons the Cuevas del Almanzora section has been proposed as a Messinian parastratotype (BIZON et al., 1975).

The suggested continuity of the sedimentation is based on a calcareous nannoplankton succession and, primarily, on an evolutionary series of planktonic foraminifera which involves the first occurrence (FO) of *Globorotalia mediterranea—G. conomiozea* (base Messinian), the last occurrence (LO) of these two species (top Messinian) and the FO of *G. margaritae* (base Zanclean), which "succeed each other without any evolutionary hiatus" in the central part of the Vera Basin (MONTENAT et al., 1976, p. 615). According to MONTENAT et al. this indicates that normal marine conditions persisted through the late Miocene-early Pliocene interval in the Betic Strait. They used this interpretation to reject Hsu and Cita's (1973) interpretation that the Mediterranean became completely isolated from the Atlantic Ocean and desiccated during the Messinian.

Two widely differing ostracode assemblages have been recorded from the Vera Basin section (BENSON, 1976): one caspibrackish *Cyprideis* fauna in the lower part of the section (Messinian) and one marine fauna in the upper part of the section (lowermost Pliocene). BENSON would have expected to have normal marine ostracodes rather than *Cyprideis* if a marine passage had been present.

A calcareous nannoplankton zonation has been established for the Cuevas del Almanzora section (MÜLLER, 1976). The *Discocaster quinqueramus* Zone (NN 11) and the lower part of the *Ceratolithus tricorniculatus* Zone (NN 12) are interpreted as belonging to the Miocene, and the upper part of Zone NN 12 as belonging to the Pliocene. The LO of *D. quinqueramus* is used to define the boundary between Zones NN 11 and NN 12. MÜLLER (1976) recorded *D. quinqueramus* in the interval between sample numbers 74129 and 74165 (see fig. 4 in MONTENAT et al., 1976). Further, she found that *Amaurolithus tricorniculatus* (see GARTNER and BUKRY, 1975 for discussion of the generic status of *Ceratolithus/Amaurolithus tricorniculatus*) occurs together with *D. quinqueramus* at the 74136, 74156 and 74158 levels, but observed that *A. tricorniculatus* was present without being accompanied by *D. quinqueramus* between 74166 and 74169. Consequently, she placed the NN 11—NN 12 boundary between samples 74165 and 74166 (fig. 2).

It was suggested by MÜLLER (1976) that the interval between samples 74165 and 74169 (approximately 3 m) may belong to the lower part of Zone NN 12, which she considered to belong to the Miocene. The overlying thick sedimentary sequence (about 40 m) was referred to as the upper part of Zone NN 12. These very close positions of the NN 11—NN 12 and the Miocene-Pliocene boundaries differ from the opinions of other biostratigraphers, who place the Miocene-Pliocene boundary close to the middle of Zone NN 12. BERGGREN and VAN COUVERING (1974) have estimated an age of 5.7 Ma for the beginning and 4.45 Ma for the
end of Zone NN 12, and the Miocene-Pliocene boundary is estimated at 5.0 Ma. Ryan et al. (1974) placed the beginning of Zone NN 12 at 5.6 Ma, its end at 4.5 Ma and the Miocene-Pliocene boundary at 5.2 Ma. The results of these workers indicate that the Miocene-Pliocene boundary should be located at a level which bisects Zone NN 12 into two parts of about the same duration.

RESULTS

Taxonomic representation

A large (more than 160 species) taxonomic diversity has been observed in the samples studied here (table 1). A great number of these are reworked from middle and lower Miocene, Oligocene, Eocene, Paleocene and Cretaceous deposits. In order to elucidate the present problem it was not considered necessary to identify every nannofossil down to the species level. For this reason, many of the reworked nannofossils are identified only to the generic level. In fig. 3 the relative abundances of those taxa which can be considered indigenous to late Miocene-early Pliocene are presented, whereas the pre-late Miocene taxa are referred to as "obviously reworked".

Table 1. Identified nannofossils in the Vera Basin.

<table>
<thead>
<tr>
<th>Amaurolithus delicatus</th>
<th>Cribrosphaerella ehrenbergii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. primus</td>
<td>C. jonesi</td>
</tr>
<tr>
<td>Arkhangelskiella cymbiformis</td>
<td>Cruciplacolithus tenuis</td>
</tr>
<tr>
<td>Arkhangelskiella sp.</td>
<td>Cyclococcolithus formosus</td>
</tr>
<tr>
<td>Braarudosphaera bigelowi</td>
<td>C. gammona</td>
</tr>
<tr>
<td>B. discola</td>
<td>C. leptoporus</td>
</tr>
<tr>
<td>Braarudosphaera sp.</td>
<td>C. luminis</td>
</tr>
<tr>
<td>Bronsonia sp.</td>
<td>C. mcintyre</td>
</tr>
<tr>
<td>Cactinastra umbellus</td>
<td>Cyclolithus pactilis</td>
</tr>
<tr>
<td>Chiasmolithus bidentis</td>
<td>Cyclococcolithina rotula</td>
</tr>
<tr>
<td>C. expansus</td>
<td>Cyclicargarolithus floridanus</td>
</tr>
<tr>
<td>C. gigas</td>
<td>Dictyococcites abisectus</td>
</tr>
<tr>
<td>C. grandis</td>
<td>D. antarcticus</td>
</tr>
<tr>
<td>Chiatostygus sp.</td>
<td>D. davesii</td>
</tr>
<tr>
<td>Coccolithus eopeleagicus</td>
<td>D. besslandii</td>
</tr>
<tr>
<td>C. miopelagicus</td>
<td>D. minutus</td>
</tr>
<tr>
<td>C. pacaeus</td>
<td>Discostaer adamanteus</td>
</tr>
<tr>
<td>C. pelagicus</td>
<td>D. aster</td>
</tr>
<tr>
<td>C. solitarius</td>
<td>D. asymmetricus</td>
</tr>
<tr>
<td>Coronocyclus nitescens</td>
<td>D. aulokos</td>
</tr>
<tr>
<td>Cretarhabdus conicus</td>
<td>D. barbadiensis</td>
</tr>
<tr>
<td>C. crenulata</td>
<td>D. berggrenii</td>
</tr>
<tr>
<td>Cretarhabdus sp.</td>
<td>D. aff. D. berggrenii</td>
</tr>
</tbody>
</table>
D. binodosus
D. bollii
D. browneri
D. calcaris
D. challenger
D. decorus
D. deflandre
D. druggii
D. elegans
D. exilis
D. gemmifer
D. gemmeus
D. icarus
D. intercalaris
D. knutperi
D. knigleri
D. lodoenis
D. loeblichi
D. multiradiatus
D. neohamatus
D. neorectus
D. obtusus
D. pentaradiatus
D. pseudoavariabilis
D. quinqueramus
D. aff. D. quinqueramus
D. saipanensis
D. stradi meri
D. stricki
D. surculus
D. tani
D. variabilis
D. woodringii
Discoasteroides megastypus
Eiffelithus eximus
E. turriselliferi
Fascialithus tympaniformis
Fascialithus sp.
Heliosphaera ampliaperta
H. bramlettei
H. burkei
H. compacta
H. dinesenii
H. granulata
H. kamptseri
H. intermedia
H. lophota
H. obliqua
H. orientalis
H. pacifica

H. perch-nilsseni
H. recta
H. sellii
Heliolithus kleinpellii
Holodiscolithus macroporus
Isthmolithus recurvus
Kamptserius magnificus
Lithostromation percarum
Lithraphidites quadratus
Marthaitrites tribrachiatus
Microrbahdulus sp.
Nicula deussata
M. mura
M. staurophora
Micrantholithus obtius
Micrantholithus sp.
Nannoconus sp.
Neococcolithus dubius
Pontosphaera attenuata
P. japonica
P. multipora
Prediscosphaera cretacea
Prinitsius martini
Reticulofenestra bivest
R. gelidus (n. comb.)
R. haqii n. sp.
R. pseudambilica
R. umbilica
Rhabdosphaera clavigera
R. procera
Scyphospaera aequatorialis
S. amboora
S. apsteinii
S. galeana
S. intermedia
S. lagena
S. turris
Scyphospaera sp.
Spheroolithus abies
S. anarhopus
S. belemnus
S. capricornatus
S. ciperoensis
S. conicus
S. heteromorphus
S. moriformis
S. neoabies
S. pacifica
S. pseudoradians
S. radians
LATE MIOCENE-EARLY PLIOCENE NANNOFOSSIL BIOCHRONOLOGY

S. veronisii n. sp.
Thoracosphaera aff. T. reticulata
Thoracosphaera sp.
Trigonocephalus carinatus
T. rugosus
Umbilicosphaera jafari
Vekshinella sp.
Watzenaneria barnesae

W. crucicentra
Zygodiscus biperforatus
Z. elegans
Z. pseudoanthophorus
Zygodiscus sp.
Zygolithis sp.
Zygrebolithis bijugatus

Datum levels

It is difficult to identify accurate datum levels in the Vera Basin section. A large amount of reworked material, preservational problems (dissolution and/or secondary overgrowth of calcite) and the low frequency of discoasters and ceratoliths are main causes which prevent the delineation of an accurate nannofossil biochronology. The section represents a relatively short time interval but three well defined datum levels can be expected to occur within it, namely the FO of A. tricorniculatus at 6.6 Ma, the LO of D. quinqueramus at 5.6 Ma and the FO of Ceratolithus acutus at 4.9 Ma (RYAN et al., 1974).

Amaurolithus tricorniculatus has not been observed in the present study although A. primus and A. delicatus sensu GARTNER and BUKRY (1975) are recorded as rare elements of the total assemblage (fig. 3).

Discoaster quinqueramus and D. aff. D. quinqueramus occur almost continuously as low frequency members of the assemblage in samples 1—9. A gap exists from samples 10—12 where D. quinqueramus was not recorded, but this species is present in sample 13. One recorded specimen of Discoaster berggrenii in sample 16, half a meter below number 74172, within the Pliocene, is considered as reworked, since this species has only been observed in sediments of late Tortonian and Messinian ages elsewhere (BUKRY, 1971a). Ceratolithus acutus has not been observed in the present study. Single specimens of D. asymmetricus have been recorded in samples 16, 18 and 20. Since this species has a well documented FO in the upper part of early Pliocene (GARTNER, 1973), only downslope contamination can be responsible for its presence in these samples.

Abundance data

Abundance data are presented in fig. 3. All prominent changes occur within the "passage zone" of MONTENAT et al. (1976, fig. 4) (fig. 2).

Coccolithus pelagicus maintains a stable relative abundance of 10—15% of the total assemblage below sample 14. This may include some pre-Messinian individuals, since C. pelagicus has a wide stratigraphic range from early Cenozoic to the present. However, this is not considered to alter the Messinian representation of the species beyond usefulness. This argument can be inferred for all other species in fig. 3, but since C. pelagicus is the most long-ranging of these, it could...
be represented by a greater number of reworked individuals. The relative abundance of *C. pelagicus* decreases to less than 1% from sample 14 to sample 20. *Dictyococcites minutus* also shows a considerable change in frequency between samples 13 and 14. It occupies a stable 21—31% of the assemblage in samples 1—13, and a relatively stable and high percentage (51—86%) of the total assemblage in samples 14—20.

Among samples 1—10 "obviously reworked" nannofossils maintain a stable 26—38% of the total assemblage. In samples 11—14 the percentage representation decreases successively to 21%, 11%, 11% and 1% respectively. The low frequency of pre-late Miocene nannofossils in sample 14 continues up to sample 20.

Less pronounced frequency changes of other species are noticed in the "passage zone". *Cyclococcolithina rotula*, *Sphenolithus veronis*, *Umbilicosphaera jafari* and to some extent *Reticulofenestra pseudouniformis*, increase in abundance in sample 11.

**DSDP samples**

The purpose of studying the DSDP samples was to investigate the relative
Table 2. Percentage *Dictyococcites minutus* of the total assemblage in the DSDP samples used. See text (p. 103) for explanation of "Time intervals".

<table>
<thead>
<tr>
<th>Leg/Site/Core/Section</th>
<th>cm</th>
<th>% <em>D. minutus</em></th>
<th>Time interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/118/5/1</td>
<td>144-145</td>
<td>83</td>
<td>1</td>
</tr>
<tr>
<td>12/118/5/3</td>
<td>121-123</td>
<td>74</td>
<td>2</td>
</tr>
<tr>
<td>14/135/2/6</td>
<td>30-32</td>
<td>89</td>
<td>3</td>
</tr>
<tr>
<td>14/135/2/6</td>
<td>110-111</td>
<td>86</td>
<td>3</td>
</tr>
<tr>
<td>14/135/2/6</td>
<td>140-142</td>
<td>82</td>
<td>3</td>
</tr>
<tr>
<td>13/123/6/1</td>
<td>125-127</td>
<td>82</td>
<td>1</td>
</tr>
<tr>
<td>13/124/5/2</td>
<td>99-100</td>
<td>79</td>
<td>1</td>
</tr>
<tr>
<td>13/125A/6/1</td>
<td>96-97</td>
<td>69</td>
<td>1</td>
</tr>
<tr>
<td>13/132/20/1</td>
<td>100-101</td>
<td>73</td>
<td>1</td>
</tr>
<tr>
<td>13/134/7/5</td>
<td>125-127</td>
<td>62</td>
<td>1</td>
</tr>
<tr>
<td>42A/372/4/1</td>
<td>99-100</td>
<td>63</td>
<td>1-2</td>
</tr>
<tr>
<td>42A/372/4/2</td>
<td>100-101</td>
<td>63</td>
<td>1-2</td>
</tr>
<tr>
<td>42A/372/9/2</td>
<td>10-11</td>
<td>74</td>
<td>4</td>
</tr>
<tr>
<td>42A/372/9/2</td>
<td>30-32</td>
<td>85</td>
<td>4</td>
</tr>
<tr>
<td>42A/372/9/2</td>
<td>40-41</td>
<td>24</td>
<td>4</td>
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<td>42A/372/9/3</td>
<td>141-142</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>42A/372/9/4</td>
<td>45-46</td>
<td>29</td>
<td>4</td>
</tr>
<tr>
<td>42A/375/1/1</td>
<td>57-58</td>
<td>89</td>
<td>1</td>
</tr>
<tr>
<td>42A/376/6/3</td>
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<td>1-2</td>
</tr>
<tr>
<td>42A/376/6/4</td>
<td>50-51</td>
<td>85</td>
<td>3</td>
</tr>
<tr>
<td>42A/376/6/4</td>
<td>140-141</td>
<td>88</td>
<td>3</td>
</tr>
<tr>
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<td>4</td>
</tr>
<tr>
<td>42A/376/8/2</td>
<td>100-101</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td>42A/376/9/3</td>
<td>100-101</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>

The abundance of *D. minutus* from adjacent areas in the late Miocene-early Pliocene interval, in order to ascertain the significance of the threefold increase in the abundance of this taxon between samples 13 and 14 in the Vera Basin section. The site locations are shown in fig. 1. A sample list and the results from the counts are presented in table 2 and fig. 4. The biochronology of these samples is discussed below.

**DISCUSSION**

*Time intervals*

In fig. 4 all investigated samples are assigned to four time intervals. The exact position of a sample within one of these time intervals is not considered to be
Fig. 4. Relative abundances (in percent of the total assemblage) of *Dictycoccites minutus* in the Vera Basin and the DSDP cores. The biostratigraphy and biochronology are adopted from BERGGREN and VAN COUVERING (1974) and RYAN et al. (1974). See text for explanation of time intervals (p. 103), and fig. 3 for the percentage of *D. minutus* in the Vera Basin and table 2 for the DSDP samples used and the percentages of *D. minutus* in those samples. (▽) and (△) represent the FO of *A. tricorniculatus* and the LO of *D. quinqueramus*, respectively.

of critical importance for the purpose of this study. Therefore, in order to avoid sorting out detailed and complicated "time" vs. "stratigraphic" positions of samples, the time intervals are shown to be of uniform lengths in spite of their unequal durations in reality.

The first time interval represents deposits younger than 5.2—5.0 Ma. All samples referred to this interval are considered to belong to the early Pliocene. Time intervals 2, 3 and 4 represent late Miocene time. The second time interval is chronologically located between 5.6 and 5.2—5.0 Ma, representing the interval between the LO of *D. quinqueramus* and the Miocene-Pliocene boundary. The third time interval is located between 6.6 and 5.6 Ma, from the FO of *A. tricorniculatus* to the LO of *D. quinqueramus*. The fourth time interval represents late Miocene time older than 6.6 Ma.

**Biochronology of the Vera Basin**

A basic assumption is made in this study in order to explain the nannofossil biochronology and the frequency data, namely that the previously established position of the Miocene-Pliocene boundary in the Vera Basin is true. As a consequence of this, samples 1—13 are considered to represent Miocene (Messinian) and samples 14—20, Pliocene (Zanclean) times. Frequency data indicate the the
position of the Miocene-Pliocene boundary can be located between samples 13 and 14. The reason for this will be discussed below. In the Pliocene, the FO of *Ceratolithus rugosus* delineates the boundary between the nannofossil Zones NN 12 and NN 13 (Martini, 1971), but since this species has not been observed in the present study and *A. primus* and *A. delicatus* are present in samples 14–20, this interval is considered to be within Zone NN 12. No nannofossil zonation has been made in the Miocene samples 1–13, although the NN 11—NN 12 boundary could be expected to be found in that interval. The LO of *D. quinqueramus* delineates the boundary between these zones (Martini, 1971). If the absolute age estimates as given by Berggren and Van Couvering (1974) and Ryan et al. (1974) are applied to the Miocene-Pliocene boundary and the nannofossil zonal boundary NN 11—NN 12 (see p. 98) it becomes apparent that this boundary most probably is lost in the sample sequence 1–13 due to reworking of *D. quinqueramus*. But since samples 1–13 are regarded as Miocene (Messinian), they are assigned to time intervals 2 and 3, and samples 14–20 to time interval 1. It cannot be confirmed with the available data whether samples 1–13 also represent time interval 3 or if they only represent time interval 2.

*Biochronology of the DSDP samples*

**Site 118**

Laughton et al. (1972) tentatively indicated the age of core 5 in site 118 as being late Miocene-early Pliocene. They found (op. cit., p. 692) only nonbirefringent ceratoliths in core 5 and suggested that it might belong to the Miocene. When examining 12/118/5/3 121–123 I observed *A. tricorniculatus, A. primus* and common *Triquetrorhabduls rugosus*, but *D. quinqueramus* was not recorded. Since *T. rugosus* becomes extinct just before the Miocene-Pliocene boundary when it is dated at 5.1 Ma (Bukry, 1973), this sample is assigned to time interval 2 of the Miocene. About 1.8 m above this sample in core 5 *T. rugosus* was not present, but one ceratolith which showed affinity to *C. acutus* was observed, indicating that this level in the core is early Pliocene. This sample is therefore assigned to time interval 1.

**Site 135**

Hayes et al. (1972) observed *Globorotalia mioae* in section 6 of core 2, but did not observe *G. margaritae* in section 6, and therefore interpreted this section as possibly belonging to the Miocene. I observed *A. primus* and *A. delicatus* accompanied by *D. quinqueramus* up to the 30–32 cm level in section 6 of core 2 and assign therefore this lowermost part of core 2 to time interval 3.

**Sites 123, 124, 125A, 132, 134 and 375**

The samples from these sites that I have studied are all taken within the early Pliocene interval according to Ryan et al. (1973) and Hsu et al. (1976).
Core 9 has been assigned to Zone NN9 (Discoaster hamatus Zone) by HsÜ et al. (1976). In the interval between core 9 section 4 at the 45—46 cm level and core 9 section 2 at the 40—41 cm level, I did not observe D. hamatus whose presence would indicate that the core represents late middle and earliest late Miocene times (MARTINI, 1971). But Discoaster calcaris was observed in this interval accompanied by Sphenolithus abies and Helicosphaera sellii. According to MARTINI (1971) and HAQ (1973) these two species have their FO's in Zone NN 10 (D. calcaris Zone). Further, I identified D. loeblichii and D. aff. D. neorec-tus in this interval. Both those species have a limited stratigraphic range in early late Miocene according to BUKRY (1971b). Since D. quinqueramus was not observed in this interval it is considered to represent early late Miocene (Zone NN 10). Discoaster quinqueramus was observed in section 2 of core 9 at the 30—32 and 10—11 cm levels, indicating middle late Miocene time (Zone NN 11). Ceratoliths were not observed at those two levels. Consequently, the investigated interval in core 9 is assigned to time interval 4. The interval between core 9 and core 4 shows gypsum and dolomitic marls of a probable late late Miocene (Messinian) origin (HsÜ et al., 1976). The two samples investigated in core 4 show a relatively diversified nannofossil assemblage representing late Miocene-early Pliocene times, but, as the nannofossils did not provide a more detailed information on the age of this core, it is assigned to time intervals 1 and 2.

Site 376

The cores of site 376 terminate in Messinian halite. Above the evaporites a set of cores were recovered which represent the late Miocene. The lowermost sample used in site 376, in core 9 section 3 at the 100—101 cm level, provided only poorly preserved nannofossils and some discoasters which showed some affinity to D. calcaris and D. quinqueramus, indicating a supply of early late Miocene material. The interval between section 2 of core 8 at the 100—101 cm level and section 1 of core 7 at the 40—41 cm level is assigned to Zone NN 11 since D. quinqueramus was present there. Ceratoliths were not observed and the interval between section 3 of core 9 and section 1 of core 7 at the 40—41 cm level is therefore assigned to time interval 4. An abrupt change in sediment type from dolomitic marlstone to nannofossil marl in section 1 of core 7 at the 50 cm level (HsÜ et al., 1976) may possibly indicate a hiatus. The two samples investigated in section 4 of core 6 contain D. quinqueramus together with A. primus, A. tricorniculatus and A. delicatus. Therefore this material may have first been deposited during interval 3, and then become reworked into the Messinian sequence. In the uppermost sample, in section 3 of core 6, D. quinqueramus is absent and may be either late Miocene or early Pliocene, and is thus assigned to time intervals 1 and 2.
Biogeographic patterns as delineated from the Vera Basin and the DSDP samples

HAQ and LOHMANN (1976) have shown that latitudinal differentiation in nannofossil assemblages existed in the Atlantic Ocean during early Cenozoic times and that distinct migrations of nannoplankton assemblages occurred across latitudes with time. They interpreted these events as responses of the nannoflora to major climatic fluctuations. McINTYRE and BÉ (1967) and GEITZENAUER et al. (1976) have shown that different nannoplankton assemblages are confined to certain surface water masses, which are defined by temperature and salinity characteristics.

The changes in the nannofossil assemblage as documented in the Vera Basin around the time of the deposition of the "passage zone" (figs. 3 and 4) appear to represent a latitudinally migrating nannoflora, caused by water mass redistribution.

Since it cannot be excluded that the Vera Basin became isolated from the marine environment during a part of the Messinian (BENSON, 1976; VAN COUVERING et al., 1976; ADAMS et al., 1977), the response to a general change of the biogeographic patterns in this region may have been delayed in the Vera Basin until marine conditions were re-established there.

Two prominent changes in the nannofossil assemblage are recorded in the Vera Basin, namely the increase of *D. minutus* and the synchronous decrease of "obviously reworked" nannofossils between samples 13 and 14. *Dictyococcites minutus* and the latter group of taxa maintain stable relations in the assemblage both below and above the "passage zone". Special attention has been paid to the observed threefold increase of *D. minutus* in the Vera Basin and in some of the DSDP cores. The frequency change of *D. minutus* is considered to represent an easily identified and significant ecotone or signal which is not restricted to a local basin but can be recognized over wide geographic areas all over the Mediterranean and in the Atlantic Ocean.

The actual threefold increase of *D. minutus* has been observed not only in the Vera Basin but also in two DSDP cores: in core 9 of site 372 and in core 7 of site 376 (table 2, fig. 4). Unfortunately, it has not been possible to locate the increase in a very precise stratigraphic framework, although data from these two cores indicate a minimum age of 6.6 Ma and a maximum age of 9.5—10.0 Ma for the initiation of the ecotone under normal marine conditions in the Mediterranean area. This means that its initiation occurs within Zone NN 11 but before the FO of ceratoliths.

The results obtained from the DSDP cores agree well with the study from the whole Atlantic Ocean presented by HAQ et al. (1976). They recorded an expansion of *D. minutus* from low latitudes into middle and high latitudes of the northern hemisphere where that species became dominant. They determined the
initiation of the expansion to the upper part of Zone NN 11 and noticed that it continued through Zones NN 12 and NN 13.

This ecotone first occurs at the Miocene-Pliocene boundary in the Vera Basin section, but since it is located stratigraphically well below the Miocene-Pliocene boundary in continuous marine sections (fig. 4), the investigated Miocene (Messinian) part of the Vera Basin section may be interpreted as having been deposited under different conditions, probably of non-marine nature. The isolation from the ocean should have lasted during the entire interval covered by samples 1 through 13. The abundant nannofossils which were deposited in this basin during this interval must then have been redeposited from older strata.

**Redeposited nannofossils in the late Miocene of the Vera Basin**

The presence of late Miocene ceratoliths in samples 1—13 indicates that the assemblage dominated by *D. minutus* (characterized by 70—80% of *D. minutus* of the total assemblage) arrived in the Vera Basin some time before the basin was isolated. This must have been reflected in the sediments deposited during that time. These sediments should also, together with the late Miocene sediments which were deposited before the arrival of the *D. minutus* dominated assemblage, be the main sources for the redeposited sediments in samples 1—13. Nannofossil abundance data indicate that no less than about 72% of the total assemblage in samples 1—13 (fig. 3) have a late Miocene origin, and thus a major part of the redeposited sediments could also be of late Miocene age.

The redeposited nannofossils in the Vera Basin Miocene represent a mixture of taxa from various stratigraphic levels (table 1). These taxa can be subdivided into two groups. One consists of species with stratigraphic ranges within the time interval of late Miocene and early Pliocene. The other consists of species which are considerably older than the first group, representing middle and early Miocene, Oligocene, Eocene, Paleocene and Cretaceous ages. This "obviously reworked" group represents an average of 28% of the total assemblage in samples 1 through 13 (fig. 3). The first group includes only three species which may noticeably increase the relative abundance of the "obviously reworked" (pre-late Miocene) group, namely *C. pelagicus*, *D. antarcticus* and *D. minutus* (fig. 3), since these have relative abundances of more than only a few percent of the total assemblage and also are represented in pre-late Miocene ages. However, it is possible to roughly calculate the relative abundance of *D. minutus* in the redeposited assemblage if it is assumed that all species, except the "obviously reworked" group, are redeposited from late Miocene sediments.

A linear sedimentation rate is assumed for the Messinian part of the Vera Basin section (see MONTENAT et al., 1976, fig. 4), in order to estimate the time interval that samples 1—13 represent. All absolute age estimates in the following are from RYAN et al. (1974). The late Miocene began at 12.0 Ma and ended at 5.2 Ma, Zone NN 11 began at 9.5 Ma and ended at 5.6 Ma. Samples 1—13
Fig. 5. Mean values of percentages of *D. minutus* in the DSDP samples. Stratigraphy and absolute ages are adopted from RYAN et al. (1974). (A) represents the assumed position of sample 1 at 5.5 Ma, (B) the assumed position of the initiation of the *D. minutus* ecotone at 7.1 Ma and (C) the position of the middle-late Miocene boundary at 12.0 Ma. The interval (A)—(B) is 1.6 Ma, (B)—(C) is 4.9 Ma and (A)—(C) is 6.5 Ma. The mean value of the percentage of *D. minutus* (of the total assemblage) in the interval (A)—(B) is 79 %, and 28 % in the interval (B)—(C) (see table 1).

represents an interval which was calculated to be 0.3 Ma, and sample 1 can therefore be placed at 5.5 Ma. This study has shown that the signal was active prior to 6.6 Ma, and according to HAQ et al. (1976) the signal was initiated in the upper part of Zone NN 11. This zone has its midpoint at 7.6 Ma, and therefore it is assumed that the signal was initiated midway between 7.6 and 6.6 Ma, at 7.1 Ma, which fits both HAQ's et al. (1976) data and the data presented in this study. Thus, the interval between the middle-late Miocene boundary and the signal is 4.9 Ma, the interval between the signal and sample 1 is 1.6 Ma and the interval from the middle-late Miocene boundary to sample 1 is 6.5 Ma (fig. 5). Further, if it is assumed that the influence from the two intervals (A)—(B) and (B)—(C) (fig. 5) are equal when the sequence represented by samples 1—13 was deposited, and that 100 % of the assemblage in samples 1—13 is derived from the intervals (A)—(B) and (B)—(C), then the percentage of *D. minutus* in samples 1—13 could be calculated to

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\frac{4.9 \cdot 28 + 1.6 \cdot 79}{6.5} = 40.6 \% \]

where 28 is the percentage mean value of the relative abundance of *D. minutus* in the DSDP cores before the initiation of the signal, and 79 is the corresponding value after the initiation of the signal in the DSDP cores. But, the late Miocene assemblage is 72 %, not 100 %, of the total assemblage in samples 1—13, thus

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72/100 \cdot 40.6 = 29.2 \% \]

This value (29 %) represents the percentage which *D. minutus* would occupy
in the redeposited assemblage if 72% of that assemblage has a late Miocene origin. The calculated value (29%) coincides well with the value obtained from counts in the Vera Basin Miocene (25%). Since these values are of the same magnitude the calculated value is considered to be consistent with the presented interpretation, which can be summarized as follows:

1. Marine sediments were deposited in the Vera Basin during late Miocene times.
2. The Vera Basin was temporarily isolated from the marine environment at least during the interval represented by samples 1—13.
3. The observed continuous occurrence of nannofossils during the isolated interval is most probably caused by redeposition from older strata.
4. The main part of the redeposited sediments and reworked nannofossils are late Miocene in age.
5. Marine conditions were re-established in the Vera Basin close to the Miocene-Pliocene boundary.

The interpretation that the Vera Basin was temporarily isolated from the world ocean would also explain why the NN 11—NN 12 boundary, as established by MÜLLER (1976), almost coincides with the Miocene-Pliocene boundary, since it can be expected to have reworked individuals of D. quinqueramus throughout the isolated interval. Further, the pronounced lower frequency of "obviously reworked" nannofossils in the "passage zone", from over 30% in sample 10 to only 1% in sample 14, is interpreted as due to changed current regimes which are likely to have occurred and influenced the pattern of sedimentation in the Vera Basin when it became reconnected to the ocean.

BENSON (1972) and VAN COUVERING et al. (1976) have suggested that an early Pliocene tectonic movement re-opened the Mediterranean to Atlantic Ocean waters. This event should coincide with the re-establishment of D. minutus as dominant species in the nannofossil assemblages. Since this event is observed in sample 14, it is considered to represent the early Pliocene.

**TAXONOMIC NOTES**

Two previously undescribed taxa are illustrated in plates I and II. One previously described taxon is recombined.

**New taxa**

*Genus Reticulofenestra* Hay, Mohler and Wade, 1966

*Reticulofenestra baqii* n.sp.

(plate I, figs. 1—4; plate II, fig. 10)

LATE MIocene-early Pliocene nannofossil biochronology

Holotype. — Plate I, figs. 1—4.

Type stratum and type locality. — Upper Miocene, Vera Basin, sample 11.

Derivation of name. — In honour of Dr. Bilal Ul Haq.

Description. — Reticulofenestra baqii is a small, elliptical reticulofenestrid with a small central opening, the distal and proximal shields being approximately of equal size and built of 40—50 crystal elements each. These narrow crystal rays are not distinguishable with a light microscope. A central collar may distally consist of coarse crystallites, but is thin in many specimens. The species is usually 3—5 μm in length. The length of the central opening is 1.0—1.5 μm.

Remarks. — Reticulofenestra baqii shows similarity to R. pseudoumbilica Gartern in possessing a central opening surrounded by a central collar and in having rather similar crosspolarized light images. Reticulofenestra baqii is distinguished from R. pseudoumbilica by its consistently smaller size and by the central opening being considerably smaller than that of R. pseudoumbilica.

Occurrence. — Reticulofenestra baqii was identified in late Miocene-early Pliocene deposits in the Vera Basin and in the same interval in the investigated DSDP cores, and has been observed to occur continuously from early Miocene (Zone NN 3?) to early Pliocene in DSDP site 116 at Rockall Bank.

Genus Sphenolithus Deflandre in Grassé, 1952

Sphenolithus verensis n. sp.
(plate II, figs. 4—6, 11—12)

Holotype. — Plate II, figs. 4—6.

Type stratum and type locality. — Upper Miocene, Vera Basin, sample 11.

Derivation of name. — After the Vera Basin.

Description. — The basal ring of spines, forming the proximal part of the individual, is obtuse and the spines are comparatively long. Perpendicular on each basal spine is a ridge attached to and directed parallel with the underlying spine. The distal part is made up of thin walls forming hollow cone-shaped elements pointed towards the median line of the sphenolith. These delicate structures give the impression of a rugged (spiny) outline when seen under crossed nicols. The sphenolith has a median extinction band when oriented parallel with the polarization directions, and the basal ring of spines are usually seen as extruded from the main part of the body. Usual height is 4—9 μm.
REMARKS. — In the light microscope *S. verensis* can be confused with *S. abies* DEFLANDRE, but can be distinguished from that species by its broader base and more irregular (spiny) outline. *Sphenolithus verensis* is not so pronouncedly or uniformly bright as *S. abies* under crossed nicols.

OCCURRENCE. — Observed in the late Miocene-early Pliocene in the Vera Basin and in the same interval in the investigated DSDP cores.

**New combination**

*Reticulofenestra gelidus* (GEITZENAUER) n. comb.

(plate I, figs. 7—9)


REMARKS. — Electron microscope studies of better preserved placoliths of this species show traces of a reticulate grillwork in its central opening, suggesting that it should be assigned to the genus *Reticulofenestra*.

OCCURRENCE. — Originally described from the late Pliocene in a Pacific subantarctic deep-sea core. This species has been observed in the late Miocene-early Pliocene of the Vera Basin and in the middle and late Miocene and early Pliocene in the DSDP site 116 at Rockall Bank.

**REFERENCES**


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Received April 20, 1978
Printed September 10, 1978
PLATES
PLATE I

Figs.
1—4 *Reticulofenestra baqii* n.sp. Holotype. Vera Basin, sample 11, 3000 X. (1) 0° to crossed nicols, (2) 45° to crossed nicols, (3) normal light, (4) phase contrast.

5—6 *Reticulofenestra pseudoumbilica* (Gartner) Gartner. Vera Basin, sample 11, 3000 X. (5) crossed nicols, (6) phase contrast.

7—9 *Reticulofenestra gelidus* (Geitzenauer) n.comb. Vera Basin, sample 20, 3000 X. (7) 0° to crossed nicols, (8) 45° to crossed nicols, (9) normal light.

10 *Discoaster quinqueramus* Gartner. DSDP 42A/375/1/1 (57—58 cm), 3000 X. (10) normal light.


12 *Dictyococcites minutus* (Haq) Haq. DSDP 42A/376/6/4 (140—141 cm), SEM micrograph 11800 X.
PLATE II

Figs.
1—3 *Sphenolithus abies* Deflandre. DSDP 4/25/4/1 (40—41 cm), 3000 ×. (1) 0° to crossed nicols, (2) 45° to crossed nicols, (3) phase contrast.

4—6, *Sphenolithus verensis* n. sp. 4—6, Holotype. 4—6, 12, Vera Basin, sample 11—12 11, 3000 ×. (4) and (12) 0° to crossed nicols, (5) 45° to crossed nicols, (6) phase contrast, (11) DSDP 42A/376/6/4 (140—141 cm), SEM micrograph 5800 ×.

7 *Amaurolithus tricorneclatus* (Gartner) Gartner and Bukry. DSDP 42A/375/1/1 (57—58 cm), 3000 ×. (7) normal light.

8 *Amaurolithus primus* (Bukry and Percival) Gartner and Bukry. Vera Basin, sample 19, 3000 ×. (8) normal light.

9 *Amaurolithus delicatus* (Gartner) Gartner and Bukry. Vera Basin, sample 17, 3000 ×. (9) normal light.

10 *Reticulofenestra bagii* n. sp. DSDP 42A/376/6/4 (140—141 cm), SEM micrograph 11600 ×.