Meded. Werkgr. Tert. Kwart. Geol. | vol. 24 (1-2) | pp. 41-57 | 1 tab., 4 figs | Leiden, June 1987

MOLLUSC BIOZONATION OF THE MIOCENE IN THE SOUTH-EASTERN NETHERLANDS AND CORRELATION WITH THE FORAMINIFERAL BIOSTRATIGRAPHY

by

B.C. Sliggers & R.J.W. van Leeuwen,
Rijks Geologische Dienst, Haarlem, The Netherlands

Sliggers, B.C., & R.J.W. van Leeuwen. Mollusc biozonation of the Miocene in the south-eastern Netherlands and correlation with the foraminiferal biostratigraphy. — Meded. Werkgr. Tert. Kwart. Geol., 24 (1-2): 41-57, 1 tab., 4 figs. Leiden, June 1987.

Miocene molluscan and foraminiferal faunas were studied in samples from bore-holes in the south-eastern part of The Netherlands. The biostratigraphy is presented and regional subdivisions of previously established zonations are proposed. Evaluation of the correlations clearly shows the extent to which the zonations are facies-dependent. This notion leads to a more accurate stratigraphic resolution and provides a base for paleo-environmental analysis.

B.C. Sliggers and R.J.W. van Leeuwen, Rijks Geologische Dienst, P.O. Box 157, 2000 AD Haarlem, The Netherlands.

Contents:

SAMENVATTING

Biozonering met behulp van mollusken van het Mioceen in zuidoost Nederland en correlatie met de biostratigrafie gebaseerd op foraminiferen.

In het begin van deze eeuw zijn op veel plaatsen in de Peel boringen geplaatst voor de Dienst der Rijksopsporing van Delfstoffen. Het mariene Mioceen bleek in dit gebied rijk aan mollusken. Deze fauna's werden in de loop van de tijd uitvoerig bestudeerd, maar dit onderzoek heeft niet tot een biostratigrafie van het Mioceen geleid.

In de afgelopen jaren is in opdracht van de Rijks Geologische Dienst een aantal boringen gezet in het zuidoosten van Nederland. Hierdoor kwam materiaal ter beschikking voor een regionaal biostratigrafisch onderzoek. De hoofdlijnen van de molluskenstratigrafie werden reeds vastgelegd in de studie van boring Broekhuizenvorst (van Rooyen et al., 1984), waar in het Mioceen drie zones werden onderscheiden, de Mol F, de Mol G, en de Mol H Zone. De regionale indeling kan worden beschouwd als een uitbreiding naar oudere afzettingen van de voor Nederland door Spaink (1975) gedefinieerde zonering, die de mariene sedimenten omvat van het bovenste Mioceen tot het onderste Pleistoceen.

In deze studie zijn de resultaten weergegeven van het vervolgonderzoek, dat naast de recent geplaatste boringen ook een aantal andere boringen in het zuidoosten van Nederland omvat. De meeste boringen werden ook op foraminiferen onderzocht en beide zoneringen zijn met elkaar vergeleken.

Uit het molluskenonderzoek blijkt dat de voor Broekhuizenvorst opgestelde zonering regionaal toepasbaar is en dat zowel de Mol F, als de Mol H Zone kunnen worden onderverdeeld. Het interval dat door de zonering van Spaink wordt bestreken, is in dit gebied zelden marien ontwikkeld. Desondanks wordt de zonering hier behandeld om nieuwe inzichten naar voren te brengen en de correlaties met de foram-zonering te bespreken.

In de Mol F Zone zijn vijf subzones onderscheiden, maar alleen de oudste, de Mol F 5, is over het gehele gebied aanwezig. De faunistische informatie en de geografische verbreiding van de jongere subzones doen vermoeden, dat zij ten dele mogelijk facies vertegenwoordigen, die naast elkaar bestaan hebben. Als dit het geval is, is de Mol F 4, die alleen in het zuidoosten voorkomt, hoogstwaarschijnlijk een ondiep marien equivalent van (een deel van) het Mol F 1-3 interval, dat in zijn verbreiding tot het noordwesten beperkt is. In de Mol F 4 worden vijf acme-zones onderscheiden.

Een formele onderverdeling van de Mol H is nog niet gedefinieerd, maar er is in principe een tweedeling mogelijk die een regressieve ontwikkeling lijkt te weerspiegelen. In het bovenste deel van de zone is een facies onderscheiden, die alleen op de Peelhorst gevonden is (Mol H 1A). De fauna's worden hier gekenmerkt door mollusken, die op afzettingen in een kustnabij en sterk door zoet water beïnvloed milieu wijzen.

Een biostratigrafie op basis van foraminiferen werd voor het Neogeen van Nederland opgesteld door Doppert (1980). In het zuidoosten van Nederland blijkt het Mioceen verder onderverdeeld te kunnen worden: in zowel de FC 2 Subzone, als de FD Zone worden twee eenheden onderscheiden.

In een deel van de miocene afzettingen komen geen kalkige fossielen voor en het is nog niet duidelijk waaraan dit moet worden toegeschreven.

De correlatie van de twee zoneringen toont aan, dat beide in hoge mate facies-afhankelijk zijn. De stratigrafische bruikbaarheid van mollusken neemt af in de richting waarin het bekken dieper werd (NW) en de bruikbaarheid van de foraminiferen wordt juist geringer in het ondiepe bereik. Alleen de gelijktijdige bestudering van mollusken en foraminiferen leidt tot een betrouwbaar stratigrafisch kader in dit gebied. Bovendien legt dit onderzoek de basis voor paleooecologische interpretaties.

INTRODUCTION

In the period between 1903 and 1916 numerous bore-holes were made by the Dienst der Rijksopsporing van Delfstoffen (ROVD) in the Peel and Achterhoek regions in order to make an inventory

of the mineral resources in the south-eastern and eastern parts of The Netherlands, respectively. Most of these holes yielded very rich molluscan faunas of Miocene age, and the most common species were identified by Molengraaff & van Waterschoot van der Gracht (1913). The occurrence of large quantities of Miocene shells in bore-holes and exposures in these parts of the country was discussed in the final report of the Rijksopsporing van Delfstoffen (ROVD) (1918). Special methods had been developed to collect large samples, and occasionally more than a cubic metre of shell material was collected from a single shell layer. Thus, the Peel region in particular became one of the most important areas in north-western Europe for the study of Miocene molluscs. However, in spite of the huge collections available, stratigraphic correlations were only made with the Sables Noirs of the Antwerp area and the Glimmerton in Germany.

During World War II, interest in the collections revived and the molluscs were studied by Burgers (1942), IJspeert (1942), Bouma (1943), van Voorthuysen (1944), Tesch (1946), Beets (1950), and Heering (1950). Their efforts have proved to be of purely palaeontological interest, because none of these authors used a biostratigraphic approach. Furthermore, they applied only general chronostratigraphic terms (e.g. Upper and Middle Miocene) based on the interpretations made by Kautsky (1925) on the basis of the faunal lists published in 1913.

The study of Miocene molluscs was continued in the nineteen fifties by Spaink, whose research yielded a provisional checklist of the molluscs stored in the collections of the Geological Survey (Spaink, 1960). A biostratigraphically oriented revision of the collection turned out to be impossible. The geographical information on the sample labels was far too incomplete for this purpose and the samples appeared to cover extremely large vertical intervals, occasionally exceeding fifty metres. Consequently, the molluscan stratigraphy had to rely on interpretations made by specialists in other countries (Glibert & de Heinzelin, 1955; Hinsch, 1952; Rasmussen, 1966; Sorgenfrei, 1958). Because an alternative terminology was lacking, stage names used in north-western Germany were introduced in The Netherlands.

Recently, however, bore-holes performed in the south-eastern part of The Netherlands for Neogene correlation projects, have provided material for a more biostratigraphically oriented study of the Miocene faunas. An attempt was made to apply the biostratigraphy defined by van den Bosch et al. (1975) for the Achterhoek, but its applicability turned out to be limited in the south-eastern region. This meant that a new regional biostratigraphic framework had to be developed. Preliminary results obtained in the Broekhuizenvorst bore-hole were published by Sliggers (in van Rooyen et al., 1984). Subsequent research has resulted in a refined biostratigraphy of the Miocene deposits in the south-eastern part of The Netherlands that may prove to be of more than regional interest. The present study is based on recently drilled bore-holes but includes a selection of older material (table 1; figs 1 and 3). For most of the sites the foraminiferal content was studied as well, and an attempt was made to correlate the respective zonations.

REGIONAL BIOSTRATIGRAPHY

The regional molluscan stratigraphy of the Miocene was compiled as a sequel to the biozonation published by Spaink (1975), which covers the later part of the Cenozoic of The Netherlands starting from the uppermost Miocene. The foraminiferal zonation for the marine Neogene and Lower Pleistocene was established by Doppert (1975, 1980). Molluscan zones are indicated by the prefix

BORE-HOLE	CODE	FORAM	Mol D	Mol E	Mol F 1, F 2	Mol F 3	QUASI BARREN INTERVAL	Mol F 5	BARREN INTERVAL	Mol G	Mol H	
1. St. Michielsgestel	45D/61	X	250.00-520.00									
2. Uden	45H/74		38.50- 46.75		46.75- 57.75	57.75- 76.10	76.10-140.00					
3. Zeeland	45H/75		29.00- 52.00		52.00- 61.00	61.00- 80.00	80.00- 87.00					
4. Cuyck	46A/47	X	30.00- 66.00	66.00- 75.00	74.00- 81.00	81.00- 97.00	97.00-113.00	113.00-126.00	126.00-140.00			
5. Beugen	46D/220	X	36.00- 57.00	57.00- 66.00	66.00- 72.00	72.00- 84.00	84.00-140.00					
6. Boxmeer	46D/190	X				45.00- 53.00	53.00- 73.00	73.00- 78.00	78.00-132.17			
7. Overloon	52B/185	X				56.00- 77.00	77.00-140.00					
8. Ballonzuil	52B/184	X					52.50- 92.00	92.00-114.00	114.00-146.50	146.50-180.50	180.50-200.00	
9. Liessel	52C/26	X						100.00-110.00	110.00-135.00	135.00-180.00	180.00-192.00	
10. Broekhuizenvorst	52E/114	X						94.00-107.00	107.00-145.00	145.00-197.00	197.00-223.00	
11. Nederweert	58A/62	X						495.00-540.00	540.00-720.00	720.00-765.00	765.00-855.00	
BORE-HOLE	CODE	FORAM					Mol F 4	Mol F 5	BARREN INTERVAL	Mol G	Mol H	Mol H 1A
12. Californië	52G/198	X					92.30-119.50	119.50-168.50	168.50-196.50	196.50-216.00	216.00-250.00	
13. Beeringen	52B/8									80.00-119.00	119.00-170.00	119.00-124.00
14. Maasbree	58B/4	X									100.00-180.00	100.00-160.00
15. Uitwateringskanaal	58B/35										70.40-120.40	70.40-100.40
16. Neer	58B/39										45.90- 63.00	45.90- 63.00
17. Baarlo	58E/115										100.00-170.00	100.00-170.00
18. Kessel	58E/199						22.50- 40.00	40.00- 87.50	87.50-100.00	100.00-120.00	120.00-207.00	
19. Belfeld	58E/91						28.00- 43.00					
20. Heidhausen	58F/52	X					100.00-135.00	135.00-173.00	173.00-210.00		210.00-255.00	
21. Roosteren	60A/235	X					262.00-286.00					
22. Broeksittard	60D/1033	X					252.00-281.00	281.00-293.00				
23. Obspringen	60B	X					264.00-318.00	318.00-376.00	376.00-387.00	387.00-430.00		
24. Nieuwstad	60A/373						265.50-301.50					
25. Straeten I	60G							451.00-455.00				

Table 1. Survey of the mollusc stratigraphy in the investigated bore-holes (intervals in metres below surface). The sites are coded according to the conventions of the Geological Survey of The Netherlands. Crosses indicate bore-holes included in the foraminifer study.

Mol and foraminiferal zones by the letter F. The (sub)zones are alphabetically and numerically coded from top to bottom.

The detailed molluscan research contributed considerably to the notion that in Spaink's earlier zonation time relations were overestimated and environmental aspects were hardly considered. The newly gained insights call for a re-evaluation of the biostratigraphy of younger deposits. This purpose is probably best served by regional studies, and it is evident that simultaneous scrutiny of foraminiferal faunas will be important.

Although in general marine deposits of Pliocene and Pleistocene age do not occur in the south-eastern part of The Netherlands, the complete biostratigraphy will be discussed in order to comment on general stratigraphic problems.

PLIOCENE AND EARLY PLEISTOCENE RECORDS

Mol A (*Hydrobia ulvae* and *Mya arenaria* Zone), and Mol B (*Serripes groenlandicus* and *Yoldia lanceolata* Zone)

The majority of the species in the Mol A assemblage point to boreal conditions and are still represented in today's North Sea fauna. When Spaink (1975) established these zones, Mol A and Mol B were interpreted as correlates of the Tiglian and Pretiglian stages, respectively. This assumption must be rejected, because there is evidence showing that these assemblages alternate within the Early Pleistocene. Mol A is now considered to represent the warm phases, whereas the Mol B fauna is seen as typical of the cold intervals (Meijer, 1986). A tripartite division of the Lower Pleistocene marine sequence (cold-warm-cold) was established. After the youngest cold phase, conditions shifted to non-marine sedimentation.

The unit encompassing the formerly separate zones correlates with foraminiferal subzone FA 1, which is characterized by an oligotypical association dominated by *Elphidiella hannai* (Cushmann & Grant, 1927) and *Cribrononion excavatum* (Terquem, 1875). The Elphidium oregonense Zonule, which locally marks the lower boundary of the foraminiferal subzone, coincides with the first occurrence of Mol B faunas. The FA 1 Zone is considered to be of Pretiglian age. Contrary to the mollusc record, the alternation of warm and cold phases is not expressed in the foraminiferal associations.

Pleistocene marine deposits were not found in the investigated area.

Mol C (*Nassarius propinquus* and *Lentidium complanatum* Zone)

The molluscs of the Mol C Zone represent a fully marine to sublittoral facies, in which *Nassarius, Cardium, Spisula*, and *Lentidium* are common. The status of this zone is rather uncertain and it is doubtful whether it can be recognized throughout The Netherlands. For the south-western part of the country correlation between Mol C and part of foraminiferal subzone FA 2, which is considered to be of Late Pliocene age, is well established.

Typical Mol C assemblages were not found in the investigated area. Here, species previously thought to be restricted to this zone are found in assemblages bearing an overall resemblance to those of Mol D and therefore assigned to the latter zone. Elsewhere, typical Mol C elements (e.g. *Eula, Potamides*) were recently found in Mol A faunas as well and without signs of reworking. These observations underline the need for reconsideration of the definition of this zone.

Mol D (*Turritella triplicata* and *Yoldia semistriata* Zone)

Over large parts of The Netherlands, two subzones can be distinguished. The upper or D 1 Subzone is characterized by the dominance of *Chlamys opercularis* (Linné, 1758) (= *Aequipecten opercularis*), whereas *Chlamys gerardi* Nyst, 1835 predominates in the D 2 assemblages (fig. 2). In the south-western part of the country transitional faunas occur frequently in the subzonal boundary interval. Typical Mol D 1 faunas correlate with the FA 2 Subzone in that area, and well-developed D 2 has its counterpart in the FB Zone (Early Pliocene).

Subdivision of Mol D is not possible in the subject area. Mol D represents the youngest marine sediments, corresponding to foraminiferal zones FA 2 and FB. As can be seen from fig. 1a, Pliocene marine sediments are only found North-West of the area under study.

MIOCENE RECORD

Mollusc zonation

Mol E (*Arcoperna sericea* and *Chlamys tigerinus* Zone)

The Mol E Zone, as established by Spaink, covers the transition between the Miocene and the Pliocene. It is characterized by a poor, badly preserved, and rather non-diagnostic macrofauna with a substantial portion of non-molluscs (*Ditrupa, Lingula*). This zone is only present in the Cuyk and Beugen bore-holes (fig. 1b).

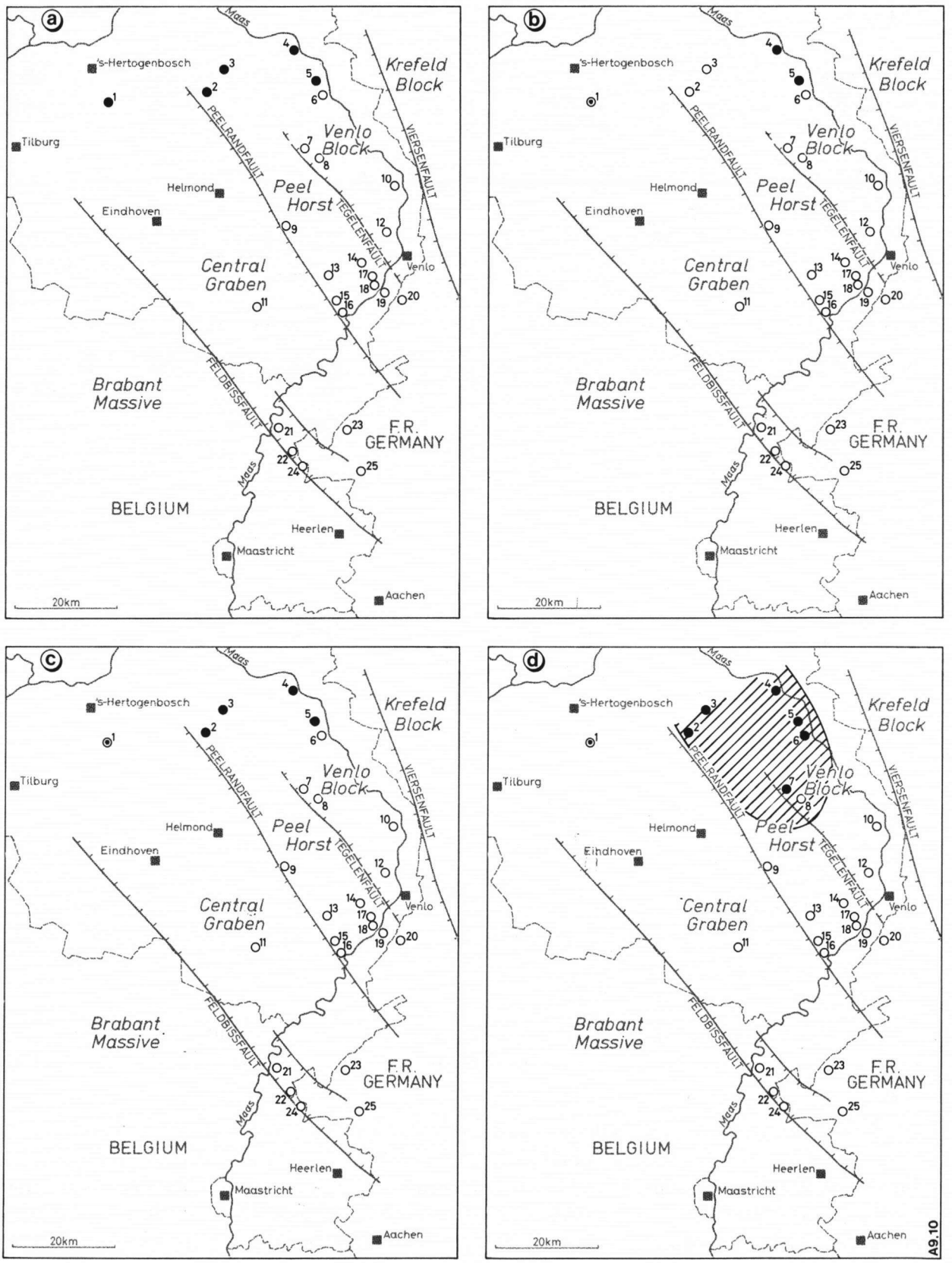
Mol F (*Astarte omalii peelensis* and *Hinia syltensis* Zone)

The faunas of the Mol F Zone constitute the main subject of the present study. A description of the zone can be found in van Rooyen et al. (1984). As shown in fig. 2, it is characterized by a large number of species and in particular many *Astarte* species are restricted to this zone. Warm-water index species, typical for the conventional Middle Miocene, are virtually absent. Many samples show remarkable changes within the F Zone, and subdivision is now possible. The subzones are essentially defined as Oppel-zones.

Mol F 1 (*Astarte syltensis* and *Astarte omalii* var. Subzone) and Mol F 2 (*Venus imbricata* var. and *Astarte beyschlagi* Subzone) have many species in common, but there are also marked differences. The first appearance of *Aclis walleri* Jeffreys, 1867 is recorded for Mol F 1 and *Astarte syltensis* Ravn, 1907 is restricted to this subzone. *Venus imbricata* Sowerby, 1826 var. and *Scalaspira eximia* (Beyrich, 1856) occur exclusively in Mol F 2 and many species disappear at its upper boundary.

Cardita laevicostata weingaertneriana Gripp, 1940 is limited to Mol F 3 (Cardita laevicostata weingaertneriana and Trivia westfalica Subzone), and *Venus multilamella* (Lamarck, 1818), *Anadara diluvii* (Lamarck, 1805), *Astarte fusca incrassata* (Brocchi, 1814), and *Turritella subangulata* (Brocchi, 1814) have their last occurrence in this subzone.

Fig. 1. Map of the south-eastern part of The Netherlands, showing major faults and the location of the investigated bore-holes (numbers refer to table 1). Solid circles show the presence and open circles the absence of the relevant molluscan (sub)zone. Dotted circles indicate that the interval was either not studied or not reached: (a) Mol D Zone; (b) Mol E Zone; (c) Mol F 1-F 2 Subzones; (d) Mol F 3 Subzone. The hatched area indicates the distribution of poor and indifferent faunas below Mol F 3.


a
b
c
d
Maas
's-Hertogenbosch
Tilburg
Helmond
Eindhoven
Venlo
Aachen
Heerlen
Maastricht
Krefeld Block
Venlo Block
Peel Horst
Central Graben
Brabant Massive
PEELRANDFAULT
VIERSENFAULT
TEGELENFAULT
FELDBISSFAULT
F.R. GERMANY
BELGIUM
20km
A9.10

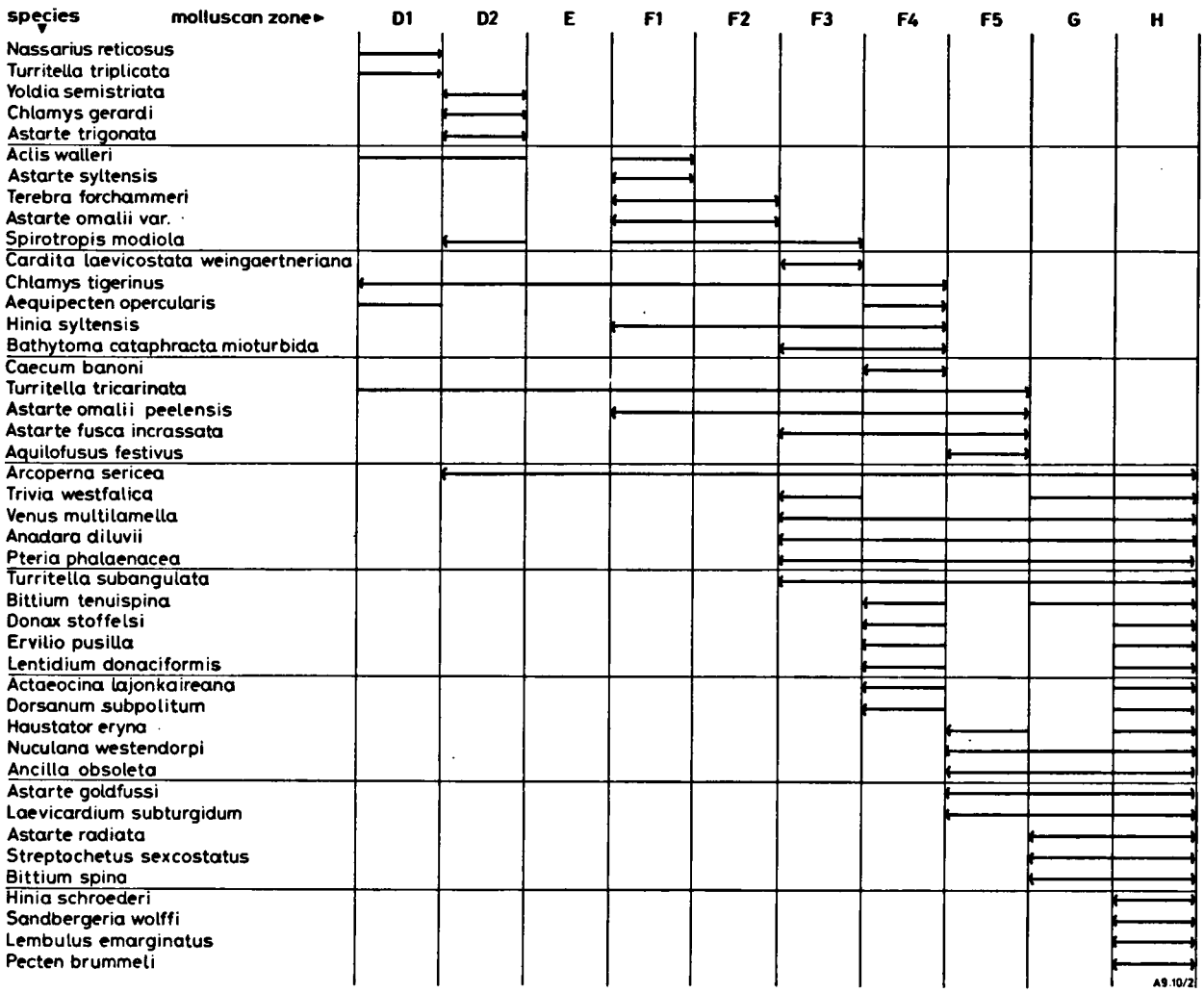


Fig. 2. Ranges of selected mollusc species in the Miocene of the investigated bore-holes.

Sediments of the Mol F 1-3 interval are found in the north-western part of the subject area, East of the Peelrand fault (fig. 1c and d). Mol F 3 faunas were recognized in the Asten 1 bore-hole (52C/142) in the Central Graben. Because the recovered material has not yet been studied completely, it was not included in the present study.

The Mol F 1-3 complex is underlain by sediments that are non-fossiliferous or yield a non characteristic macrofauna. Below these assemblages are present that can be assigned to the Mol F 5 Subzone.

Mol F 4 (*Caecum banoni* and *Pteria phalaenacea* Subzone) is found in a very restricted area, where non-marine deposits dominate (fig. 3a). Here, Mol F 4 comprises the youngest marine deposits. It directly overlies the Mol F 5 Zone and is characterized by an assemblage indicative of a brachyhaline environment. The association suggests a salinity between 18 and 30‰. In the four southernmost bore-holes (Roosteren, Broeksittard, Obspringen, and Nieuwstad), five zonules have been distinguished; these are characterized in order of increasing age by acmes of

Lutetia nitida (Reuss, 1867) — zonule F 4-1
Aequipecten opercularis (Linné, 1758) — zonule F 4-2
Glycymeris obovata baldii Glibert & van de Poel, 1965 — zonule F 4-3
Bittium tenuispina Sorgenfrei, 1958 — zonule F 4-4
Acteocina lajonkaireana (de Basterot, 1825) — zonule F 4-5.

Zonule 2 is furthermore characterized by the first appearance of *A. opercularis* and the last occurrences of *Dorsanum subpolitum* d'Orbigny, 1852, *Lentidium donaciformis* (Nyst, 1836), and *Donax stoffelsi* (Nyst, 1845).

The assemblages indicate deposition in the higher part of the sublittoral zone with water depths to about ten metres. A clean sandy substrate is suggested and the acmes of *Bittium* point to a seaweed vegetation. Species indicative of a deeper environment are present in the lowermost unit (*Astarte waeli* Glibert, 1957, *A. omalii peelensis* Spaink, 1968, *A. angulata* Lehmann, 1885). This suggests a regressive trend within Mol F 4 (Sliggers, 1986). The zonules become less distinct toward the North-West.

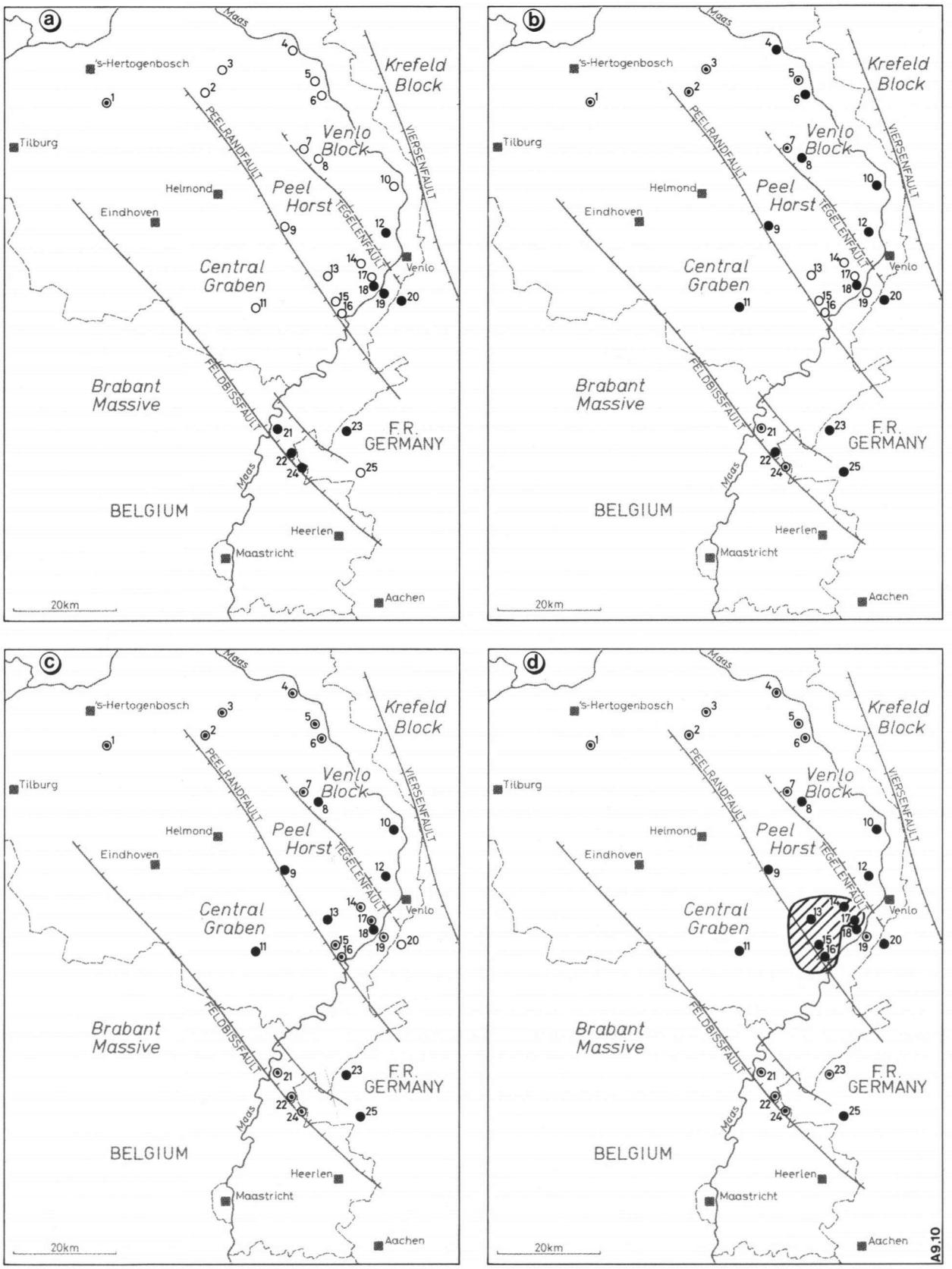
Mol F 5 (*Nuculana westendorpi* and *Astarte fusca incrassata* Subzone) is a conspicuous unit characterized by the presence of Late Miocene Astartidae and the last occurrences of *N. westendorpi* (Nyst, 1839) and *Haustator eryna* (d'Orbigny, 1852). It occurs in both the north-western and south eastern parts of the investigated area (fig. 3b). Mol F 5 is separated from the older Mol G by an interval without molluscs.

Mol F 1 shares a number of species with the assemblages of the Syltian in north-western Germany, among them *A. syltensis*. Most of the other *Astarte* species used to define molluscan zones in north-western Germany (Hinsch, 1986), were not found in the area under investigation [e.g. *Carinastarte vetula* (Philippi, 1847), *C. reimersi* (Semper, 1907), *C. rollei* (Semper, 1907), *Astarte gleuei* Wollemann, 1906]. Nevertheless, there seems to be much similarity between Mol F 3 and the NW German Langenfeldian faunas. *Sipho solitarius* (Philippi, 1845), a species typical of the Lüneburgian Substage of the Langenfeldian, only occurs in Mol F 4. Up to now *N. westendorpi* and *H. eryna* were considered to become extinct at the end of the Reinbekian and Hemmoorian respectively. However, after their co-occurrence with Late Miocene Astartidae was observed in The Netherlands, the peculiar assemblage was recognized in north-western Germany as well. There it led to the introduction of a new substage, called the Levensauian (Hinsch, op. cit., see also Hinsch, 1987), transitional between Reinbekian and Langenfeldian.

Mol G (*Eudolium dingdense* and *Aquilofusus festivus* Zone)

Mol G, which was defined by Sliggers in van Rooyen et al. (op. cit.), comprises the ranges of a number of species, i.e. *Streptochetus abruptus* (Beyrich, 1856), *Eudolium dingdense* Anderson, 1964, *Hinia catullii* (Bellardi, 1882), *H. cavata* (Bellardi, 1882), *Cerithiella genei* Bellardi & Michelotti, 1840, *Amyclina banatica* (Boettger, 1901) and *Aquilofusus festivus* (Beyrich, 1856). Except for these species, the assemblages show much resemblance to the faunas of Mol H.

In the South-West the Mol G Zone was generally reached, contrary to the North-West of the investigated area (fig. 3c). Mol G is not represented in the Heidhausen bore-hole, where a quasi-barren interval separates Mol F 5 from Mol H. The faunas of Mol G show a strong resemblance to the mollusc associations of the Reinbekian in north-western Germany.


a
b
c
d
Maas
's-Hertogenbosch
Tilburg
Helmond
Eindhoven
Krefeld Block
Venlo Block
Peel Horst
Central Graben
Brabant Massive
PEELRANDFAULT
TEGELENFAULT
VIERSENFAULT
FELDBISSFAULT
Venlo
F.R. GERMANY
BELGIUM
Heerlen
Maastricht
Aachen
20km
A9.10

Mol H (*Haustator eryna* and *Hinia schroederi* Zone)

This zone was described by Sliggers (in van Rooyen et al., op. cit.). Many species are restricted to Mol H, the most prominent being *Hinia schroederi* (Kautsky, 1925), *Lembulus emarginatus* (Lamarck, 1819), *Ostrea digitalina* Dubois de Montperreux, 1831, *Conus clavatulus* d'Orbigny, 1852, *Rissoina obsoleta* (Partsch, 1856), *Clavatula boreoromana* (Kautsky, 1925), *Pecten brummeli* Nyst, 1864 and *Ringicula ravni* Sorgenfrei, 1958. The last-mentioned two species are only significantly represented in the Asten-1, Broekhuizenvorst, Nederweert, Uitwateringskanaal, and Kessel bore-holes. They are restricted to the lower part of Mol H and indicate a deeper environment than in the higher parts of Zone Mol H.

A regressive trend is also suggested by the presence of species typical of a brachyhaline environment in the upper part of the zone. These assemblages are characterized by the common occurrence of *L. emarginatus, H. eryna, Dorsanum boreobaccatum* Kautsky, 1925, *Loripes fragilis* (Philippi, 1836), *Microloripes niveus* (von Eichwald, 1830) and *Dosinia basteroti* (Agassiz, 1845) (Mol H 1).

Locally, this aspect is so strongly developed that the facies was distinguished as Mol H 1A. The faunas reflect deposition in a shallow marine environment with a substantial influx of freshwater. It is interesting to note that the special fauna of Mol H 1 is restricted to the Peel Horst (fig. 3d). This suggests that the area was either shallower than the surrounding parts of the basin or more strongly influenced by run-off.

The presence of *Hydrobia, Nerita, Stenothyra, Bullia, Dreissena, Amiantis, Corbula*, and *Lentidium* in the most pronounced brachyhaline faunas is striking, since they were only known from localities in the Aquitaine and Vienna basins. The resemblance to the southern Miocene faunas suggests that the connection through the Calais Strait continued to exist after it was opened in the Early Miocene.

The Mol H assemblages resemble the faunas of the Hemmoorian in north-western Germany. The subdivision into a brachyhaline upper part and an euhaline lower unit defines the Oxlundian and Behrendorfian substages in that area.

None of the samples studied yielded mollusc faunas traditionally considered as lowermost Miocene ("Vierlandian"). Research on the rich associations collected by the ROVD is planned for the near future. The Oligocene and probably Miocene gastropods from the Peel region were discussed by Beets (1950).

Foraminiferal zonation and correlations

In the south-western part of The Netherlands Mol E corresponds to foraminiferal subzone FC 1, which represents the uppermost Miocene. This relationship could not be substantiated in the investigated area. The sediments assigned to Mol E yield a poor foraminiferal fauna. *Bolboforma*, thought to belong to the Algae (Chrysophyta) (von Daniels and Spiegler, 1974; Spiegler, 1987), occurs in low numbers at Cuyck, which suggests that the interval should be correlated with the older FC 2 Subzone. This is not unlikely because, in our opinion, the general features of Mol E are determined mainly by the state of preservation of the fauna. Leaching of sediments in a period of emergence could

Fig. 3. Map of the south-eastern part of The Netherlands, showing major faults and the sites of the investigated bore-holes (for symbols, see fig. 1): (a) Mol F 4 Subzone; (b) Mol F 5 Subzone (the distribution of the barren interval between Mol F 5 and Mol G is identical, except that it is absent in holes 20, 23, and 25); (c) Mol G Zone; (d) Mol H Zone (encircled area shows the distribution of the Mol H 1A facies).

explain the restriction of the Mol E Zone to Cuyk and Beugen and its absence more to the North-West (fig. 1b).

Correlations within the Mol F-H interval are shown schematically in fig. 4. Sediments assigned to Mol F yield a foraminiferal fauna typical of the FC 2 Subzone. The associations are characterized by the almost continuous presence of *Elphidium antoninum* (d'Orbigny, 1846) and the abundance of flattened *Bolboforma* species. Planktonic Foraminifera are scarce and dextrally coiled *Neogloboquadrina* predominate.

In the north-western part of the subject area, a subdivision into two parts can be made in the FC 2 Subzone. The upper part (FC 2A) is characterized by high frequencies of *Trifarina angulosa*

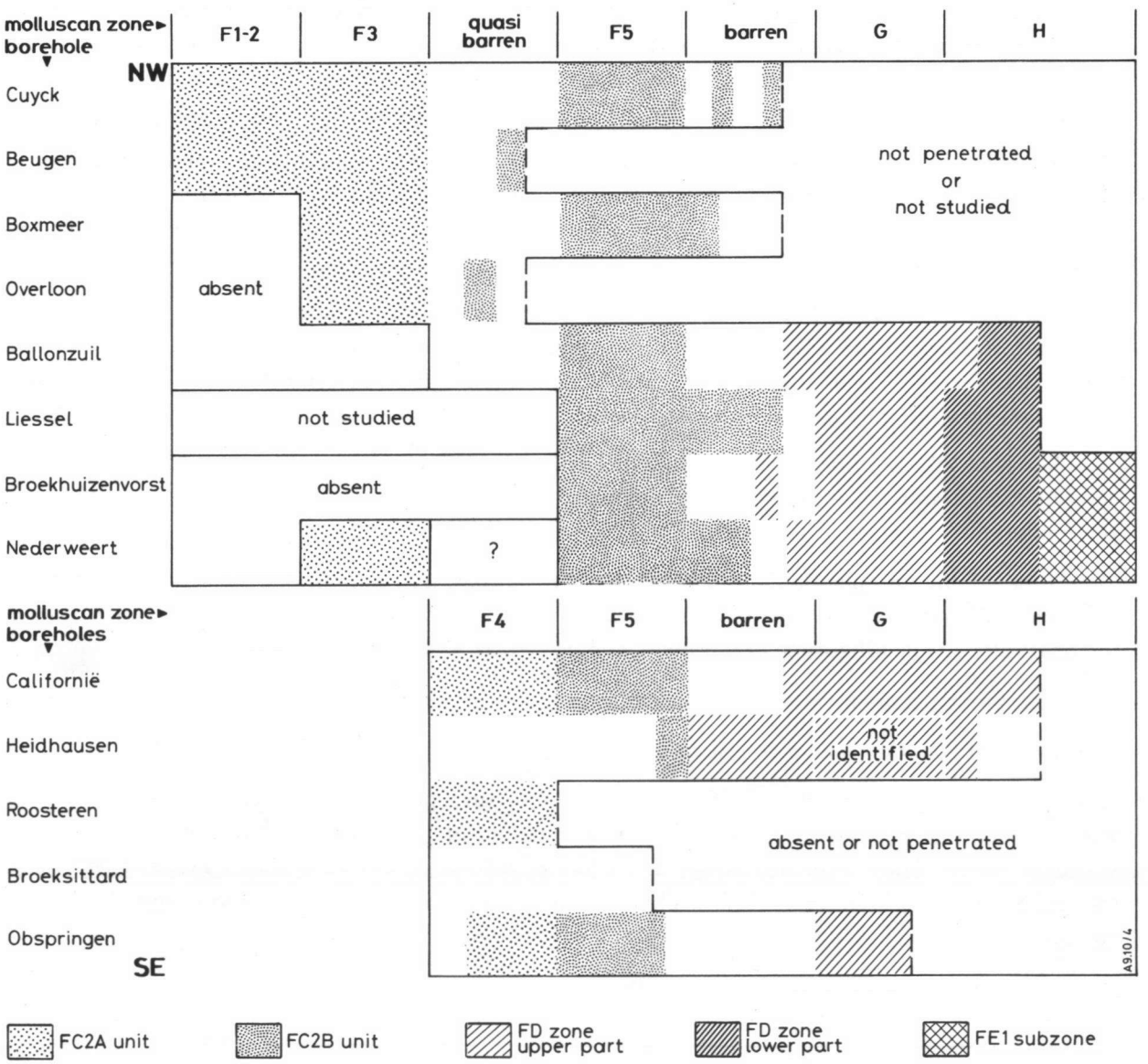


Fig. 4. Diagram illustrating the correlations between the molluscan and the foraminiferal zonations. The symbols used for the foraminiferal zones are explained in the legend. Intervals without Foraminifera or with an inconclusive fauna are indicated by open spaces.

(Williamson, 1858). The *Bulimina* assemblages are dominated by *B. aculeata* d'Orbigny, 1826, and *B. elongata* d'Orbigny, 1846 occurs only sporadically. The lower unit (FC 2B) is marked by the dominance of a small, rather smooth or finely rugose *Uvigerina*, provisionally labelled *U. parkeri* Karrer, 1877. This species accounts for more than fifty percent of the fauna in some samples, but it is virtually absent in the younger strata. *B. elongata* is the most abundant *Bulimina* species, and *B. aculeata* is almost absent. The units are generally separated by an interval in which Foraminifera are rare or absent. Similar horizons are occasionally present within the FC 2B. The existence of a level with poorly developed faunas was not observed in the Nederweert bore-hole, but its occurrence may have been obscured by inaccurate sampling procedures. A barren interval occurs between the FC 2 and the FD zones. In this part of the area FC 2A corresponds to the Mol F 1-3 interval. Mol F 5 consistently correlates with part of the FC 2B. The vertical extension of the FC 2B unit exceeds that of Mol F 5, and samples without characteristic molluscs, collected both below and above Mol F 5, sometimes contain a FC 2B fauna.

The FC 2 Subzone is more difficult to subdivide in the south-eastern part of the region, where the molluscs show a different succession. Results of the foraminiferal analysis of material from the Californie and Heidhausen bore-holes were compiled by Doppert (in Hager, 1981), but the FC 2 had not been subdivided at that time.

FC 2B can be easily recognized in Californie, where it is separated from the FD Zone by a barren interval. The molluscs indicate Mol F 5. The Mol F 4 interval contains few *T. angulosa*, and *U. parkeri* is missing. *B. aculeata* is a common constituent of the faunas and *B. elongata* is virtually absent. These observations suggest that Mol F 4 correlates with FC 2A.

At Heidhausen, the marine deposits corresponding to Mol F, have been assigned to FC 2, but the faunas are poorly developed. FC 2B can be identified in one sample only, situated immediately above the FC 2/FD boundary, where molluscs indicate Mol F 5. Upward, Foraminifera become extremely rare and subdivision of the FC 2 is no longer possible. *U. parkeri* is intermittently present up to 118 metres below the surface and *T. angulosa* is completely absent. Single specimens of the mentioned *Bulimina* species are found. The mollusc faunas remain characteristic for Mol F 5 up to 135 metres, however, and the overlying deposits are assigned to Mol F 4.

Within the Mol F/FC 2 interval, the foraminiferal record becomes less conclusive toward the South-East. The stratigraphical applicability of the molluscs is reduced to some degree toward the north-western part of the region, where intervals without diagnostic species could still be classified by means of Foraminifera. In view of the general paleogeography (Zagwijn & Doppert, 1978), these trends are evidently the expression of a northward deepening of the depositional environment.

Similar results were obtained in the south-eastern part of the Central Graben. The Roosteren bore-hole reaches only into the Mol F 4 deposits. The sediments contain a characteristic FC 2 assemblage. *U. parkeri* is absent and *T. angulosa* is almost continuously present, although in fairly low numbers. *B. aculeata* occurs and *B.elongata* is missing. Accordingly, the sediments were assigned to FC 2A.

Correlations are essentially the same in the Obspringen bore-hole. The uppermost part of the Mol F 4 Subzone (260-295 m below surface) contains a FC 2 fauna in which diagnostic species for the subunits are lacking. Foraminifera are extremely rare in the uppermost sediments. Downwards the faunas are dominated by *Ammonia beccarii* (Linné, 1758), a species indicative of a near-shore environment, but not providing stratigraphical information. This species remains an important constituent of

the faunas occurring between 295 and 318 metres. In this interval, covering the lower part of Mol F 4, *T. angulosa* is intermittently present in low frequencies and *U. parkeri* is absent. *Bulimina* species are rare, but *B. aculeata* is more common than *B. elongata*. A significant change in the foraminiferal faunas is observed at 318 metres, coinciding with the Mol F 4/F 5 boundary. *B. elongata* becomes one of the most frequent species and typical FC 2A species are absent. *U. parkeri* is intermittently present in low abundances. Foraminifera are almost absent in the lower part of the Mol F 5 and both fossil groups are missing between 379 and 387 metres.

In Broeksittard, the Mol F 4/F 5 interval has a rather inconclusive foraminiferal fauna. Subzone FC 2 was positively identified at depths between 259 and 274 metres, but a more precise stratigraphic position cannot be given. The associations of this interval are alternately dominated by *A. beccarii*, *Cibicides* spp., and Polymorphinidae. *T. angulosa* is absent and single specimens of the other diagnostic species were found. Foraminifera occur up to 253 metres, but the faunas are almost exclusively composed of *A. beccarii* and typical FC 2 elements are absent. Foraminifera are absent between 274 and 280 metres, and the *Ammonia* facies reappears between 280 and 295 metres.

Summarizing we may conclude that the Mol F 1/F 4 interval corresponds to FC 2A and that Mol F 5 has its counterpart in the FC 2B unit. There is a possibility that Mol F 4 is a shallow-water equivalent of at least part of the Mol F 1/F 3 interval. The major units in the deeper parts of the basin are separated by an interval poor in calcareous fossils. The counterpart of this interval among the deposits in the south-eastern part of the area has not yet been identified with certainty.

Although the FC 2 Subzone was traditionally placed in the Late Miocene (e.g. van Staalduinen et al., 1979), Herngreen's recent findings suggest that it extends into the formal Middle Miocene (Herngreen, 1987).

The Mol G-H interval correlates with part of the FD Zone, which is easily recognized by the abundance of *Asterigerina staeschei* ten Dam & Reinhold, 1941. Foraminifera are absent from the upper part of the barren interval between Mol F and Mol G, but FD faunas occur intermittently in the lower part, which suggests that the environment was too deep to be favourable for molluscs. The local absence of Foraminifera is still unexplained. It may be of primary origin, but it might also be a result of decalcification. A deeper facies could also account for the apparent absence of Mol G in Heidhausen. It is noteworthy that this is the only bore-hole in which there is no barren interval between the FC 2 and FD zones. Lithostratigraphic correlations based on gamma-ray log characteristics (Zagwijn, pers. comm.) indicate that the upper part of the FD Zone in Heidhausen corresponds with the carbonate-free sediments in the North-West.

A subdivision can usually be made in the FD Zone. The upper part is characterized by the common or frequent occurrence of *Uvigerina* species belonging to the *U. semiornata*-group as defined by von Daniels & Spiegler (1977). The lower part is characterized by the consistent presence of *U. tenuipustulata* van Voorthuysen, 1950, a species limited to the upper part of the Hemmoorian stage in north-western Germany.

The Mol G/H boundary coincides with the last occurrence datum of *U. tenuipustulata* in the north-western part of the region, except in the Ballonzuil bore-hole where its disappearance occurs at a stratigraphically lower level. *U. tenuipustulata* is generally absent in the south-eastern sites. At Californie, single specimens occur intermittently within the Mol G-H interval, but their rarity precludes stratigraphic interpretation. The species is completely absent at Heidhausen.

Von Daniels (1986) has shown that *U. tenuipustulata* occurs only occasionally in near-shore deposits but is omnipresent in the deeper parts of the basin. This distribution would explain very well its scarceness in the south-eastern part of the area and possibly also its restricted range at Ballonzuil.

Maasbree is the only bore-hole with the Mol H 1A facies that was included in the foraminiferal research. The foraminiferal record was studied below 130 metres, only partly overlapping the mollusc zonation (see table 1). *U. tenuipustulata* is virtually absent in Mol H 1A but becomes frequent below 164 metres, where the molluscs indicate the lower part of Mol H. These findings corroborate the facies-dependence of *U. tenuipustulata*. It should be mentioned that scattered specimens of *A. beccarii* occur in the investigated part of Mol H 1A.

The FE 1 Subzone was identified at Broekhuizenvorst (van Rooyen et al., 1984) and Nederweert. It is characterized by great abundance of *Trifarina gracilis* (Reuss, 1851) and absence of *U. tenuipustulata*. The latter species was found in low numbers at Broekhuizenvorst, where its presence was considered as caving. This subzone coincides approximately with that part of the Mol H Zone characterized by the last occurrences of *Pecten brummeli* and *Ringicula ravni*.

The nannoplankton floras in Broekhuizenvorst were studied by Verbeek (in van Rooyen et al., op. cit.). They indicate that the interval comprising the lower part of the FD and the FE 1 can be correlated with NN 4, which covers the last part of the Early Miocene. Older Neogene marine sediments are presumably absent in the Venlo Block but may be present in the north-western part of the Central Graben.

CONCLUDING REMARKS

Facies dependence of both molluscs and benthic Foraminifera determines the limits of the individual zonations. As a rule, stratigraphic events in near-shore environments are better documented by molluscs. This holds in particular for the Mol G/H boundary, which has no counterpart in the foraminiferal faunas In the south-eastern part of the region. Occasionally, however, differences between coexisting facies seem to be so important that the environmental aspects mask time-stratigraphic information in the mollusc assemblages (Mol F 1-3 versus Mol F 4). For this reason, it is not always possible to correlate shallow and deep facies. The foraminiferal record represents a coarser stratigraphic tool in the context of a shallow-water environment and may help to solve the correlation problem, at least as far as the position in the main stratigraphic framework is concerned.

On the other hand, molluscs lose their stratigraphic significance toward the deeper parts of the basin, where the important events are more clearly reflected by the foraminiferal record. Thus, only simultaneous study of both groups of fossils can lead to a reliable stratigraphy for the area. What is more, the facies-dependence provides us with general information about the environment, which can provide a framework for paleogeographic and paleoenvironmental reconstructions.

Major events are assumed at the Mol H/G boundary, the FD/FC 2B boundary, and between the FC 2B and FC 2A units. The existence of barren intervals remains problematic. Such intervals could be of primary origin, but they could conceivably be the result of decalcification.

ACKNOWLEDGEMENTS

The authors are indebted to the Director of the Geological Survey of The Netherlands for permission to publish the results of their studies. They also wish to thank colleagues A.W. Burger, N.G. Neele, and W.H. Zagwijn for stimulating discussions and valuable suggestions, A.P. Marselje for the preparation of the drawings, and Mrs I. Seeger for reading the English text.

REFERENCES

Beets, C., 1950. Oligozäne und wahrscheinlich miozäne Gastropoden aus dem Peelgebiete (südliche Niederlande). — Meded. Geol. Sticht., C(IV)1(8): 1-78, 4 pl.

Bosch, M. van den, M.C. Cadée & A.W. Janssen, 1975. Lithostratigraphical and biostratigraphical subdivision of Tertiary deposits (Oligocene-Pliocene) in the Winterswijk-Almelo region (eastern part of the Netherlands). — Scripta Geol., 29: 1-167, 23 pl.

Bouma, A.H.R., (1943). Miozäne Gastropoden aus dem Peelgebiete (Trochidae, Adeorbidae, Solariidae, Scalidae, Calyptraeidae, Xenophoridae, Naticidae, Actaeonidae, Ringiculidae, Retusidae, Scaphandridae, Pteropoda, Scaphopoda). — (unpubl. manuscript, originally intended to be published in Meded. Geol. Sticht.), 75 pp., 5 pls.

Burgers, W., (1942). Contribution à la connaissance des mollusques miocènes du bassin de la Mer du Nord. — (unpubl. manuscript, originally intended to be published in Meded. Geol. Sticht.), 75 pp.

Daniels, C.H. von, 1986. Uvigerina in the NW European Neogene. In: G.J. van der Zwaan, F.J. Jorissen, P.J.J.M. Verhallen & C.H. von Daniels (eds.). Atlantic-European Oligocene to Recent Uvigerina. — Utrecht Micropal. Bull., 35: 67-120.

Daniels, C.H. von, & D. Spiegler, 1974. Bolboforma n. gen. (Protozoa ?) — eine neue stratigrafisch wichtige Gattung aus dem Oligozän/Miozän Nordwestdeutschlands. — Paläont. Z., 48 (1/2): 57-76.

Daniels, C.H. von, & D. Spiegler, 1977. Uvigerinen (Foram.) im Neogen Nordwestdeutschlands (Das Nordwestdeutschen Tertiärbecken, Beitrag nr. 23). — Geol. Jb., (A)40: 3-59.

Doppert, J.W.C., 1975. Foraminiferenzonering van het Nederlandse Onder-Kwartair en Tertiair. In: W.H. Zagwijn & C.J. van Staalduinen (eds.). Toelichting bij de geologische overzichtskaarten van Nederland. Haarlem (Rijks Geologische Dienst), pp. 114-118.

Doppert, J.W.C., 1980. Lithostratigraphy and biostratigraphy of marine Neogene deposits in the Netherlands. — Meded. Rijks Geol. Dienst, 32-16: 255-312.

Glibert, M., & J. de Heinzelin de Braucourt, 1955. La faune et l'âge miocène supérieur des Sables de Deurne, I. Description, II. Conclusions. — Bull. Inst. roy. Sc. nat. Belg.: 31(71): 1-27; 32(72): 1-12.

Hager, H., 1981. Das Tertiär des Rheinischen Braunkohlenreviers, Ergebnisse und Probleme. — Fortschr. Geol. Rheinld u. Westf., 29: 529-563.

Heering, J., 1950. Miocene Pelecypoda of the Netherlands (Peelregion). — Meded. Geol. Sticht., C(IV)1(10): 1-51, 8 pl.

Herngreen, G.F.W., 1987. Correlation between Miocene beds of the SE Netherlands and Italy based on dinoflagellate biozonation. — Meded. Werkgr. Tert. Kwart. Geol., 24 (1-2): 31-40, 6 figs (this issue).

Hinsch, W., 1952. Leitende Molluskengruppen in Obermiozän des östlichen Nordseebeckens. — Geol. Jb., 67, 143-194, 3 pl.

Hinsch, W., 1977. Die Faciesverteilung und Mesofauna im Miozän des Unterelbegebietes. — Geol. Jb., (A)40: 115-153.

Hinsch, W., 1986. Proposals for RCNNS and results of IGCP 124, 2. Biozonation. In: A.W. Janssen (ed.). Documents for the third meeting of RCNNS at Leiden, The Netherlands, 5-8 November 1986, pp. 58-64.

Hinsch, W., 1987. Definition of the Reinbekian/Langenfeldian boundary and subdivision of younger Neogene stages in deep and shallow environment by means of molluscs. — Meded. Werkgr. Tert. Kwart. Geol., 24 (1-2): 125-146, 7 figs, 3 tabs, 1 pl. (this issue).

Kautsky, F., 1925. Das Miozän von Hemmoor und Basbeck-Osten. — Abhandl. preuss. Geol. Landesanstalt, (NF) 97: 1-255, 12 pl.

Meijer, T., 1986. Non-marine biozonation in relation with transgressions in the Quaternary of the Netherlands. — Abstr. 9th Intern. Malacol. Congr., Edinburgh 1986.

Molengraaff, G.A.F., & W.A.J.M. van Waterschoot van der Gracht, 1913. Niederlande. — Handbuch der regionalen Geologie, 1(3).

Rasmussen, L.B., 1966. Molluscan faunas and biostratigraphy of the marine younger Miocene formations in Denmark, 1: Geology and biostratigraphy. — Danmarks Geol. Unters. (2)88: 1-358.

Rijksopsporing van Delfstoffen (ROVD), 1918. Eindverslag van den Dienst der Rijksopsporing van Delfstoffen in Nederland 1903-1916. Amsterdam, 664 pp., 10 encls.

Rooyen, P. van, J. Klostermann, J.W.C., Doppert, C.K. Rescher, J.W. Verbeek, B.C. Sliggers & P. van Glasbergen, 1984. Stratigraphy and tectonics in the Peel-Venlo area as indicated by Tertiary sediments in the Broekhuizenvorst and Geldern T 1 boreholes. — Meded. Rijks Geol. Dienst, 38(1): 1-27.

Sliggers, B.C., 1986. Biostratigraphical aspects of the Miocene molluscs in the southeastern part of the Netherlands, with special reference to near-coastal communities. — Abstr. 9th Intern. malacol. Congr., Edinburgh 1986.

Sorgenfrei, T., 1958. Molluscan assemblages from the marine Middle Miocene of South Jutland and their environments, 1-2. — Danmarks Geol. Unters., (2)79: 1-503, 76 pl.

Spaink, G., 1960. Vorläufige Namenliste der miozänen Mollusken aus den Niederlanden, anwesend in den Sammlungen der Geologische Stichting. Haarlem (Geol. Dienst), 21 pp. and suppl. (mimeographed, unpublished internal report).

Spaink, G., 1975. Zonering van het mariene Onder-Pleistoceen en Plioceen op grond van molluskenfauna's. In: W.H. Zagwijn & C.J. van Staalduinen (eds.). Toelichting bij de geologische overzichtkaarten van Nederland. Haarlem (Rijks Geol. Dienst): 118-122.

Spiegler, D., 1987. Encapsulated Bolboforma (Algae, Chrysophyta) from the Late Miocene deposits in the North Atlantic. — Meded. Werkgr. Tert. Kwart. Geol., 24 (1-2): 157-166, 3 pls (this issue).

Staalduinen, C.J. van, H.A. van Adrichem Boogaert, M.J.M. Bless, J.W.C. Doppert, H.M. Harsveldt, H.M. van Montfrans, E. Oele, R.A. Wermuth & W.H. Zagwijn, 1979. The geology of the Netherlands. — Meded. Geol. Dienst, 31(2): 9-49.

Tesch, P., (1946). Miocene gastropoden uit het zuidelijke Peelgebied (Fusidae tot Conidae in de indeeling van Von Zittel 1924) naar de onvoltooide studie van W. Burgers bewerkt. — (unpublished manuscript, originally intended to be published in Meded. Geol. Stichting).

Voorthuysen, J.H. van, 1944. Miozäne Gastropoden aus dem Peelgebiet (Niederlande) (Rissoidae-Muricidae, nach Zittel's Einteilung 1924). — Meded. Geol. Sticht., C(IV)1(5): 1-116, 13 pl.

IJspeert, C., 1942. Monographie der miozänen taxodonten Bivalven aus dem Peelgebiete (die Niederlande). — Meded. Geol Sticht., C(IV)1(1): 1-72, 4 pl.

Zagwijn, W.H., & J.W.C. Doppert, 1978. Upper Cenozoic of the southern North Sea Basin: palaeoclimatic and palaeogeographic evolution. — Geol. Mijnbouw, 57(4): 577-588.

Manuscript received 6 April 1987, revised version accepted 22 April 1987.