Lithostratigraphical and biostratigraphical subdivision of Tertiary deposits (Oligocene - Pliocene) in the Winterswijk - Almelo region (eastern part of the Netherlands).

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Bosch, M. van den, M. C. Cadée and A. W. Janssen. Lithostratigraphical and biostratigraphical subdivision of Tertiary deposits (Oligocene - Pliocene) in the Winterswijk - Almelo region (eastern part of the Netherlands). — Scripta Geol., 29: 1-167, 37 figs., 10 tables, 23 pls., 2 enclosures. Leiden, June 1975 (with summaries in Dutch and German).

Tertiary sediments (Oligocene - Pliocene) in the Gelderse Achterhoek and Twente (Winterswijk - Almelo region, eastern part of the Netherlands, provinces of Gelderland and Overijssel) are lithologically subdivided in a number of members. In this paper the Ratum Member, the Brinkheurne Member, the Winterswijk Member, the Aalten Member, the Eibergen Member, the Zenderen Member and the Lievelde Member are introduced. The Delden Member, already introduced in 1860, is redefined; this member occurs between the Zenderen Member and the Lievelde Member. The Aalten Member is subdivided in two new beds, the Miste Bed and the Stemerdink Bed respectively. For each of the lithological units a stratotype and some reference sections are designated. In the palaeontological part the fossil content of the lithological units is described. In the Brinkheurne Member two new biozones are introduced: the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone and the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone. In the Aalten Member four new biozones are distinguished: the *Hiatella arctica* Acme Zone, the *Astarte radiata* Acme Zone, the *Spisula* sp. Acme Zone and the *Limopsis aurita* Acme Zone. Finally, the lithological units described in this paper are correlated with deposits in Belgium, Germany, and Denmark by means of lithological and palaeontological characteristics.

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Introduction

The Tertiary deposits in the Gelderse Achterhoek and Twente (eastern part of the Netherlands, provinces of Gelderland and Overijssel) have been the subject of a detailed investigation with regard to the stratigraphy, fossil content and geographical distribution since the year 1960. Field work was successively done by the "Geologie-kader van District 6 - 12" of the Nederlandse Jeugdbond voor Natuurstudie, by the Werkgroep voor Tertiaire en Kwartaire Geologie and by the Rijksmuseum van Geologie en Mineralogie (National Museum of Geology and Mineralogy, indicated as RGM below). A series of provisional papers on local discoveries and stratigraphical results appeared as a result of the continued field work. A complete review of this investigation for the area around Winterswijk (map-sheet 41 East) is in preparation, as well as a historical survey and a stratigraphical and geographical interpretation of classic localities in the area (van den Bosch, in preparation).

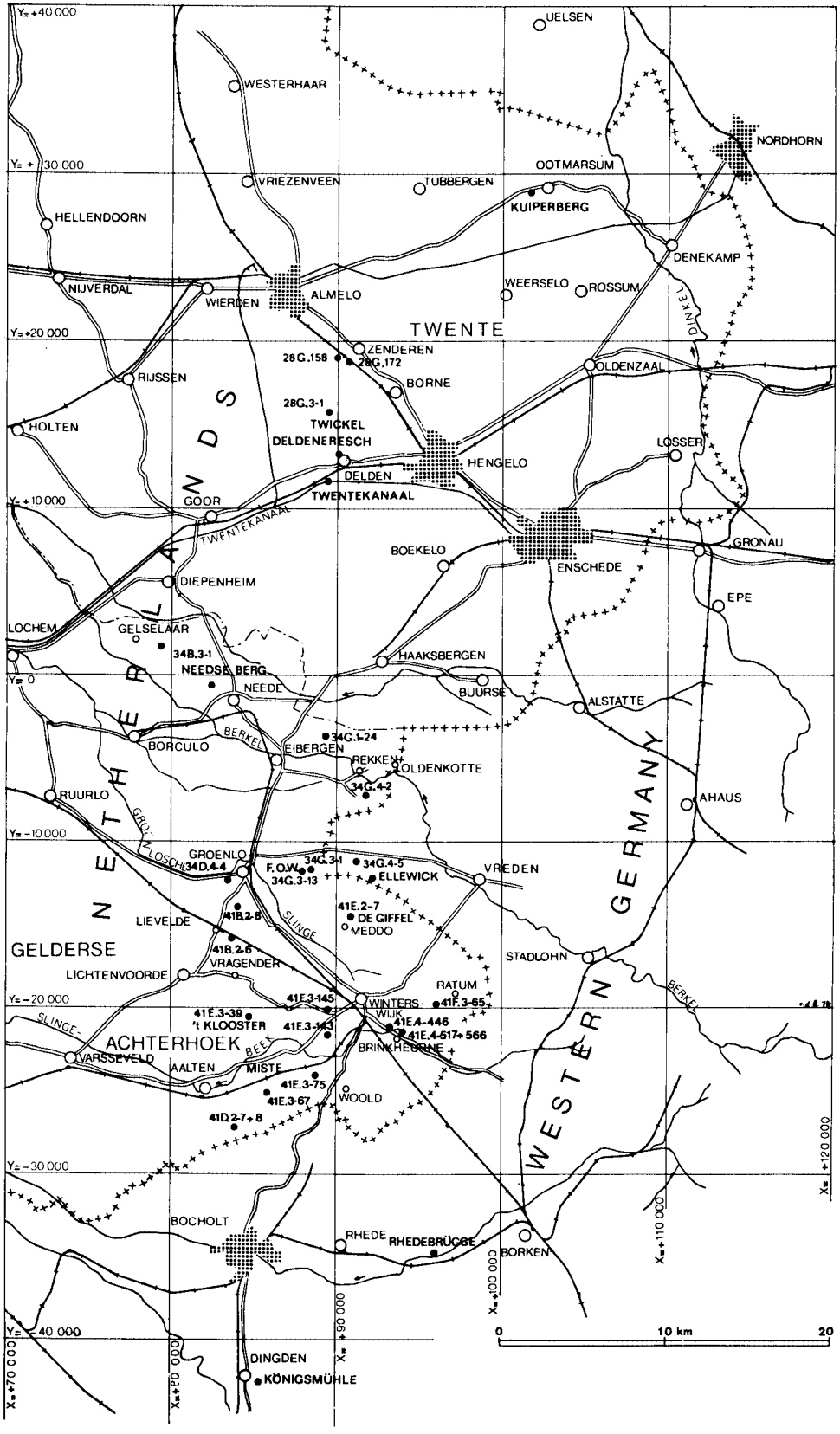
During the investigation it became clear that several deposits could easily be correlated with foreign localities (e.g. Dingden, Boom), but the greater part of the deposits appeared to be undescribed. During the field work the need of a local lithostratigraphy for the area of the Gelderse Achterhoek and Twente was urgently felt. Also, it seemed useful to give a concise record of the fossil content of the lithostratigraphical units. This paper is restricted to these subjects, but most certainly they are not yet treated in full detail.

The palaeontological research is still in an initial stage; many of the faunas mentioned in this paper are still insufficiently collected and several localities have not yet been studied exhaustively. Furthermore large quantities of fossil material remain to be sorted out. For two members a subdivision in biozones by means of the macrofauna could be established, by which a fair understanding of the facies-time relation was obtained. A combination of all available data made a useful correlation with deposits in Belgium, Germany and Denmark possible. A survey of these correlations is given as enclosure 2.

METHODS OF THE LITHOLOGICAL DESCRIPTIONS

The sediment samples collected from borings and exposures have generally been described in the field. These descriptions have been elaborated, if necessary, in the laboratory.

The sediments were described according to the norm sheets N 209, N 210 and N 213 of the "Hoofdcommissie voor de Normalisatie in Nederland". The contents of accessory components were estimated; an extensive laboratory research was not possible in most cases, because of the time and expenses this would require. The graphs of the grain sizes that join the boring sections (see enclosure 1) were composed by measuring the diameter of the grains in the samples with the aid of a Wild M 5 stereo-microscope with a measuring occular, thus estimating the average diameter (= 50% value) and a maximum grain size that will roughly agree with the 90% value. The grain sizes mentioned in the graphs only concern the granulometric composition of the sand fraction and not the amount of sand in the sediment; the latter is given in the lithological description. The lithological symbols used in the boring sections do not conform to any system of normalization: the


Y= +40 000
Y= +30 000
Y= +20 000
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Y= -10 000
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Y= -30 000
Y= -40 000
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X= +80 000
X= +90 000
X= +100 000
X= +110 000
X= +120 000
UELSEN
WESTERHAAR
NORDHORN
OOTMARSUM
VRIEZENVEEN
TUBBERGEN
KUIPERBERG
HELLENDOORN
DENEKAMP
NIJVERDAL
WIERDEN
ALMELO
WEERSELO
ROSSUM
TWENTE
DINKEL
ZENDEREN
28G.158
28G.172
OLDENZAAL
RIJSSEN
BORNE
28G.3-1
TWICKEL
HOLTEN
DELDENERESCH
LOSSER
HENGELO
DELDEN
TWENTEKANAAL
GOOR
TWENTEKANAAL
GRONAU
BOEKELO
ENSCHEDE
DIEPENHEIM
EPE
LOCHEM
GELSELAAR
34B.3-1
NEEDSE BERG
HAAKSBERGEN
NEEDE
BUURSE
ALSTATTE
BERKEL
BORCULO
EIBERGEN
34G.1-24
REKKEN
OLDENKOTTE
34G.4-2
RUURLO
AHAUS
GROOT
GROENLO
34D.4-4
F.O.W.
34G.3-1
34G.4-5
34G.3-13
ELLEWICK
VREDEN
41E.2-7
DE GIFFEL
LIEVELDE
41B.2-8
MEDDO
SLINGE
GELDERSE
41B.2-6
VRAGENDER
STADLOHN
LICHTENVOORDE
RATUM
41E.3-145
WINTERS-
WIJK
41F.3-65
41E.3-39
't KLOOSTER
41E.3-143
41E.4-446
41E.4-517+566
SLINGE-
ACHTERHOEK
BEEK
BRINKHEURNE
VARSSEVELD
AALTEN
MISTE
41E.3-75
41E.3-67
WOOLD
41D.2-7+8
BOCHOLT
RHEDE
RHEDEBRÜCKE
BORKEN
DINGDEN
KÖNIGSMÜHLE
0
10 km
20
NETHERLANDS
WESTERN GERMANY

norm sheet V 696 (September 1951) has proved its impracticability. The symbols used here are explicated in the legend on the enclosure.

In the translation of the lithological descriptions, that were originally written in Dutch, gradual differences have been indicated as listed below.

Grain sizes:

Dutch designation	grain size	English translation
uiterst grof zand	1.000 - 2.000 mm	extremely coarse sand
zeer grof zand	0.500 - 1.000 mm	very coarse sand
grof zand	0.333 - 0.500 mm	coarse sand
matig grof zand	0.200 - 0.333 mm	rather coarse sand
matig fijn zand	0.125 - 0.200 mm	rather fine sand
fijn zand	0.083 - 0.125 mm	fine sand
zeer fijn zand	0.063 - 0.083 mm	very fine sand
uiterst fijn zand	0.016 - 0.063 mm	extremely fine sand
slib	0.002 - 0.016 mm	silt
lutum	< 0.002 mm	lutum

Quantity of accessory components:

Dutch designation	English translation
spoor	a trace, with traces of
uiterst weinig, iets	extremely few, some, somewhat
zeer weinig	very few
weinig	few
matig weinig	rather few
matig sterk; matig veel	rather; rather many
sterk, zeer sterk; veel, zeer veel	very; very much
uiterst sterk; uiterst veel	extremely; abundant

Depending from the context some graduations are indicated in different ways. So, for example, "rather few" can also be used as "rather little", or "with a rather low content of", and so on.

The exact content of sand, clay, or silt in percentages of weight can not be determined without a laboratory research. Proper denomination of the sediments also depends on the mutual relation of sand and clay with respect to the porosity and plasticity. The descriptive terms used in this paper have been estimated and indicate only relative graduations. An exact norm is difficult to establish for these accessory components, because the specific gravity is different for each component, compare for example shells with wood remains, glauconite with quartz!

If an accessory component is found in a percentage of more than 50, it is regarded to be the main component, e.g. shell grit with a high content of sand.

ACKNOWLEDGEMENTS

In the first place we would like to thank the many members of the Werkgroep voor Tertiaire en Kwartaire Geologie, who have co-operated in the field work for many

◀ Fig. 1. Locality map of the area investigated. Black dots represent borings and exposures mentioned in this paper.

years and got through an enormous lot of work without personal profit and often under difficult circumstances. Secondly we expres our gratitude to the many landowners and farmers in the Gelderse Achterhoek and Twente, who gave every possible assistance and consent to the field work, usually without any recompensation. Especially we are indebted to the family J. Hesselink on the "Stemerdink" farm at Brinkheurne, Winterswijk; much of the field work was done with this farm as a basis and boring machinery and other tools have been stored here for years.

We owe Messrs J. van der Linden and H. Guldemond (both of the RGM) for field assistance during the recent boring of some stratotypes.

Mr E. A. van der Meene, geologist of the Rijks Geologische Dienst (Lochem), gave useful assistance in the elaboration of the fundamental idea; we discussed with him problems concerning the lithostratigraphical rank of the units. Through his agency we obtained data from the Zenderen area of Rijkswaterstaat. Also Mr C. Doppert, geologist of the Rijks Geologische Dienst (Haarlem), gave useful advice with regard to the rank of the lithostratigraphical units.

Drs P. C. Zwaan and C. E. S. Arps, both of the RGM, were kind enough to spend their time on the solution of several mineralogical problems. We thank Mr T. Veldhuyzen (RGM) and Mr W. A. M. Devilée (Geologisch en Mineralogisch Instituut, Leiden), who made the photographs, and Mrs C. J. Riethoven-van Leeuwen (RGM), who typed the manuscript. Finally, we are very grateful to Dr C. F. Winkler Prins, Dr M. van den Boogaard and Mr P. P. Takken of the RGM who, as members of the editorial board of this periodical, spend much time in critically reading and correcting the manuscript and contributed to the final representation of the paper.

Lithostratigraphy

General remarks — The description of the stratigraphical units in this chapter is based on borings and measurements that have been made during the period 1960 to 1974.

The new units have been described according to the rules of the International Subcommission on Stratigraphic Classification (1972). Each unit is defined by a short diagnosis to which a (future) extension of the unit should roughly satisfy.

For each unit an attempt is made to record the corresponding denomination in the older Dutch literature. The main sources in this respect have been the annual reports and publications of the "Rijksopsporing van Delfstoffen" during the period 1908 to 1924, the "Geologische Kaart van Nederland" of P. Tesch, as well as several minor publications.

A review of borings used in this paper can be found at p. 119. For each boring the stratigraphical sequence is mentioned there, as well as the presence of stratotypes, reference sections etc. By means of this review details of any desired boring section can easily be found.

AFZETTING VAN RATUM (RATUM MEMBER), NEW MEMBER

General concept — Sands, more or less silty, locally with thin sandy clay-streaks,

glauconite content variable, at the base usually reworked Eocene or Mesozoic components, poor in autochthonous fossils.

This lithological unit is introduced here as a member named after the hamlet Ratum, where the stratotype is situated. In the older literature this member was often indicated as "Onder-Oligoceen". The deposits crop out in the strip Winterswijk - Eibergen (Rekken) - Hengelo - Ootmarsum. Also in deep-borings in a more western direction the Ratum Member has been encountered, e.g. in deep-boring Lochem from 326 to 352 m below surface (ten Dam, 1945).

Stratotype — Boring 41F.3-65, on the right bank of the Willinkbeek at Ratum, municipality of Winterswijk, depth 1.50 - 19.00 m below surface; map-sheet 41F; co-ordinates X = + 96.115, Y = – 19.660; height of surface c. 41 m + N.A.P.
Locality map of borings and outcrops see fig. 2. Geological cross-section see fig. 3. Boring section and estimated grain sizes of the sediment see enclosure 1, fig. 1.

This boring was executed by the Rijksmuseum van Geologie en Mineralogie, July 1974. Boring method: auger-boring to 3.00 m, bailer-sampling with casing 63 mm Ø to 19.20 m. Sampling each 50 cm. Samples RGM 183 983 to RGM 184 022.

0.00 - 1.00 m	Quaternary: sand.
	Brinkheurne Member:
1.00 - 1.50 m	light bluish grey, very hard, very heavy clay, occasionally sandy, few small pyrite stems.
	Ratum Member, stratotype section:
1.50 - 3.00 m	dark grey, fine sand, with a high clay content, many thin sandy clay-streaks, rather little fine mica, some glauconite, pyrite concretions, at the top some weathered shell remnants.
3.00 - 6.50 m	grey, fine sand, generally very silty, few streaks of sandy clay, little fine mica, some glauconite, at the top pyrite concretions.
6.50 - 10.50 m	grey, fine sand, rather silty, little fine mica, some glauconite, from 7.00 to 7.50 m some pyrite concretions.
10.50 - 12.00 m	light grey, fine sand, slightly silty, some fine mica, some glauconite, at the base some Mesozoic rock fragments.
12.00 - 12.50 m	grey, fine sand, rather silty, few sandy clay-streaks, little fine mica, some pyrite grains, few Mesozoic rock fragments.
12.50 - 14.00 m	dark grey, fine sand, rather silty, few sandy clay-streaks, little fine mica, some pyrite concretions, few Mesozoic rock fragments.
14.00 - 16.50 m	dark grey, fine sand, rather silty, some pyrite concretions, little fine mica, few Mesozoic rock fragments.
16.50 - 17.00 m	dark grey, fine to rather fine sand, rather silty, some sandy clay-streaks, some fine mica, some glauconite, rather few Mesozoic rock fragments.
17.00 - 19.00 m	dark grey, fine to rather fine sand, rather silty, little fine mica, rather much glauconite, rather many Mesozoic rock fragments.
19.00 - 19.20 m	Liassic clay.

The stratotype is selected here because the sequence, so typical for the Gelderse Achterhoek, is well exposed in the Willinkbeek: Mesozoicum - Ratum Member - Brinkheurne Member. In the outcrop with a length of about 70 m, situated upstream of the stratotype (boring 41F.3-65), the Ratum Member can be studied in the bottom and bank of the brook (see fig. 2).

The inclination of the strata in north-western direction, measured alongside the brook, is about 7%. The Ratum Member is covered here by heavy clay, which

will be described as Brinkheurne Member below. In this clay a mollusc fauna of Rupelian age was collected.

Reference sections — In the Willinkbeek, as mentioned above, 5 to 70 m upstream of the stratotype 41F.3-65 (see fig. 2). In the banks and bottom of the brook the Ratum Member is well exposed. In the north-western part of the outcrop the deposits are clayey. The boundary with the overlying Brinkheurne Member can also be seen in the bank of the brook. Upstream, the Ratum Member becomes less clayey and somewhat more glauconitic. At this place it can only be seen in the bottom of the brook, but it can be reached easily with a spade or an auger. The contact with the Mesozoic strata is not exposed.

Boring 41E.4-446, at "Wassink", Brinkheurne, municipality of Winterswijk, depth 26.50 - 34.90 m below surface (see enclosure 1, fig. 2); map-sheet 41E; co-ordinates X = + 93.305, Y = - 21.050 (see fig. 4). For further information about this boring and the samples see the description of the Brinkheurne Member, p. 10.

0.00 - 1.00 m	Quaternary: mixed deposits, boulder clay.
1.00 - 26.50 m	Brinkheurne Member, stratotype section, see p. 10.
	Ratum Member, reference section:
26.50 - 26.75 m	dark grey, rather fine sand, with a high clay content, some glauconite, some mica, some very small shell fragments.
26.75 - 29.00 m	dark grey, rather fine sand, rather silty, little mica, some glauconite.
29.00 - 30.50 m	dark grey, rather fine sand, rather silty, rather few streaks of sandy clay, some mica, some glauconite.
30.50 - 31.50 m	grey, rather fine sand, little glauconite, some mica.
31.50 - 33.00 m	dark grey, rather fine sand, rather silty, rather many streaks of sandy clay, some glauconite, some mica.

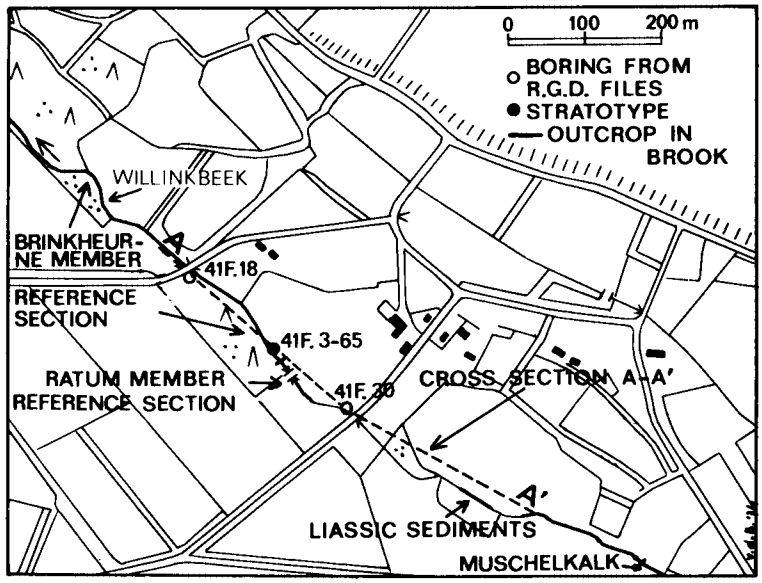

Fig. 2. Map showing the type-locality of the Ratum Member. For cross-section A - A' see Fig. 3.

33.00 - 34.00 m dark grey, rather fine sand, with a low silt content, some sandy clay-streaks, some glauconite, some mica.
34.00 - 34.90 m grey, rather fine sand, little glauconite, some mica.

34.90 - 37.25 m Liassic sediments.

Clay-pits of the Scholten brick-works on the Kuiperberg near Ootmarsum. At this place the deposits were heavily deformed bij glacial action. Geological situation and lithology described by Bosch (1971, p. 25-45). In that paper the Ratum Member is indicated as "Onder-Rupelien".

Regional aspects — In the Gelderse Achterhoek the Ratum Member directly overlies the Mesozoic, the basal deposits usually contain reworked components from these Mesozoic sediments. Because these components hardly or not show traces of transport and because only material from the underlying Mesozoic deposits is found, it is likely that these Mesozoic components have been transported over a short distance only.

From Eibergen (Rekken) to the north, in Twente, the Ratum Member generally overlies Eocene sands. In this region the base of the member contains one or more beds of phosphoritic concretions, reworked from the Eocene deposits, among which many shark-teeth are found, as in Rekken (Oldenkotte), Rossum, Ootmarsum (Kuiperberg) (van den Bosch, 1964b).

The thickness of the Ratum Member does in general not exceed 8 to 12 m, but at places where an older relief exists the thickness can be far less, the deposits can even be missing completely, or, on the contrary, the thickness can be much more, as is the case in the stratotype: 17.50 m.

In the Ratum Member rather small lateral differences occur in the silt content and the number of clay-streaks, the glauconite content and the grain size. In the lower part of the Ratum Member fine quartz gravel occurs locally, usually together with coarse glauconite.

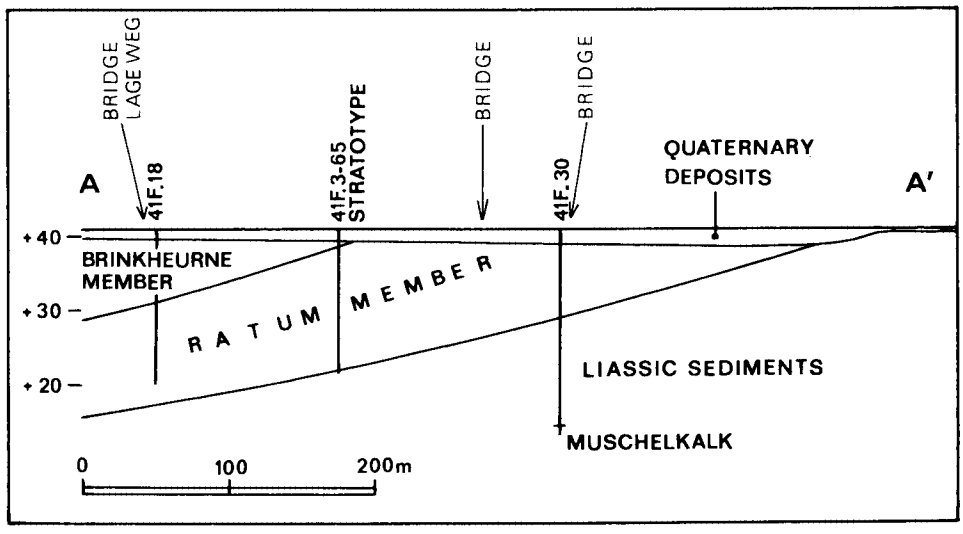

Fig. 3. Geological cross-section of the Ratum Member stratotype. For a locality map see Fig. 2.

The Ratum Member is known from several tens of borings in the eastern part of the Netherlands.

Stratigraphical aspects — The Ratum Member is considered to be of early Rupelian age on the base of autochthonous shark-teeth found is several borings and outcrops in Twente (van de Geyn, 1937; van den Bosch, 1964b). With regard to its stratigraphical position, it resembles the sands underlying the Boom Clay in the Ruisbroek - Niel - St. Niklaas region in Belgium (south and west of Antwerp). The fauna of these sands, however, also contains elements indicating an Early Oligocene (Lattorf) age; a paper on the molluscs in this fauna is in preparation by Cadée and Janssen. The "Walsumer Meeressand" from the Ruhr-area in western Germany occurs in a similar position. In the Mainz-Basin too, a sandy deposit known as "Unteres Meeressand" occurs below the "Septarienton".

In the Gelderse Achterhoek and Twente there are no indications that deposits from brackish water, as found in the Tongeren-area (Belgium), have ever been present. The Late Eocene sands from Twente and the area west of Vreden (western Germany) show a lithological resemblance with the Ratum Member, but the latter can be distinguished by its thick basal gravel consisting of reworked phosphoritic concretions. There are differences in the faunas but, owing to the fact that both deposits are poor in autochthonous fossils, this can hardly be determined in boring samples.

The Ratum Member was probably deposited in a shallow marine environment, especially the lower part has the character of a very shallow transgressive deposit.

AFZETTING VAN BRINKHEURNE (BRINKHEURNE MEMBER), NEW MEMBER

General concept — Heavy clays, only locally with a very small content of very fine sand. Colour at the base bluish grey or sea-green, at the top usually dark olive-green to dark greenish grey. Scattered large pyrite concretions and rather many small pyrite stems, as well as several levels with calcareous septaria occur. Especially at the base and at the top isolated molluscs and foraminifera, as well as scattered fish remains (e.g. shark-teeth) are found. The upper boundary is drawn at the level where a rather coarse sand fraction appears in the clay. The overlying strata represent the Winterswijk Member, described below, see p. 14. This boundary can generally not be drawn accurately.

This lithological unit is here introduced as a member named after the hamlet Brinkheurne, east of Winterswijk, where the stratotype is situated. In the literature this member is usually referred to as "septariënklei" or "Rupelien". The deposits crop out commonly in the eastern part of the Gelderse Achterhoek and Twente. Many brick-works have been digging these clays, as for example at Winterswijk, Oldenkotte near Rekken, Rossum, Borne and Ootmarsum, and in western Germany at Ellewick and Rhedebrügge (see fig. 1).

More to the west the Brinkheurne Member is encountered in many deep-borings as a distinct lithological unit, so for example in deep-boring Lochem from 291 to 326 m below surface (ten Dam, 1945). Here it is overlain by a sandy clay, whilst the Ratum Member lies underneath.

Stratotype — Boring 41E.4-446, at "Wassink", Brinkheurne, municipality of

Winterswijk, depth 1.00 - 26.50 m below surface; map-sheet 41E; co-ordinates X = + 93.305, Y = – 21.050; height of surface c. 37.60 m + N.A.P. Locality map of borings and outcrops see fig. 4, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 2. This boring was made by M. van den Bosch, July to September 1969. Boring method: auger-boring to 1.00 m, mud-boring 3" Ø to 29.00 m, bailer-sampling with casing 63 mm Ø to 34.90 m, mud-boring 2" Ø to 37.35 m below surface. Samples RGM 184 023 to RGM 184 050 and RGM 184 065 to RGM 184 079. Geothermical log data are available in the files of the RGM.

0.00 - 1.00 m	Quaternary: mixed deposits, boulder clay.
	Brinkheurne Member, stratotype section:
1.00 - 3.00 m	brownish grey to dark greyish green, very stiff and very heavy clay, some very fine mica, gypsum crystals.
3.00 - 6.00 m	dark greyish green, very stiff, very heavy clay, some fine mica, from 4.00 - 5.00 m some pyrite concretions.
6.00 - 7.00 m	dark greenish grey, very stiff, very heavy clay, some very fine mica, some bituminous streaks.
7.00 - 8.00 m	dark greenish grey, very stiff, very heavy clay, some fine mica.
8.00 - 9.00 m	dark greenish grey, very stiff, very heavy clay, some fine mica, many pyrite concretions, many foraminifera and some very fine shell remnants.
9.00 - 9.55 m	greenish grey, very stiff, very heavy clay, some fine mica.

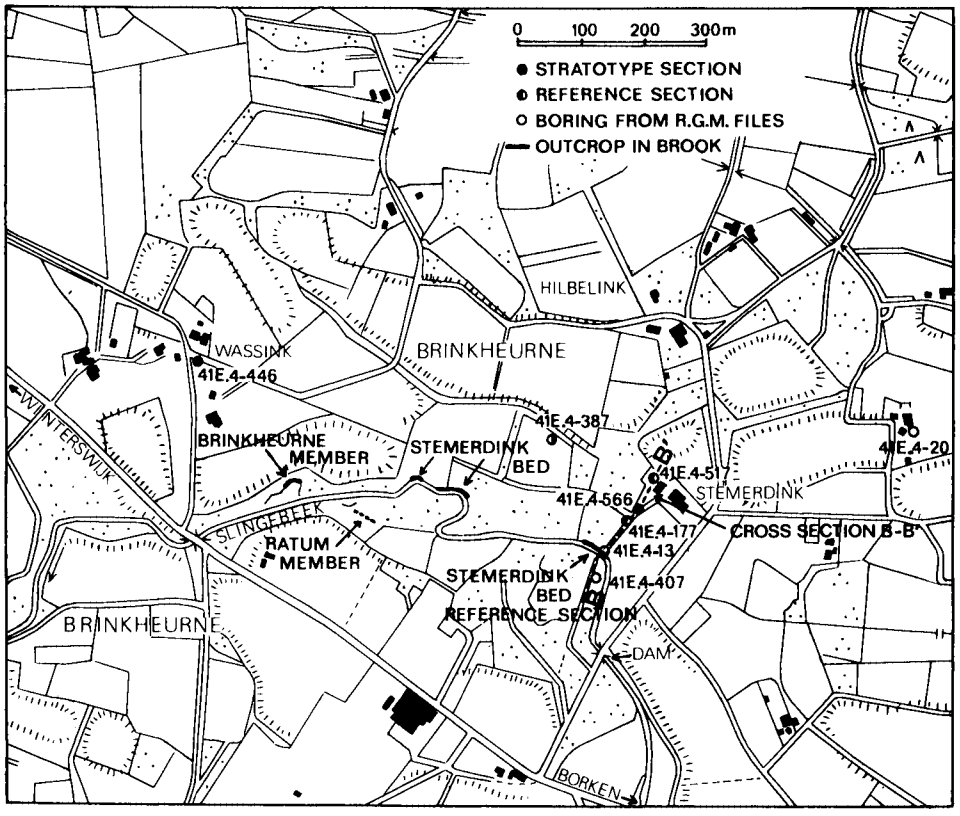

Fig. 4. Map showing the type-localities of the Brinkheurne Member (boring 41E.4-446) and the Stemerdink Bed (boring 41E.4-566). For cross-section B - B' see Fig. 9.

9.55 - 9.85 m	light brownish grey, very hard, glass-like calcareous septarium, with iridescent pyrite on the septa.
9.85 - 10.00 m	greenish grey, very stiff, very heavy clay, little fine mica, some fine pyrite.
10.00 - 16.50 m	greenish grey, very stiff, very heavy clay, some fine mica.
16.50 - 19.00 m	greenish grey, very stiff, very heavy clay, some very fine mica, some pyrite, few foraminifera, some small shell remnants.
19.00 - 20.00 m	greenish grey, very stiff, very heavy clay, some fine mica.
20.00 - 21.00 m	sea-green, very stiff, very heavy clay, with a low content of fine sand, with traces of fine mica, some pyrite, from 20.15 to 20.32 m a rather soft calcareous septarium.
21.00 - 26.00 m	sea-green, very stiff, very heavy clay, with a low content of fine sand, with traces of fine mica, some pyrite, some small shell fragments.
26.00 - 26.50 m	sea-green and dark greenish grey, very stiff, heavy clay, with a low sand content, with traces of fine mica, some small shell fragments.
26.50 - 34.90 m	Ratum Member: reference section, see p. 8.
34.90 - 37.35 m	Liassic sediments.

The stratotype is selected at this place because the Brinkheurne Member lies at very shallow depth for several hundreds of metres to the south and to the south-east. Therefore sampling can easily be done with a simple auger. At a distance of 240 m south-east of the stratotype the Brinkheurne Member crops out in an old meander of the Slinke beek, at the border of the high agricultural land there (called "es" in Dutch), see fig. 4. Borings in this area have yielded rare mollusc shells from the clay.

Somewhat north-east of the stratotype a fault is found, running south-east to north-west, on the other side of which younger Oligocene and Miocene sediments are present. Presumably the Brinkheurne Member lies at the site of the stratotype nearly horizontally. The upper boundary is eroded at this locality, probably some 15 m are missing.

Reference sections — The clay-pit of the brick-works "de Vlijt" and "te Siepe" south-west of Winterswijk (locality map see fig. 5; geological cross section see fig. 6) and also the clay section below the Winterswijk Member in its stratotype 41E.3-143, depth 2.55 - 7.55 m, at the most southern clay-pit. Further data about this section are given in the description of the Winterswijk Member, see p. 15. In the clay-pits these brick-works have been exploiting different levels of the Brinkheurne Member: in the north-east the lowest layers are reached, whilst to the south-west the top of the sediments is excavated. These pits are, however, nowhere deep enough to reach the basal deposits of the Brinkheurne Member with the bivalve *Cyclocardia kickxi* (Nyst & Westendorp, 1839). Although the deposits are only poorly fossiliferous and the fossil contents varies considerably in the different pits a relatively rich molluscan fauna has been collected from these clay-pits during the years.

Section 41E.3-143 is also the upper boundary stratotype. After a short brake in the sedimentation the Winterswijk Member is deposited on top of the Brinkheurne Member (see also van Hinsbergh, 1972). The basal layer of the Winterswijk Member is very fossiliferous, especially in smaller fossils. The top metre of the Brinkheurne Member also contains a relatively large number of small fossils, mainly molluscs and foraminifera. It contains also more fish remains than normal. In the chapter on the palaeontology this will be dealt with in more detail.

The Willinkbeek at Ratum, municipality of Winterswijk. The clay is exposed downstream the stratotype of the Ratum Member, 41F.3-65. It can be seen from this boring to 900 m downstream. Occasionally dislocated calcareous septaria are found in the brook. Only the lower part of the Brinkheurne Member with the bivalve *Cyclocardia kickxi* is exposed here. The bluish grey colour is characteristic for this lower part of the member. The position of the outcrop is shown in fig. 2.

The clay-pits of the Scholten brick-works on the Kuiperberg near Ootmarsum. The deposits have been heavily deformed here by glacial action. Geological position and lithology have been described by Bosch (1971, p. 25-45). In that paper the Brinkheurne Member is indicated as "Boven-Rupelien". The basal layers of the Brinkheurne Member with the bivalve *Cyclocardia kickxi* are exposed here.

Boring 28G.3-1 at the Twickel estate, on the Twickelse Vaart, municipality of Delden, depth 21.65 - 35.00 m below surface (base of member not reached), see enclosure 1, fig. 13. Map-sheet 28G; co-ordinates X = + 89.600, Y = + 15.790; height of surface c. 14.50 m + N.A.P. For further information about this boring and the samples see the description of the Delden Member.

0.00 - 1.40 m	Quaternary: sand.
1.40 - 7.50 m	Delden Member, stratotype section, see p. 45.
7.50 - 13.00 m	Zenderen Member, reference section, see p. 41.
13.00 - 16.00 m	Eibergen Member, see p. 43.
16.00 - 21.65 m	Aalten Member, reference section, see p. 30.
	Brinkheurne Member, reference section:
21.65 - 23.00 m	bluish grey, very solid, heavy clay, locally more brittle, occasional pyrite concretions, slightly calcareous.
23.00 - 24.00 m	as above, not calcareous.
24.00 - 25.00 m	as above, highly calcareous, with a rather thick soft septarium.
25.00 - 28.00 m	as above, not calcareous.
28.00 - 29.00 m	dark grey, very heavy, hard clay, locally somewhat brittle, scattered pyrite concretions, slightly calcareous, with traces of very fine sand.
29.00 - 31.00 m	dark grey, very heavy, hard clay, locally somewhat brittle, scattered pyrite concretions, rather strongly calcareous.
31.00 - 33.00 m	bluish grey, very heavy, hard clay, locally somewhat brittle, scattered pyrite concretions, slightly calcareous.
33.00 - 35.00 m	as above, not calcareous.

Regional aspects — In the Gelderse Achterhoek and Twente the Brinkheurne Member is almost invariably deposited on top of the Ratum Member, separated by a distinct boundary. Only at places where elevations in the old Mesozoic relief exist, the Brinkheurne Member can directly overlay older formations. In the Brinkheurne Member levels of calcareous septaria occur, that can only accidently be demonstrated in borings. The impression exists that at least two, but presumably even four of these septaria levels will be present in the Winterswijk area. The mollusc shells found at the base of the member represent a fauna slightly different from the one in the top of the member. In between, the clay is almost barren which can explain the low fossil content of some of the clay-pits, as for example at Ellewick and Oldenkotte. Important faunas have been collected at Winterswijk ("de Vlijt") and Ootmarsum (Kuiperberg).

The thickness of the Brinkheurne Member depends upon the tectonical

movements during the sedimentation. Thicknesses of 45 m can be considered as normal, but they increase gradually to the west. Locally, however, the thickness is far less, e.g. 12 m in boring 41E.4-517 at "Stemerdink" near Winterswijk; or, in subsiding areas, the thickness may even be several tens of metres more.

In the Brinkheurne Member glauconite is hardly encountered. Sand - up to a grain size of 100 to 125 μm - only occurs in small, hardly visible quantities, mainly in the lower part of the member, where some extremely thin sand-streaks can occur. The upper part of the deposit can locally be somewhat bituminous.

At the line of outcrop of the Brinkheurne Member, more or less in the strip Winterswijk - Rekken - Haaksbergen - Hengelo - Borne - Ootmarsum, the clay is frequently exposed in small brooks and deep trenches and ditches. Fossils are only rarely found in these outcrops because of the oxidation of pyrite, as a result of which the calcareous fossils are attacked.

Stratigraphical aspects — The Brinkheurne Member is usually correlated with the late Rupelian on the occurrence of the bivalve *Nuculana deshayesiana* (Nyst, 1835). Other characteristic fossils, the presence of calcareous septaria and the lithology in general suggest a close relationship with the Boom Clay in Belgium and the "Ratinger Ton" in the Ruhr-area in western Germany. The lithostratigraphical sequence of the deposits in the eastern part of the Netherlands agrees also fairly well with this supposition. Corresponding sediments have often been indicated as "Septarienton" in Germany and as "septariënklei" in the Netherlands.

The occurrence of calcareous septaria in the Brinkheurne Member could indicate a rather shallow, warm, quiet sea (Buurman, 1971). Sedimentation at a distance of several tens of kilometres from the coast is probable.

AFZETTING VAN WINTERSWIJK (WINTERSWIJK MEMBER), NEW MEMBER

General concept — Hard, more or less sandy clay layers alternate with very fine sand with a high silt or clay content. Colour grey, to dark grey or greenish grey. Very little glauconite, mainly in the more sandy parts. Few large pyrite concretions, but at places many small pyrite stems. Occasionally some, usually soft, calcareous septaria. Few scattered molluscan shells and fish remains.

The Winterswijk Member can be distinguished from the Brinkheurne Member by the occurrence of a clearly visible fraction of fine sand, also in the hard clays. The lower boundary can not always be drawn accurately, as the transition is often gradual.

This lithological unit is introduced here as a member named after the municipality of Winterswijk, where the member is frequently encountered and where the stratotype is situated. In the older literature this member can not exactly be recognized. At one time it has been indicated as "septariënklei" and at another time as Miocene, dependant from the sand content observed.

This member is mainly known from Winterswijk and Eibergen (Rekken), more to the north it is not encountered, as a result of later erosion. More to the west the Winterswijk Member is always present in deep-borings, where it is found between the Brinkheurne Member and sediments of Late Oligocene or Miocene age. In deep-boring Lochem (ten Dam, 1945) the section from c. 226 to 291 m below surface corresponds with the Winterswijk Member, on top of it Late Oligocene sediments are found.

Stratotype — Section 41E.3-143, in the south-western part of the clay-pit complex of the brick-works "de Vlijt" and "te Siepe", c. 1.5 km south-west of Winterswijk, depth 0.25 - 2.55 m below surface; map-sheet 41E; co-ordinates X = + 89.550, Y = – 21.600; height of surface - without partly removed Quaternary deposits - c. 38.00 m + N.A.P. Locality map of borings and outcrops see fig. 5, geological cross section see fig. 6, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 4. This section was measured by staff members of the Rijksmuseum van Geologie en Mineralogie, on 10 May 1974. Exposed in the wall of the clay-pit: 0.00 - 3.50 m, auger-boring in the wall of the clay-pit: 3.50 - 7.55 m, which more or less agrees with the depth of the abandoned clay-pit. Samples RGM 184 080 to RGM 184 093.

0.00 - 0.25 m	Quaternary: boulder clay (c. 1.50 m were removed).
	Winterswijk Member, stratotype section:
0.25 - 0.50 m	light brownish grey, rather sandy clay, some mica, many iron-stains.
0.50 - 0.75 m	light brownish grey, rather sandy clay with thin streaks of whitish very fine sand, some mica, rather few iron-stains.
0.75 - 1.05 m	light brownish grey, finely laminated clay with a low to rather high content of fine sand, some mica, many iron-stains.
1.05 - 1.30 m	light grey, finely laminated clay with fine sand, little fine mica, rather many iron-stains.
1.30 - 1.55 m	light greenish grey clay with fine sand, little fine mica, some small iron-stains (oxidation to about 1.50 m below surface).
1.55 - 1.80 m	light greenish grey clay with fine sand, little fine mica, finely laminated, a single very thin streak of dark grey, very fine sand, some weathered shell remnants, few small pyrite stems.
1.80 - 2.05 m	as above, with streaks of heavy clay.
2.05 - 2.30 m	light greenish grey clay with a low content of fine sand, finely laminated, little fine mica, some small molluscan shells, foraminifera, some green glauconite.
2.30 - 2.55 m	as above, with some weathered fragments of calcareous septaria, pyrite concretions, bone fragments, many small fish remains, pieces of clay — reworked from the underlying deposit — and some larger molluscan shells and shark-teeth.
	Brinkheurne Member, reference section:
2.55 - 2.75 m	dark greenish grey, hard, very heavy clay, finely laminated, with a few molluscan shells and foraminifera, little fine mica.
2.75 - 3.05 m	as above, less fossiliferous.
3.05 - 3.30 m	dark greenish grey, hard, very heavy clay, finely laminated, some molluscan shells and foraminifera, little fine mica.
3.30 - 7.55 m	dark greenish grey, hard, very heavy clay, finely laminated, some foraminifera, fine mica, small pyrite stems, at 6.85 m a soft calcareous septarium.

The stratotype was selected at this place because a good fauna has been collected in the clay-pits where it is situated. Furthermore the member lies at a very shallow depth all over the "Groote Veld" (see fig. 5). The contact with the Brinkheurne Member could be described here; more to the south-west the Aalten Member has been found, overlying the Winterswijk Member (see geological cross section, fig. 6). Section 41E.3-143 is also the boundary-stratotype of the Brinkheurne Member and the Winterswijk Member. This boundary is abrupt at this place, because of a short brake in the sedimentation (van Hinsbergh, 1972). The base of the Winterswijk Member contains a greater amount of glauconite and also many small shark-teeth and molluscan shells, which for the greater part were presumably

reworked from the top of the Brinkheurne Member. A few decimetres higher a poor molluscan fauna was found in situ.

Reference sections — Boring 41E.4-177 and boring 41E.4-517 at "Stemerdink", Brinkheurne, municipality of Winterswijk (see fig. 4). These borings, situated at a distance of only 80 m from each other, give a very good impression of the Winterswijk Member.

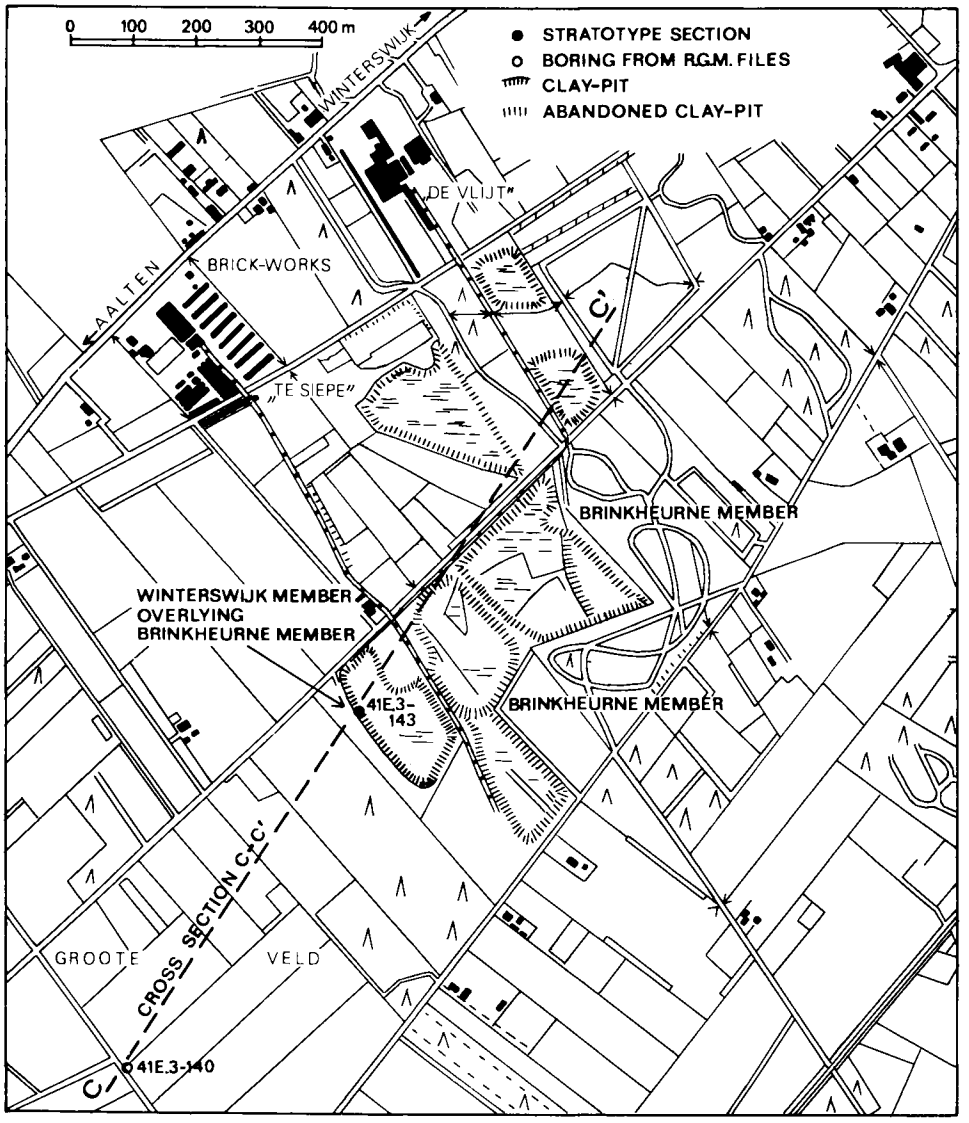

Fig. 5. Map showing the type-locality of the Winterswijk Member. For cross-section C - C' see Fig. 6.

Boring 41E.4-177 was made by M. van den Bosch, from March to July 1968; map-sheet 41E; co-ordinates X = + 93.975, Y = – 21.295; height of surface c. 37.30 m + N.A.P. Samples RGM 184 094 to RGM 184 180.

0.00 - 1.50 m	Quaternary.
1.50 - 16.30 m	Aalten Member.
16.30 - c. 40.00 m	Winterswijk Member, reference section.
c. 40.00 - 48.42 m	Brinkheurne Member (base not reached).

This boring has been described in extenso by van den Bosch (1969b, p. 35-38).

Boring 41E.4-517 was made by M. van den Bosch, in the spring of 1972; map-sheet 41E; co-ordinates X = + 94.040, Y = – 21.240; height of surface c. 39.20 m + N.A.P. Boring method: mud-boring 100 mm Ø to 77.10 m below surface. Samples RGM 184 181 to RGM 184 216; bore-hole logs and geothermical logs are available in the RGM files. Locality map see fig. 4, geological cross section see fig. 9. For boring section and estimated grain sizes of the sediment see enclosure 1, fig. 3.

0.00 - 3.50 m	Quaternary: sand, boulder clay, sand.
3.50 - 19.50 m	Aalten Member.
	Winterswijk Member, reference section:
19.50 - 22.20 m	dark greenish grey, rather sandy clay, laminated with less sandy parts.
22.20 - 24.22 m	dark grey, heavy clay with rather many streaks of fine sand, small pyrite stems.
24.22 - 26.25 m	dark grey clay, containing rather much fine sand with thin streaks of heavy clay, small pyrite stems.
26.25 - 28.11 m	dark grey, rather heavy clay with thin streaks of fine sand, small pyrite stems.
28.11 - 32.19 m	dark grey, rather sandy clay, laminated with less sandy parts, small pyrite stems.
32.19 - 34.20 m	as above, somewhat more sandy.

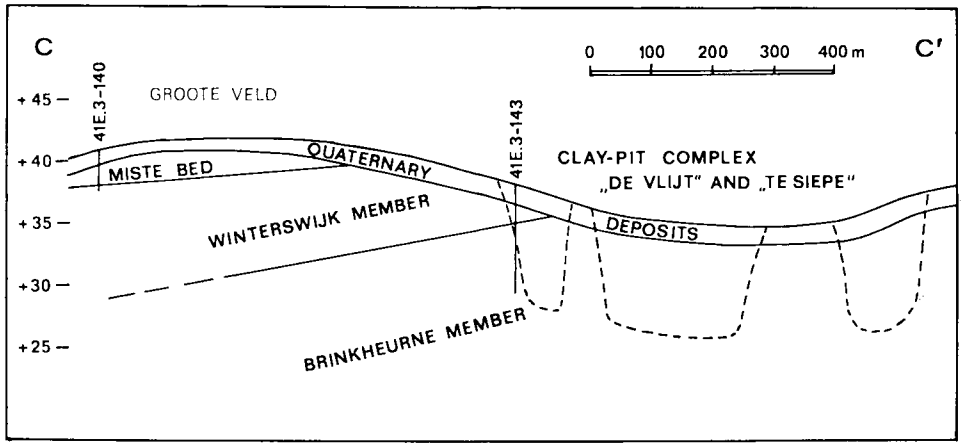

Fig. 6. Geological cross-section of the Winterswijk Member stratotype. For a locality map see Fig. 5.

34.20 - 36.23 m	dark grey, rather sandy clay with few thin streaks of heavy clay; small pyrite stems.
36.23 - 38.25 m	grey, very sandy clay, a single streak of solid clay, small pyrite stems.
38.25 - 40.32 m	grey, extremely sandy clay, a single streak of heavy clay, small pyrite stems.
40.32 - 42.42 m	grey, very sandy clay, rather many streaks of heavy clay, small pyrite stems.
	Brinkheurne Member:
42.42 - 44.43 m	dark greenish grey, rather heavy clay, pyrite concretions.
44.43 - 50.63 m	dark greenish grey, very heavy clay, coarse pyrite concretions.
50.63 - 52.70 m	dark sea-green, very heavy clay with some very thin streaks of fine sand, coarse pyrite concretions.
52.70 - 54.72 m	very dark greenish grey, very heavy clay, little fine sand, coarse pyrite concretions.
	Ratum Member:
54.72 - 55.30 m	dark greenish grey, fine to rather fine sand, rather silty, little fine glauconite.
55.30 - 77.10 m	pre-Tertiary consolidated rocks.

Regional aspects — In the area investigated the Winterswijk Member has only been found up to now in the region of Winterswijk and Eibergen (Rekken). As far as known at this moment, the member always overlies the heavy clay of the Brinkheurne Member. The lower boundary is, as mentioned above, not always sharp. Usually the transition is gradual. Only in the stratotype the boundary is abrupt, as a result of a short brake in the sedimentation.

In the area of Winterswijk and Eibergen (Rekken) the Winterswijk Member is always unconformably overlain by the Aalten Member, when the latter has not been removed by later erosion. More to the west the Winterswijk Member is often overlain by sediments of Late Oligocene age, as for example in boring 41D.2-7 and 41D.2-8 at Aalten and in deep-boring Lochem. Presumably the boundary of the Winterswijk Member with the Late Oligocene sediments is also gradual. On top of these the Aalten Member has been deposited unconformably. The hiatus represents a period during which the Winterswijk Member was completely removed in the eastern part of Twente.

Pyrite almost exclusively occurs as thin, small, irregularly shaped stems, embedded in the clay usually in a vertical position. Calcareous septaria are found, but it is unknown whether they occur in distinct beds. The clay yields many fossils, mainly foraminifera. However, when the Winterswijk Member occurs near to the surface, a few metres at the top are always decalcified.

In the Winterswijk Member glauconite is only found in small quantities, it is restricted in general to the more sandy levels. A sand fraction - up to a grain size of 125 to 175μm - is, however, always present; also the heavier part of the clay contains this quartz sand, thus making it easy to distinguish it from the Brinkheurne Member.

The thickness of the Winterswijk Member is not exactly known, since the upper part has usually been removed by erosion. Near Winterswijk a maximal thickness of 25 to 30 m seems a fair estimate. In deep-boring Lochem the thickness is 65 m. One gets the impression that the bottom and top sediments of the member are the most sandy.

The line of outcrop at Winterswijk and Eibergen (Rekken) is irregular, as a result of younger tectonical movements. The Winterswijk Member comes close to surface in the Woold-area (near the "Grote Steen") south of Winterswijk, in the "Groote Veld" south-east of Winterswijk, somewhat east of the Stemerdink farm

(east of Winterswijk), north of Winterswijk at Meddo and also south and south-west of Rekken near Eibergen.

Stratigraphical aspects — The Winterswijk Member is considered to be late Rupelian. It is the continuation of the sedimentary cycle Ratum Member - Brinkheurne Member. The sediments still contain the bivalve *Nuculana deshayesiana.* Lithologically there is a good resemblance with the "Lintforter Schichten" in the Ruhr-area that occur on top of the "Ratinger Ton" in that area, likewise with a gradual transition. From the present investigation one can conclude that the Oligocene sedimentary cycle in the eastern part of the Netherlands and that of the Ruhr-area in western Germany have much in common.

In many papers, in which the Winterswijk Member is correlated with the Rupelian, the member has been called "septariënklei" or "Septarienton". The Winterswijk Member was certainly not deposited in a deep marine environment, but it is difficult to determine whether it originated in deeper water than the Brinkheurne Member or not. The appearance of a distinct sand fraction in the sediment might point to a changed current or to epeirogenetic processes in the source area. It is not necessarily connected with a changing depth of the sea or with local regressions.

AFZETTING VAN AALTEN (AALTEN MEMBER), NEW MEMBER

General concept — The basal part of this member consists of glauconitic sands that gradually become more silty upwards and grade into clayey sands and sandy clays; at the top of the member a rather heavy clay occurs with an inconspicuous sand fraction.

The Aalten Member is subdivided into two parts: Miste Bed for the lower, mainly sandy, sediments and Stemerdink Bed for the upper, mainly clayey, sediments. These beds will be described below.

The sediments of the Aalten Member are dark brownish grey; sometimes the Miste Bed is blackish because of the high glauconite content. Locally, but mainly in the lower part of the member, pyrite is encountered, usually as irregular lumps.

In the Gelderse Achterhoek the Aalten Member is extremely fossiliferous, especially the lower part of the Miste Bed. The fossil content decreases quickly towards the top of the member but at the very top of the deposit some foraminifera and molluscan shells are still found. In Twente, as far as known up to now, only the base of the Aalten Member is somewhat fossiliferous.

This lithological unit is introduced here as a member named after the municipality of Aalten, where good boring sections exist and where the stratotype is situated. From the descriptions in the older literature the member can not always be recognized. It is usually indicated as Miocene, but in that case the younger Miocene deposits are included too. The highly fossiliferous parts of the Aalten Member, however, have been recognized as "Middle Miocene".

The Aalten Member is known all over the Gelderse Achterhoek and Twente. In deep-boring Lochem (ten Dam, 1945), situated more to the west, the section from 166 to 196 m below surface represents the Aalten Member.

Stratotype — Boring 41E.3-67, at "Borninkhof", Haart, municipality of Aalten,

depth c. 8.00 - 20.80 m below surface; map-sheet 41E; co-ordinates X = + 85.935, Y = – 25.025; height of surface c. 30 m + N.A.P. Locality map see fig. 7, geological cross section see fig. 8, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 6. This boring was made by M. van den Bosch from 14 to 16 July 1969. Boring method: casing 125 mm Ø to 4.20 m, mud-boring 3" Ø to 22.00 m below surface. Samples RGM 184 217 to RGM 184 236.

0.00 - 1.70 m Quaternary deposits.

Eibergen Member, reference section:

1.70 - 3.00 m dark blackish green, very sandy clay, with very much mica, a streak of rather fine glauconitic sand.

3.00 - 5.00 m dark blackish green to dark green clay with a rather high content of fine sand, much fine mica.

5.00 - 6.00 m dark green clay with a high content of fine sand, very much fine mica.

6.00 - 7.00 m dark greenish black clay with a rather high content of fine sand, very much fine mica.

7.00 - 8.00 m as above, with a low content of fine sand.

Aalten Member, stratotype section:

Stemerdink Bed, reference section:

8.00 - 10.00 m dark greenish grey, very hard clay with a low content of fine sand, much fine mica.

10.00 - 12.00 m greenish grey and dark greenish grey, rather heavy, hard clay with a low content of fine sand, rather little fine mica, few weathered shells.

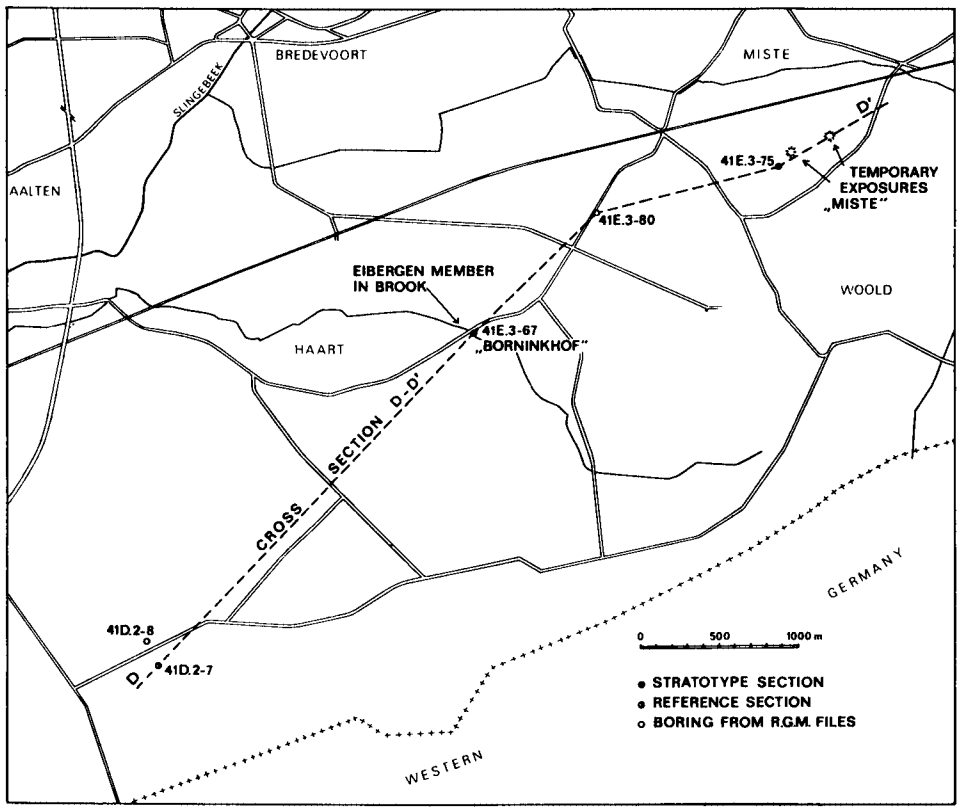

Fig. 7. Map showing the type-localities of the Aalten Member (boring 41E.3-67) and the Miste Bed (boring 41E.3-75). For cross-section D -D' see Fig. 8.

12.00 - 13.00 m light greenish grey, rather heavy clay with a low content of fine sand, some fine mica, rather few molluscan shells.
13.00 - 14.00 m dark greenish grey clay with a low content of fine sand, little fine mica, rather few shells.
14.00 - 15.00 m dark greenish grey clay with a rather high content of fine sand, little fine mica, rather few shells.
15.00 - 16.00 m dark greenish grey clay with a high content of fine sand, some fine mica, a few pockets of glauconitic sand, rather few shells.

Miste Bed, reference section:
16.00 - 18.00 m dark greenish grey, rather clayey, fine to rather fine, glauconitic sand, with some fine mica, rather many shells.
18.00 - 19.00 m dark blackish green, rather silty, fine to rather fine, glauconitic sand, with some fine mica, many shells.
19.00 - 20.80 m dark blackish green, somewhat silty, rather fine, glauconitic sand, with some mica, very many shells.

Winterswijk Member:
20.80 - 22.00 m light bluish grey, hard and stiff clay with a low content of fine sand.

The part from 16.00 to 18.00 m of this boring is also typical reference section of the *Spisula* sp. Acme Zone, described below (see p. 90).

The stratotype is selected here since, according to the investigations of de Vogel (1971), all the biozones described below can clearly be distinguished in this boring, which is not always the case in other borings. Furthermore the stratotype is situated in an area with only little tectonical disturbance; the deposits show a slight inclination to the west (see fig. 8).

Laag van Miste (Miste Bed), new bed

General concept — This bed consists mainly of sands with a variable silt and clay content; it represents the lower part of the Aalten Member, as described above.

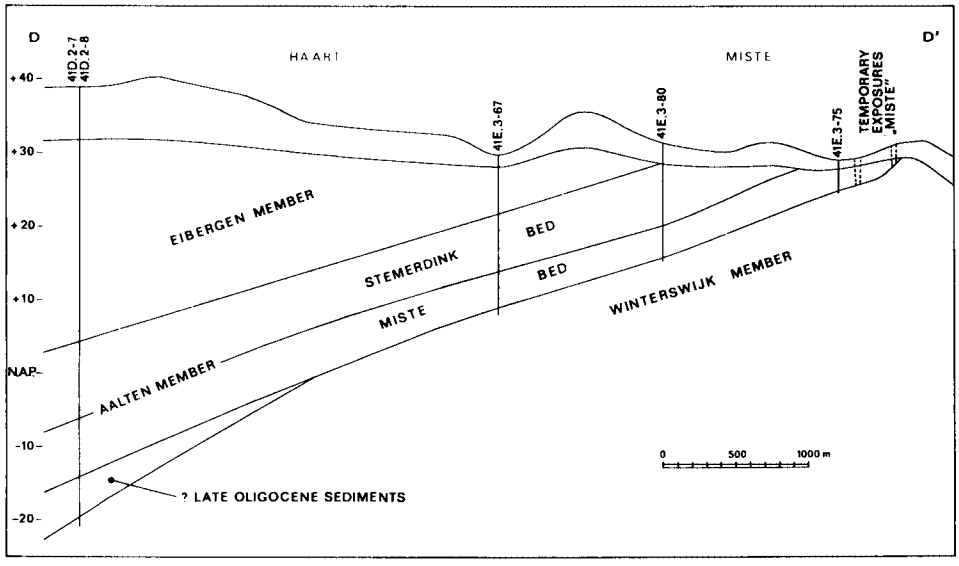

Fig. 8. Geological cross-section of the Aalten Member and Miste Bed stratotypes. For a locality map see Fig. 7.

Especially near the base these sands contain much glauconite that can be rather coarse locally. Usually, the sand is very fossiliferous. At some distance from the base a horizon of phosphorite concretions containing glauconite has locally been found in situ (not reworked). Elsewhere, however, similar concretions, presumably from the same horizon, are found as reworked components at the base of the member, so far only at places where the *Hiatella arctica* Acme Zone is missing. In the basal sediments also harder and less glauconitic phosphorite concretions, showing more distinct signs of transport, are always present. They must have been derived from sediments older than the Aalten Member and younger than the Winterswijk Member, as is indicated by the fossil content (see p. 74, pl. 11).

This lithological unit is introduced here as a bed named after the hamlet Miste, where the stratotype is situated. It is very difficult to draw the upper boundary of the Miste Bed accurately, because it has been fixed at the level where a very clayey sand changes into a very sandy clay. It should be noticed here that the grain size of the sand fraction is not a criterion to distinguish between sand or clay. Decisive is only the lutum-sand ratio that can hardly be estimated without a laboratory investigation. In the field the boundary between the Miste Bed and the Stemerdink Bed is drawn at the level where the sediments become fictile and behave as clay. The very clayey sand at the top of the Miste Bed is not fictile, it crumbles as a result of its low coherence.

Stratotype — Boring 41E.3-75 at Miste, municipality of Winterswijk, depth 1.25 - 4.10 m below surface; co-ordinates X = + 87.880, Y = – 24.000; height of surface c. 29.00 m + N.A.P. Boring method: bailer-sampling 125 mm Ø to final depth; made by M. van den Bosch, 4 September 1969; samples RGM 184 237 to RGM 184 244. Locality map see fig. 7, geological cross-section see fig. 8, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 7.

0.00 - 1.25 m	Quaternary: boulder clay.
	Aalten Member, reference section:
	Miste Bed, stratotype section:
1.25 - 1.60 m	dark green, partly iron-stained, rather clayey sand, very glauconitic, roots of trees.
1.60 - 1.75 m	dark green, rather clayey, glauconite sand, very rich in quartz, little weathered shell-grit and larger shells (*Venus, Glycymeris*), many phosphorite concretions in situ.
1.75 - 2.25 m	dark greenish black, slightly clayey, glauconite sand, very rich in quartz, few shells *(Glycymeris, Astarte),* some phosphorite concretions in situ, fish remains.
2.25 - 2.75 m	dark greenish black, slightly clayey, glauconite sand, very rich in quartz, rather many shells *(Glycymeris, Aporrhais, Laevicardium),* rather many phosphorite concretions in situ, fish remains.
2.75 - 3.25 m	dark greenish black, slightly silty, glauconite sand, very rich in quartz, many shells (among which many gastropods), some phosphorite concretions in situ, a quartz pebble.
3.25 - 3.75 m	dark greenish black, slightly silty, glauconite sand, very rich in quartz, many shells, some fish remains, some reworked small black phosphorite concretions.
3.75 - 4.00 m	dark greenish black, slightly silty, glauconite sand, very rich in quartz, very many shells, some reworked black phosphorite concretions.
4.00 - 4.10 m	dark greenish black, slightly silty glauconite sand, very rich in quartz, very many shells, few reworked small black phosphorite concretions, some reworked shell fragments.
4.10 - 4.30 m	Winterswijk Member.

The stratotype of the Miste Bed is selected here because in this area the bed lies close to the surface. From several excavations a very rich fauna was collected, the two lower molluscan acme zones and the bed of phosphorite concretions in situ can be distinguished here very well. The stratigraphical position is discussed above in the description of the Aalten Member (see fig. 8). The regional aspects will be discussed below. The part from 3.25 to 4.10 m below surface of the boring 41E.3-75 is also the typical reference section of the *Hiatella arctica* Acme Zone (see p. 83).

Laag van Stemerdink (Stemerdink Bed), new bed

General concept — This bed consists mainly of clay with a variable content of fine sand; it represents the upper part of the Aalten Member, as described above. At the base it has a high content of fine sand. Upwards the sand content decreases quickly and the deposit grades into a heavy clay with a low sand content.

The clays contain hardly any glauconite; upwards the mica content increases distinctly. At the base the Stemerdink Bed is usually rather rich in molluscan shells, the fossil content decreasing upwards, but in the uppermost part of the bed some shells still occur. In Twente the Stemerdink Bed is generally unfossiliferous.

This lithological unit is introduced here as a bed named after the Stemerdink farm at Brinkheurne, municipality of Winterswijk. The stratotype is situated on the Stemerdink farmyard.

It is difficult to draw the lower boundary of the Stemerdink Bed accurately because of the gradual transition of the sandy sediments into more clayey deposits, as discussed above in the description of the Miste Bed.

Stratotype — Boring 41E.4-566 on the Stemerdink farmyard at Brinkheurne, municipality of Winterswijk, depth 2.30 - 8.50 m below surface; map-sheet 41E; coordinates X = + 93.990, Y = - 21.280; height of surface c. 37.50 m + N.A.P. Boring executed by the Rijksmuseum van Geologie en Mineralogie, November 1973; boring method: auger-boring to 4.00 m, bailer-sampling with casing 63 mm ϕ to final depth. Samples RGM 184 246 to RGM 184 274. Locality map see fig. 4, geological cross section see fig. 9, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 8.

0.00 - 2.30 m	Quaternary: sand, boulder clay.
	Aalten Member, reference section:
	Stemerdink Bed, stratotype section:
2.30 - 3.00 m	dark greenish brown, heavy clay with a low content of fine sand, a single molluscan shell, little fine mica.
3.00 - 3.50 m	dark greenish brown, heavy clay with a rather low content of fine sand, few molluscan shells *(Astarte, Eudolium)*, rather much fine mica.
3.50 - 4.00 m	dark greenish brown alternating with dark greenish grey, heavy clay with a low content of fine sand, some shells, rather little fine mica.
4.00 - 4.50 m	dark greenish clay with a rather high content of fine sand, some heavy streaks, few shells, rather much fine mica.
4.50 - 5.00 m	greenish grey, heavy clay with some fine sand, some dark brownish grey, sandy streaks, some shell fragments, some mica, in the sandy streaks rather much mica.
5.00 - 5.50 m	dark greenish grey, heavy clay with a low content of fine sand, some shells, rather little fine mica.
5.50 - 6.00 m	dark greenish grey, heavy clay with a low content of fine sand, alternating with dark greenish brown clay with fine sand, little shell grit, rather little fine mica.

6.00 - 6.50 m dark greenish brown clay with a high content of fine sand and some very thin sand streaks, few shells and little shell grit, rather little fine mica.
6.50 - 7.00 m dark greenish brown clay with a very high content of fine sand, few shells and little shell grit, little fine mica.
7.00 - 7.50 m dark greenish brown, very clayey fine sand, little shell grit, little fine mica.
7.50 - 8.00 m dark greenish brown clay with a high content of fine sand, little shell grit, little fine mica.
8.00 - 8.50 m dark greenish brown clay with a very high content of fine sand, little shell grit, little fine mica.

Miste Bed, reference section:

8.50 - 9.00 m dark greenish brown, very silty fine sand, little glauconite, some shells, little fine mica.
9.00 - 9.50 m as above, rather few shells and shell fragments.
9.50 - 10.00 m as above, rather many shells and shell fragments.
10.00 - 10.50 m dark greenish brown, very silty fine sand, rather much glauconite, little shell grit, some fine mica.
10.50 - 11.00 m dark greenish brown, rather silty sand, rather much glauconite, some fine mica, rather few shells and shell fragments.
11.00 - 11.50 m as above, very silty.
11.50 - 12.00 m dark greenish grey, rather fine sand, rather silty, much glauconite, some fine mica, rather few shells and shell fragments.
12.00 - 12.50 m as above, rather many shells and shell fragments.
12.50 - 13.50 m dark greenish grey, rather fine sand, slightly silty, much glauconite, some fine mica, rather many shells and shell fragments.
13.50 - 15.50 m dark greenish grey, rather fine sand, slightly silty, very much glauconite some fine mica, many shells and shell fragments.
15.50 - 17.25 m as above, much glauconite.

17.25 - 17.50 m Winterswijk Member.

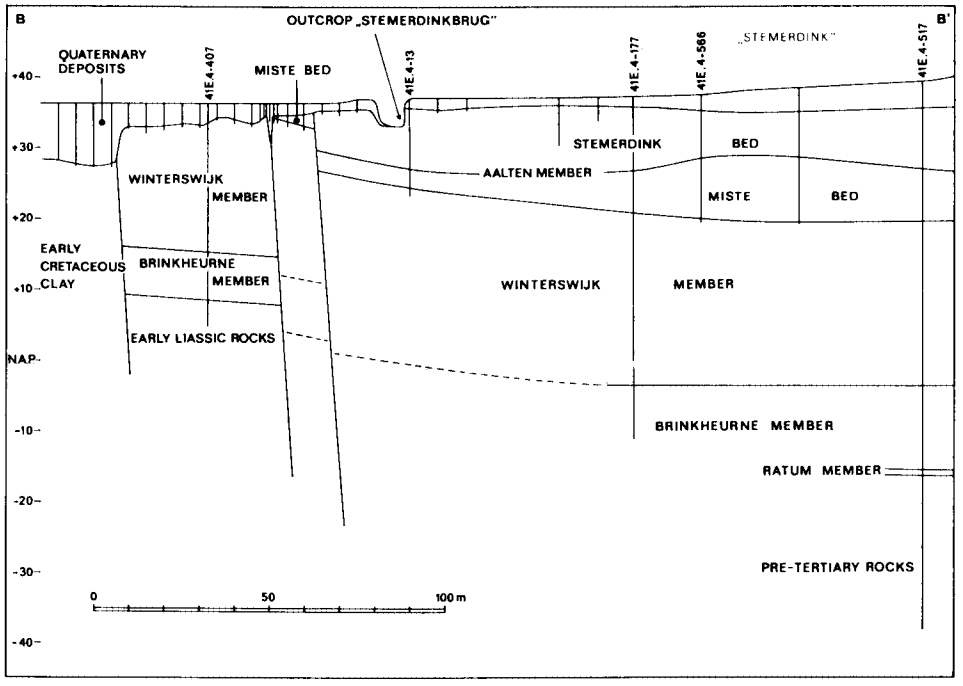

Fig. 9. Geological cross-section of the Stemerdink Bed stratotype. For a locality map see Fig. 4.

The stratotype of the Stemerdink Bed was selected here because the bed has been extensively investigated in this neighbourhood. Near the Stemerdink farm many borings have been made while 85 m to the south-west, measured from the type locality, the well-known outcrop "Stemerdinkbrug" is situated in which the Stemerdink Bed is exposed and where a good fauna has been collected (see figs. 4 and 9).

Boring 41E.4-566 is located nearly in the centre of a depression filled with Miocene sediments. This depression is connected with a complicated fault system (van den Bosch, 1970). The regional aspects will be discussed below, together with those of the Miste Bed and the Aalten Member.

Reference sections — The relevant parts of the stratotype of the Aalten Member are designated as reference sections of the Miste Bed and Stemerdink Bed. The stratotype of the Miste Bed is also a reference section of the Aalten Member. The part immediately below the stratotype of the Stemerdink Bed (8.50 - 17.25 m below surface) is designated as a reference section of the Miste Bed. Both the stratotype of the Stemerdink Bed and this reference section of the Miste Bed form together a reference section of the Aalten Member.

Boring 41E.4-387, west of the Stemerdink farm at Brinkheurne, municipality of Winterswijk; map-sheet 41E, co-ordinates X = + 93.860, Y = - 21.175, height of surface 37.37 m + N.A.P. This boring was made by M. van den Bosch, 4 and 5 April 1969. Locality map see fig. 4. Boring method: mud-boring 3" Ø to 12 m below surface, bailer-sampling with casing 63 mm Ø to 19 m; undisturbed cores were obtained from the traject of 6.00 - 7.00 m below surface. Samples RGM 184 275 to RGM 184 293. Geothermical logs are available in the RGM files.

0.00 - 1.50 m	Quaternary: boulder clay.
	Aalten Member, reference section:
	Stemerdink Bed, reference section:
1.50 - 5.00 m	dark greenish brown, stiff, rather heavy clay with a trace of fine sand, much mica.
5.00 - 7.00 m	dark greenish grey, hard clay with a low content of fine sand, rather much mica, a single mollusc shell.
7.00 - 8.00 m	dark greenish brown, soft clay with a rather high content of fine sand, little mica, some small pockets of glauconite sand, some shells.
8.00 - 9.00 m	as above, with a high content of fine sand, some mica.
9.00 - 10.00 m	dark greyish green clay with a rather high content of fine sand, some mica, some small pockets of glauconite sand, rather few shells.
10.00 - 12.00 m	dark greyish green clay with a rather high content of fine sand, little mica, some small pockets of glauconite sand, rather many shells, downwards somewhat more sandy.
	Miste Bed, reference section:
12.00 - 13.00 m	dark greenish grey, somewhat clayey, glauconite sand, fine to rather fine, little shell grit, little mica.
13.00 - 13.50 m	dark greenish black, very silty, fine to rather fine, glauconite sand, rather few shells, rather little mica.
13.50 - 14.00 m	dark greenish black, fine to rather fine, glauconite sand, laminated with brownish, very sandy clay, rather few shells, little mica.
14.00 - 18.00 m	dark brownish green, fine sand, very silty, much glauconite, rather many shells, some mica.
18.00 - 18.90 m	as above, with some hard, black reworked phosphorite concretions.
	Winterswijk Member:
18.90 - 19.00 m	light greenish grey, hard clay, with a low content of fine sand.

The part from 6.00 to 11.00 m of this boring is also the typical reference section of the *Limopsis aurita* Acme Zone, described below (see p. 93).

Outcrop "Stemerdinkbrug", in the right bank of the Slinge beek near the Stemerdink farm, Brinkheurne, municipality of Winterswijk, co-ordinates X = + 93.930, Y = – 21.340, see figs. 4 and 9. Reference section of the Stemerdink Bed.

Boring 41D.2-7, 2 km south-east of Aalten, depth 34.50 - 53.00 m below surface; map-sheet 41D, co-ordinates X = + 83.965, Y = –27.125, height of surface c. 39.50 m + N.A.P. Boring made by M. van den Bosch, February 1970. Boring method: bailer-sampling with casing 125 mm Ø to 7.35 m below surface, wash-boring 90 mm Ø to 56.00 m below surface. Samples RGM 184 294 to RGM 184 383. Bore-hole logs and geothermical logs are available in the RGM files. Locality map see fig. 7, geological cross section see fig. 8, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 5. The description of the lower part of this section (53.00 - 60.00 m) is taken from boring 41D.2-8, situated at a short distance from the 41D.2-7 boring.

0.00 - 7.35 m	Quaternary: sand.
7.35 - 34.50 m	Eibergen Member, reference section, see p. 35.
	Aalten Member, reference section:
	Stemerdink Bed, reference section:
34.50 - 35.00 m	very sandy clay, very much fine mica, little fine glauconite, some shells.
35.00 - 36.75 m	dark greenish grey, rather heavy clay, somewhat sandy, much fine mica, few shells.
36.75 - 39.00 m	dark greenish grey, rather heavy clay, the upper part somewhat sandy, the lower part slightly sandy, little mica, very few shells.
39.00 - 40.00 m	dark greenish grey, rather heavy clay with a rather low content of fine sand, very little mica, few shells.
40.00 - 41.50 m	dark greenish grey clay, rather sandy, some mica, very few shells.
41.50 - 42.50 m	as above, rather few shells.
42.50 - 43.50 m	as above, few shells.
43.50 - 45.00 m	dark greenish grey clay, very sandy, some mica, rather few shells.
	Miste Bed, reference section:
45.00 - 45.50 m	dark greenish grey, very fine sand, very clayey, some mica, rather few shells.
45.50 - 46.00 m	as above, with traces of glauconite.
46.00 - 46.50 m	dark greenish grey, very fine sand with a high content of clay, some mica, traces of glauconite, rather many shells.
46.50 - 47.00 m	dark greenish grey, very fine sand, rather clayey, some mica, some glauconite, rather many shells.
47.00 - 48.00 m	as above, little glauconite.
48.00 - 48.50 m	dark greenish grey, very fine sand, very clayey, some mica, little glauconite, rather many shells.
48.50 - 49.00 m	as above, few shells.
49.00 - 49.50 m	dark greenish grey, very fine sand, very clayey, some mica, rather little glauconite, rather few shells.
49.50 - 50.00 m	as above, extremely clayey.
50.00 - 50.50 m	as above, rather many shells.
50.50 - 51.00 m	greenish grey, very fine sand, extremely clayey, some mica, rather many shells, rather little glauconite, rather few small reworked phosphorite concretions.
51.00 - 51.50 m	greenish grey, very fine sand, extremely clayey, some mica, few shells, rather much glauconite, rather few small reworked phosphorite concretions.
51.50 - 52.00 m	as above, very clayey.

52.00 - 53.00 m greenish grey, very fine sand, extremely clayey, some mica, much glauconite, very few shells, many reworked phosphorite concretions, especially at 52.50 m.

? Late Oligocene:
53.00 - 58.50 m dark grey, fine to very fine sand, alternating with thin clayey streaks, silt content decreasing to the base, some weathered shell grit, mica, foraminifera.

Winterswijk Member:
58.50 - 58.90 m grey, sandy, stiff clay.
58.90 - 60.00 m grey, very sandy clay with streaks of clayey sand, many pyrite concretions.

Abandoned clay-pit of the F.O.W. brick-works and boring 34G.3-1 in this clay-pit, south-west of Zwilbroek, municipality of Eibergen, depth 4.80-15.55 m below surface; map-sheet 34G, co-ordinates X = + 88.700, Y = – 11.800, height of surface c. 32.00 m + N.A.P., measured during the years 1961 to 1965; the upper part of this section to 7.55 m was exposed in the front of the clay-pit, the description of the part from 7.55 to 15.55 m was made by means of auger- and wash-borings. Samples RGM 184 384 to RGM 184 397. Locality map of clay-pit and borings see fig. 12, geological cross section see fig. 13.

Eibergen Member, reference section:
0.30 - 0.80 m dark brownish grey clay containing some fine sand, much fine weathered mica.
0.80 - 1.95 m blackish grey, somewhat greenish clay containing little very fine sand, very much fine mica, small pyrite concretions.
1.95 - 4.80 m dark greenish grey clay with a low content of fine sand, laminated with very thin streaks of very fine glauconitic sand (every 8 to 15 mm), very much fine mica; from 3.20 m downwards darker in colour.

Aalten Member, reference section:
Stemerdink Bed, reference section:
4.80 - 7.20 m dark greenish grey, rather heavy clay with a low content of fine sand, much mica, some concentrations of very fine glauconitic sand, some shells (*Glossus, Pycnodonte*), to the base gradually more shells.
7.20 - 7.85 m greenish grey, hard, rather heavy clay with some pockets of very fine glauconitic sand, laminated with somewhat brownish clay, some shells. Bottom of the clay-pit at 7.55 m.
7.85 - 8.20 m light greyish green, rather heavy clay with a low content of fine sand, some mica, some concentrations of very glauconitic sand, some shells (*Glossus,* gradually lighter in colour and with more greenish grey streaks.
8.55 - 8.80 m (gradual transition) greenish grey, very hard clay with a rather high content of fine sand, somewhat laminated, little mica, few shells, to the base somewhat more sandy.
8.80 - 10.65 m (gradual transition) brownish green clay with a high content of fine sand, little mica, few shells, to the base gradually more shells and more greenish in colour, below 10.35 m somewhat less sandy.
10.65 - 12.25 m greenish grey clay with an extremely high content of fine sand, some mica, some shells, to the base gradually more shells and more sandy.

Miste Bed, reference section:
12.25 - 13.55 m dark brownish grey, very clayey fine sand, some mica, rather many shells.
13.55 - 15.55 m dark brownish grey, very silty sand, many shells (mainly in lenses), to the base more shells and less silty, glauconite content increasing downwards, at the base some reworked black phosphorite concretions and shark-teeth.

15.55 - 15.60 m Winterswijk Member.

Boring 34G.1-24, north-east of the Ticheloven farm at Eibergen-Loo, depth 0.80-4.15 m below surface; map-sheet 34G, co-ordinates X = + 89.385, Y = – 3.830, height of surface c. 24.50 m + N.A.P. This boring was made by M. van den Bosch in September 1969. Boring method: bailer-sampling with casing 125 mm Ø to final depth. Samples RGM 184 404 to RGM 184 410. Also the older boring 34G.1-1/43 T, published by Janssen (1967, p. 121), designated as stratotype section of the "Laag van Ticheloven", which is located at the same place. Further remarks about this latter boring are given in the paragraph "stratigraphical aspects" of the Aalten Member, see p. 32. Locality map see fig. 10, geological cross section see fig. 11, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 9.

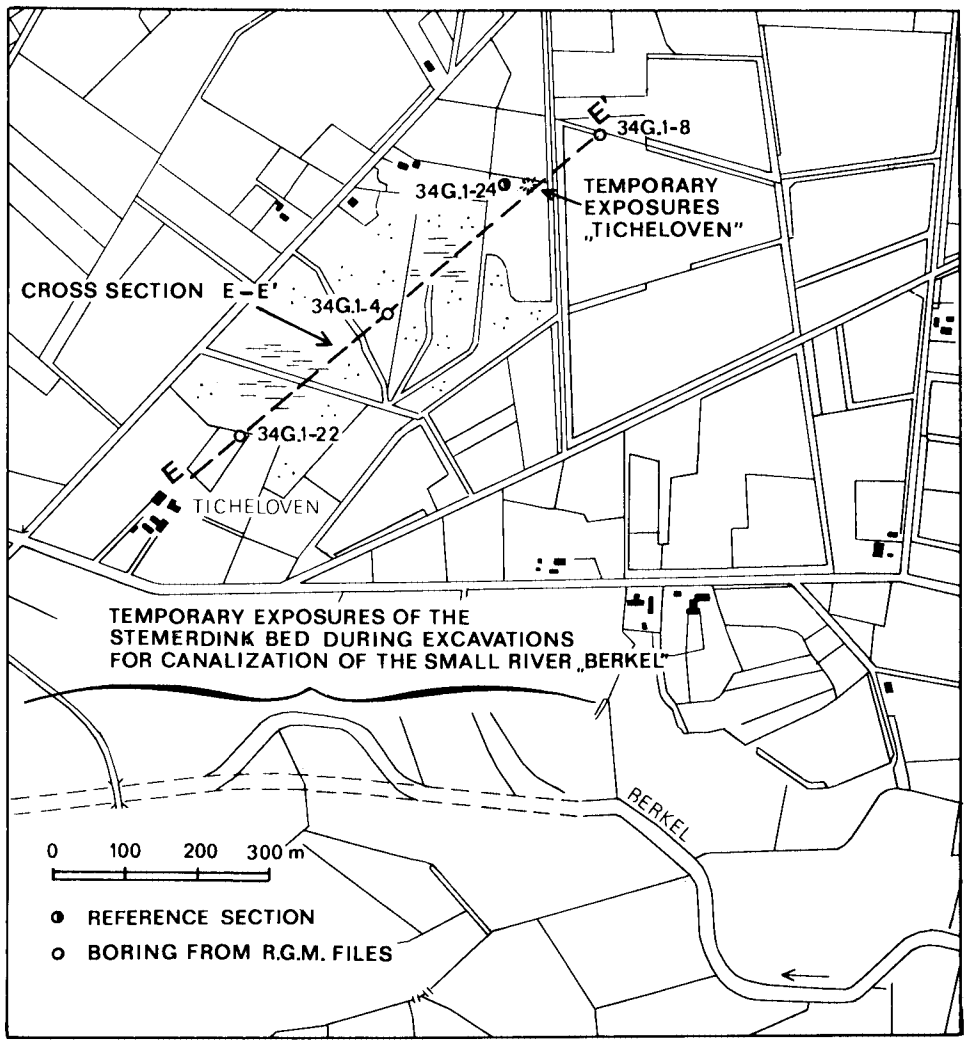

Fig. 10. Map showing the locality of the Aalten Member reference section (boring 34G.1-24), also typical reference section of the *Astarte radiata* Acme Zone. For cross-section E - E' see Fig. 11.

0.00 - 0.80 m Quaternary: sand.

Aalten Member, reference section:
Stemerdink Bed, reference section:

0.80 - 1.75 m dark brown, green-spotted, stiff clay with a rather high content of fine sand, rather much fine mica, very few shells.

1.75 - 2.00 m dark greenish grey clay with a rather high content of fine sand, some glauconite, rather much fine mica, very few shells.

2.00 - 2.50 m dark greenish brown clay with a rather high content of fine sand, little coarse glauconite, rather little fine mica, few shells.

2.50 - 3.00 m dark greenish grey, very sandy clay, some coarse glauconite, rather much mica, few shells.

3.00 - 3.50 m dark greenish grey, extremely sandy clay, little coarse glauconite, little mica, rather few shells, some small black reworked phosphorite concretions.

Miste Bed, reference section:

3.50 - 4.00 m dark greenish grey, rather fine to rather coarse sand, very silty, much coarse glauconite, some mica, many shells and shell grit, some small black reworked phosphorite concretions.

4.00 - 4.15 m dark brownish grey, rather coarse sand, rather silty, very much coarse glauconite, very many shell fragments and shell grit, rather many reworked phosphorite concretions and shark-teeth, large pieces of pyrite.

4.15 - 4.35 m Brinkheurne Member.

The part from 3.50 to 4.15 m below surface of this boring is also the typical reference section of the *Astarte radiata* Acme Zone, that will be described below, see p. 85. In the neighbourhood of this reference section small tectonical movements have occurred that are indicated in the cross section of fig. 11. Strike and fall of the deposits are not exactly known. At several tens of metres east of this reference section the Aalten Member was excavated with the spade several times, thus a

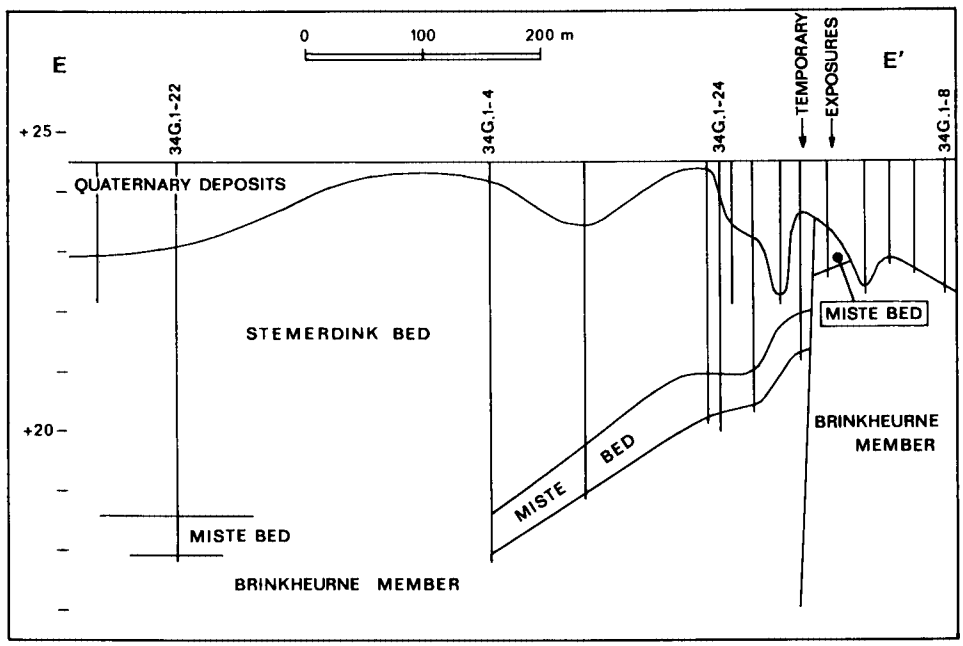

Fig. 11. Geological cross-section of the Aalten Member reference section (boring 34G.1-24). For a locality map see Fig. 10.

good impression of the fauna was obtained. A large quantity of the reworked phosphorite concretions at the base was collected. They show two different types: hard, black, rounded concretions, clearly transported, and soft, glauconitic concretions, with less distinct signs of transport. The second kind resembles the concretions found in situ at Miste (boring 41E.3-75). Some 800 m south of the reference section the Stemerdink Bed has been exposed over a large distance in 1970 during excavations for canalization of the small river Berkel (see fig. 10). The fossil content was not very high there.

Boring 28G.3-1 at the Twickel estate, on the Twickelse Vaart, municipality of Delden, depth 16.00 - 21.65 m below surface; map-sheet 28G, co-ordinates X = + 89.600, Y = + 15.790, height of surface c. 14.50 + N.A.P. Further information about this boring see the description of the Delden Member, p. 45. Locality map see fig. 14, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 13.

0.00 - 1.40 m	Quaternary: sand.
1.40 - 7.50 m	Delden Member, stratotype, see p. 45.
7.50 - 13.00 m	Zenderen Member, reference section, see p. 41.
13.00 - 16.00 m	Eibergen Member, see p. 43.
	Aalten Member, reference section:
	Stemerdink Bed, reference section:
16.00 - 17.00 m	very dark brown, heavy clay, not calcareous, little very fine mica.
17.00 - 18.00 m	very dark brownish grey, heavy clay, slightly calcareous, rather little very fine mica.
18.00 - 19.00 m	very dark brownish grey, rather heavy clay, not calcareous, with a rather high content of very fine sand, little very fine mica.
19.00 - 20.00 m	very dark brownish grey, rather heavy clay, somewhat calcareous, with a rather high content of very fine sand, little fine mica; in the more sandy parts, that sometimes occur in layers, rather little glauconite.
20.00 - 21.00 m	dark brownish grey, calcareous clay with a rather high content of fine sand, alternating with clayey sand layers containing black coarse glauconite, some shell fragments.
	Miste Bed, reference section:
21.00 - 21.65 m	dark greenish black, very silty sand, calcareous, with much coarse black glauconite and few shells, alternating with some more clayey streaks, at the base some large hard concretions and small black phosphorite concretions.
21.65 - 35.00 m	Brinkheurne Member, reference section, see p. 13.

The large hard concretions noticed here during the boring operations at the base of the Aalten Member could not be collected from the bore hole, so their real nature is uncertain. In an excavation for a new highway near to the water-tower of Delden (locality called "Deldeneresch", see fig. 14), 2.5 km south of the boring 28G.3-1, glacially deformed Tertiary sediments were exposed, among which also sediments of the Aalten Member (van den Bosch, 1972; Janssen, 1972b). At its base a layer of glauconitic sand occurred in which locally molluscan shells and reworked black phosphorite concretions were found, resembling the part from 21.00 to 21.65 m below surface in the boring 28G.3-1 described above.

The clay-pit complex of the Scholten brick-works on the Kuiperberg near Ootmarsum (fig. 1). From glacially deformed Tertiary sediments, Bosch (1971) described a dark green to almost blackish, often clayey, rather fine sand, very rich in glauconite, indicated by him as "Midden-Mioceen (? Laag van Ticheloven)". The thickness is estimated by him at 4 to 7 m. Approximately 0.30 m above the base a layer of phosphorite concretions containing glauconite occurs here in situ, resembling the concretions in situ of Miste (boring 41E.3-75). Below this layer of concretions a level with the bivalve *Pecten brummeli* Nyst occurs. This locality is designated as reference section of the Miste Bed.

Regional aspects — All over the region studied the Aalten Member concordantly overlies Oligocene sediments; so, in Twente it is encountered on top of the Brinkheurne Member, south of Eibergen and Rekken and near Winterswijk on top of the Winterswijk Member, and near Dingden in western Germany already on top of Late Oligocene sediments. Also more to the west Late Oligocene deposits are found below the Aalten Member, as in deep-boring Lochem.

The remainders of the deposits older than the Aalten Member that were removed by erosion are found as a thin basal gravel at the base of the Miste Bed. The components of this basal gravel are mainly calcareous septaria and fragments of these, pyrite concretions, some quartz pebbles, hard black phosphorite concretions (several of them with moulds of mollusc shells), and black shark-teeth, everything with distinct signs of transport. In the excavations at Miste and in borings in this region reworked loose shells are frequently found in the basal metres of the Miste Bed, usually together with some reworked shark-teeth that can not be connected with the reworked phosphorite concretions, and that represent a fauna different from the autochthonous fauna of the Miste Bed, see p. 77. Above we mentioned the fact that the phosphorite concretions occurring locally in situ in the Miste Bed are elsewhere found in the basal gravel of the member. This is the case for example at Stemerdink, east of Winterswijk, and at Ticheloven near Eibergen (boring 34G.1-24).

Furthermore a reworked mollusc and foraminiferal fauna was found in the basal 2 to 4 m of the Miste Bed in the boring Königsmühle near Dingden (western Germany); this material must have been derived from the underlying Late Oligocene sediments. In boring 41D.2-7 at Aalten this phenomenon was also demonstrated, but in a far lesser degree.

The coarse glauconite grains occurring in the Miste Bed might partly have been derived from older deposits (Boekschoten, 1969), but not from the Winterswijk or Brinkheurne Members, as glauconite is hardly encountered in these deposits.

The thickness of the Aalten Member shows local differences as a result of tectonical movements, but in southern direction an increase of the thickness can be roughly recognized: Delden 5.65 m, F.O.W. clay-pit at Zwilbroek (Eibergen) 10.75 m, Stemerdink, east of Winterswijk 15.00 m, south-east of Aalten 18.50 m. In deep-boring Lochem a thickness of 30 m was found; further data from more western localities are not available.

Together with the increasing thickness in a southern direction the sand content in the Aalten Member also shows an important increase: the Miste Bed increases in thickness while the Stemerdink Bed becomes more sandy. In the neighbourhood of Miste, south-west of Winterswijk, and near "de Krim", west of Winterswijk, the lower part of the Miste Bed is notably less silty then elsewhere. At these places rather fine to rather coarse blackish glauconite sand is encountered

that is extremely fossiliferous, especially a very rich mollusc fauna is found. At "de Krim" the lower part of the Miste Bed should be described as a compact shell bed containing glauconite grains, rather than as a sand rich in shells.

Stratigraphical aspects — On the base of the rich mollusc fauna the Aalten Member is considered to be of Miocene age. It can be correlated with the fauna of the "Reinbek Stufe" in north-western Germany. The sediments of the member show a transgressive character (de Vogel, 1971). The basal sands of the Miste Bed have presumably been deposited not far from the coast in a shallow marine environment. Upwards the sediments and the fauna demonstrate an increasing sea-depth and a greater distance from the coast. The basal sands have been locally removed by erosion shortly after deposition (proved by the absence of the coarse sands containing the *Hiatella arctica* Acme Zone, and at the same time the presence of phosphorite concretions from te Miste Bed in the basal gravel).

The sea-depth during the deposition of the higher part of the Aalten Member is difficult to estimate: the heavy clays at the top of the member suggest rather deep water.

The "Dingdener Schichten" (Janssen, 1967) — the stratotype of which is situated near the Königsmühle at Dingden, western Germany — can be correlated with the upper part of the Aalten Member. The Stemerdink Bed corresponds with the "Dingdener Glimmerton" (Janssen, 1967), while the Miste Bed can be correlated with the part from 4.00 to 14.00 m below surface in the boring Dingden. This latter part of the Dingden boring is subdivided by Janssen (1967) in "Dingdener Feinsand" and "Laag van Ticheloven". The upper boundary of the "Dingdener Feinsand" was fixed in the Dingden boring on lithological characteristics. The lower boundary of the "Dingdener Feinsand" in the boring Dingden was defined by means of the faunal association, and is therefore not a lithological boundary. It should be recommended to assign the part from 4.00 to 14.00 m below surface to the "Dingdener Feinsand".

The "Laag van Ticheloven" (Janssen, 1967), also mentioned in the boring Dingden from 8.50 to 14.00 m below surface (op. cit.), has been lithologically defined at the stratotype, which is the complete Miocene section of the old boring 34G.1-1/43 T at Ticheloven near Eibergen. This series of Miocene sediments at Ticheloven comprehends several lithological units and can at Dingden be correlated not only with the "Laag van Ticheloven", but also with the "Dingdener Schichten". The stratotype of the 'Laag van Ticheloven" correlates with parts of the Stemerdink Bed and the Miste Bed. It is recommended to abandon the lithological name "Laag van Ticheloven".

AFZETTING VAN EIBERGEN (EIBERGEN MEMBER), NEW MEMBER

General concept — This member comprehends mainly clays with a varying content of fine sand and usually with very much fine mica. The basal deposits of the member are clearly more sandy than the sediments in the higher part of the section. Near the top the sand content increases again and intercalations of very fine, very clayey sand occur, also with very much fine mica.

The colour of the clays is in general dark brownish black to dark greenish black, the more sandy parts usually being dark green. When freshly broken the clay glitters because of the high mica content.

Glauconite occurs in very small quantities in the sandy part at the base of the member, upwards it disappears. In the upper part of the member, where the sand content increases, the glauconite is also found again. This glauconite is very fine and dark green in colour. Shells and foraminifera are not found, except for a sporadical occurrence near the top of the member. The absence of fossils is not a result of decalcification; presumably the sediments have never contained calcareous fossils. However, the member is famous for its numerous whale bones and other remains of vertebrates, among which also frequent shark-teeth.

This lithological unit is introduced here as a member named after the municipality of Eibergen, where the member is present on a large scale and the stratotype is situated.

In the literature the member can not be recognized with certainty, but it was often indicated as "Boven-Mioceen", although the reasons for this denomination are not obvious. In deep-boring Lochem (ten Dam, 1945), situated more to the west, the part of 147 to 166 m below surface belongs to the Eibergen Member. Here also, it has been described as a clay, rich in mica, in which foraminifera are lacking.

Stratotype — Clay-pit and boring 34G.3-13, in the clay-pit complex of the F.O.W. brick-works (Groenlo), situated on the "Zwollesche Veld" near Zwilbroek, municipality of Eibergen, depth 0.00-8.50 m below surface; map-sheet 34G, co-ordinates X = + 88.100, Y = – 11.640, height of surface c. 32.00 m + N.A.P. The part of 0.00 to 7.00 m is exposed in the front of the clay-pit, from 7.00 to 9.50 m an auger-boring was made. The section was measured by staff members of the RGM in 1973. Samples RGM 184 411 to RGM 184 428. Locality map of clay-pits and borings see fig. 12, geological cross section see fig. 13, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 10.

Eibergen Member, stratotype section:

0.00 - 1.00 m	dark brown, plastic clay with a rather high content of very fine sand, rather little, very fine mica, some large pockets of Quaternary sand and gravel.
1.00 - 1.50 m	dark brown clay with a rather high content of fine sand, rather much fine mica.
1.50 - 2.00 m	dark brownish black, hard clay with a low content of very fine sand, much very fine mica.
2.00 - 2.50 m	dark brownish black, rather heavy, hard clay with a low content of very fine sand, much very fine mica.
2.50 - 3.50 m	dark brownish black, hard clay with a rather low content of very fine sand, small pockets and streaks of very fine sand, much very fine mica.
3.50 - 4.50 m	dark greenish black, hard clay, with a low content of very fine sand in streaks and pockets, much very fine mica.
4.50 - 5.50 m	dark greenish black, hard clay with a rather high content of fine sand in streaks and pockets, much very fine mica.
5.50 - 6.50 m	dark greenish black clay with a high content of very fine sand, traces of very fine glauconite.
6.50 - 7.00 m	dark green clay with a very high content of fine sand, much very fine mica, traces of fine glauconite.
7.00 - 7.50 m	dark green, very fine, clayey sand, much very fine mica, traces of fine glauconite.
7.50 - 8.00 m	dark green clay with a very high content of fine sand, much very fine mica, traces of fine glauconite.
8.00 - 8.50 m	dark greenish black clay with a rather low content of fine sand, sandy streaks, much very fine mica, little fine glauconite.

Aalten Member (Stemerdink Bed):

8.50 - 9.00 m dark brownish black, hard, rather heavy clay with a low content of fine sand, laminated, much very fine mica, some foraminifera, little fine glauconite.

9.00 - 9.50 m dark greenish grey, hard, heavy clay with a low content of very fine sand, much very fine mica, some foraminifera and small shell fragments, little fine glauconite.

The stratotype is selected at this place because the member is well exposed in this clay-pit, and also because a large collection of vertebrate fossils has been collected from this clay-pit. In the neightbourhood of this clay-pit no tectonical disturbances have been demonstrated, the deposits show only a slight dip in western direction.

It is quite possible that after some time it will be desirable to subdivide the Eibergen Member into several beds because of the lithological diversity of the sediments.

Reference sections — Abandoned clay-pit of the F.O.W. brick-works at Eibergen where the 34G.3-1 boring is situated, depth 0.30-4.80 m below surface. Further information and description of this reference section: see reference sections of the Aalten Member, p. 27. See also figs. 12 and 13.

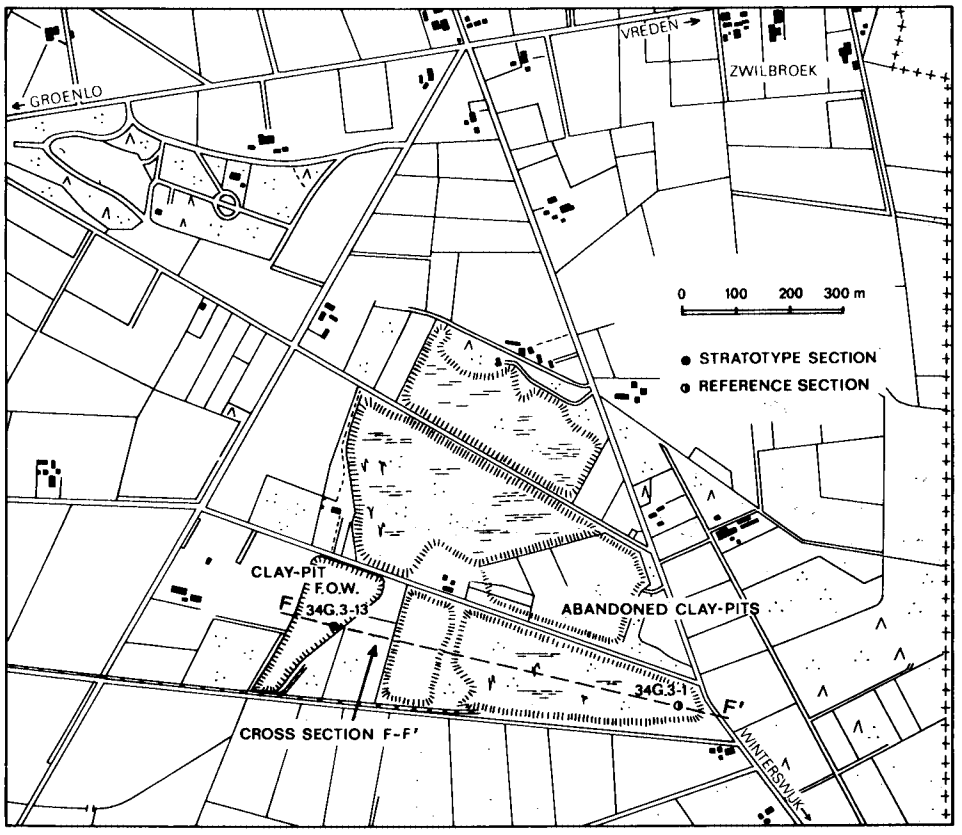

Fig. 12. Map showing the type-locality of the Eibergen Member (34G.3-13). For cross-section F - F' see Fig. 13.

Boring 41E.3-67 at "Borninkhof", Haart, municipality of Aalten, depth 1.70-8.00 m below surface. Further information and description of this reference section see the description of the Aalten Member stratotype, p. 19.

Boring 41D.2-7, 2 km south-east of Aalten, depth 7.35-34.50 m below surface. Further information about this boring see reference sections of the Aalten Member.

0.00 - 7.35 m	Quaternary: sand.
	Eibergen Member, reference section:
7.35 - 11.00 m	dark green, very fine sand, extremely clayey, much fine mica, little fine glauconite.
11.00 - 12.00 m	dark green, very fine sand with a very high clay content, much fine mica, little fine glauconite.
12.00 - 14.00 m	dark green, very fine sand with a very high clay content, much fine mica, little fine glauconite.
14.00 - 14.50 m	dark green, very fine sand, extremely clayey, rather much fine mica, little fine glauconite.
14.50 - 17.00 m	dark greenish brown clay with a high content of fine sand, much fine mica, little fine glauconite.
17.00 - 18.80 m	dark greenish brown clay with a high content of very fine sand, much fine mica, little fine glauconite.
18.80 - 20.00 m	dark greenish brown clay with a high content of fine sand, much fine mica, little fine glauconite.
20.00 - 21.00 m	dark greenish brown clay with a very high content of fine sand, much fine mica, little fine glauconite.

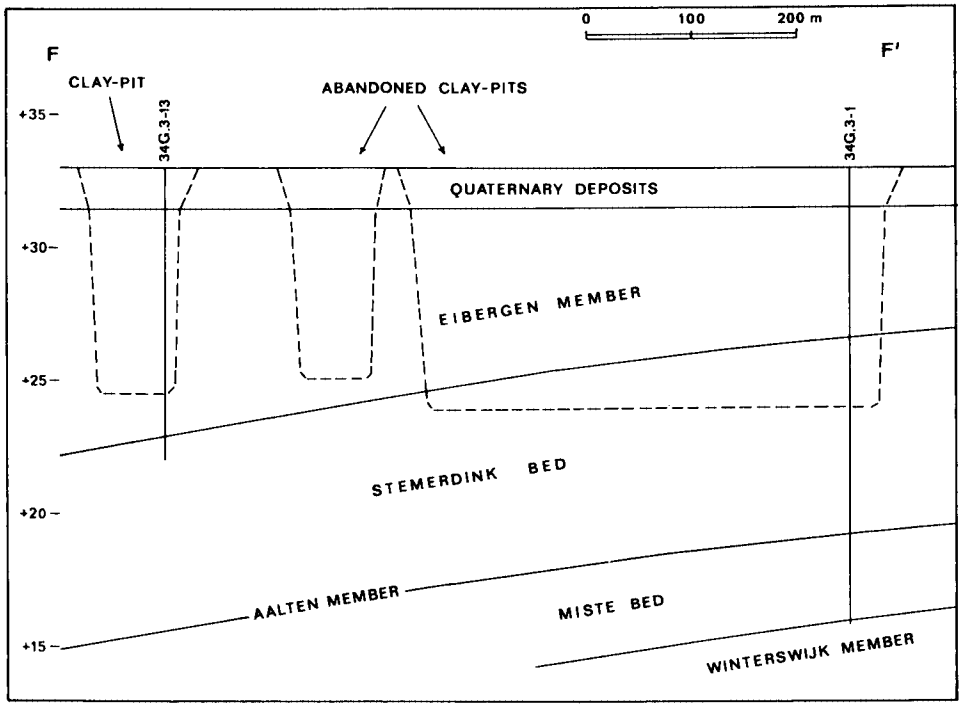

Fig. 13. Geological cross-section of the Eibergen Member stratotype. For a locality map see Fig. 12.

21.00 - 21.80 m	dark greenish brown clay with an extremely high content of fine sand, much fine mica, little fine glauconite.
21.80 - 24.80 m	dark greenish brown clay with a very high content of fine sand, much fine mica, little fine glauconite.
24.80 - 29.00 m	dark greenish black clay with a very high content of fine sand, very much fine mica, little fine glauconite.
29.00 - 30.80 m	dark greenish black clay with an extremely high content of fine sand, very much fine mica, little fine glauconite.
30.80 - 33.00 m	dark green, very fine sand, extremely clayey, much fine mica, little fine glauconite.
33.00 - 34.50 m	dark green, very fine sand, very clayey, much fine mica, little fine glauconite.
34.50 - 53.00 m	Aalten Member, reference section, see p. 26.
53.00 - 58.50 m	Late Oligocene sediments, see p. 27.
58.50 - 60.00 m	Winterswijk Member, see p. 27.

It is not certain whether the sandy part from 7.35 to 14.50 m in this section can be correlated with the Zenderen Member, described below. The small grain sizes and the clay content made us decide to reckon this part to the Eibergen Member.

Boring 41E.3-39 near the wood "'t Klooster" at the "Schaarsheide", municipality of Aalten, depth 5.35-15.00 m below surface; map-sheet 41E, co-ordinates X = + 85.035, Y = – 20.640, height of surface c. 39.00 m + N.A.P. Boring made by M. van den Bosch in July 1966. Boring method: bailer-sampling with casing 63 mm Ø to 7.50 m, wash-boring 50 mm Ø to final depth. Samples RGM 184 429 to RGM 184 457. Locality map see fig. 16, geological cross section see fig. 17.

0.00 - 3.35 m	Quaternary: boulder clay, glacially deformed Tertiary deposits.
3.35 - 5.35 m	Delden Member, reference section, see p. 49.
	Eibergen Member, reference section:
5.35 - 6.00 m	dark brown, very hard clay with a low content of fine sand, very much mica, some very thin green sandy streaks with mica and much glauconite.
6.00 - 6.25 m	dark greenish brown, less hard clay with a rather high content of fine sand, much fine mica, rather much glauconite.
6.25 - 6.40 m	dark brown, very hard clay with a low content of fine sand, much fine mica, little glauconite.
6.40 - 6.65 m	dark brown, hard clay with a rather high content of fine sand, much mica, rather much glauconite.
6.65 - 7.00 m	dark brown, very hard, laminated clay with traces of fine sand, much fine mica, some glauconite.
7.00 - 7.35 m	dark brownish grey, less hard clay with a rather high content of sand, rather much glauconite, much fine mica.
7.35 - 7.50 m	dark brownish grey, very hard, somewhat spotted clay with traces of fine sand, rather much glauconite, much fine mica, some very small pyrite stems.
7.50 - 8.50 m	dark brownish green, very hard, somewhat spotted clay with a low content of fine sand, some glauconite, much fine mica.
8.50 - 9.50 m	dark green, very fine, clayey sand, little mica, little glauconite.
9.50 - 10.50 m	dark green, very fine, clayey sand, little mica, rather much glauconite, a single shell *(Astarte)*, some sandy clay streaks with much mica.
10.50 - 11.00 m	dark brownish green, stiff and heavy clay, laminated, with traces of fine sand, little glauconite, rather much mica.
11.00 - 11.50 m	dark brownish green, very hard, heavy clay, laminated, with traces of fine sand, little glauconite, locally very much fine mica.

11.50 - 11.90 m	dark brownish green, stiff clay with a low content of fine sand, rather much fine mica, some glauconite.
11.90 - 12.50 m	dark brown, very hard, stiff clay with a low content of fine sand, much very fine mica, some glauconite.
12.50 - 13.00 m	dark brown and dark brownish grey, stiff clay with a low content of fine sand, much very fine mica, some glauconite.
13.00 - 13.50 m	dark brownish green, stiff clay with a low content of fine sand, some glauconite, much very fine mica.
13.50 - 14.00 m	dark brown, very hard clay with a low content of very fine sand, much very fine mica; alternating with dark green, extremely fine sand, very silty, some mica, rather much glauconite.
14.00 - 14.40 m	dark brownish green, very hard clay with locally a rather high content of fine sand, rather much mica, rather much glauconite.
14.40 - 15.00 m	dark brown and dark brownish green, very hard clay with a low content of fine sand, rather much fine mica, rather much glauconite, locally black-spotted.

Outcrop in the small brook running through the wood " 't Klooster", 200 to 375 m, downstream from the reference section 41E.3-39, see also fig. 16. The section in the outcrop roughly agrees with this boring. The outcrop is designated as a reference section because of the good accessibility. Fossils have not been found in this exposure.

Boring 41B.2-6 on the railway Zutphen-Winterswijk at Lievelde, municipality of Lichtenvoorde, depth 15.70-40.00 m below surface; map-sheet 41B, co-ordinates X = + 83.800, Y = – 15.700, height of surface c. 30 m. + N.A.P. Further information about this boring see the description of the Lievelde Member stratotype. Locality map see fig. 16, geological cross section see fig. 17, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 15.

0.00 - 0.15 m	Quaternary: black earth.
0.15 - 9.00 m	Lievelde Member, stratotype section, see p. 52.
9.00 - 15.70 m	Delden Member, reference section, see p. 49.
	Eibergen Member, reference section:
15.70 - 16.70 m	greenish grey, rather stiff clay with a high content of fine sand, rather much mica, much glauconite, some shell fragments.
16.70 - 17.70 m	dark green, rather stiff clay with a rather high content of fine sand, rather much mica, rather much glauconite.
17.70 - 19.00 m	light greenish grey, extremely clayey, fine sand, rather much glauconite, much mica.
19.00 - 19.20 m	greenish grey, very clayey, fine sand, much glauconite, rather little mica.
19.20 - 20.00 m	dark green, hard clay with a rather high content of fine sand, much glauconite, much mica, some streaks of very fine sand with little glauconite and mica.
20.00 - 20.65 m	dark green, extremely clayey sand, much glauconite, rather much mica, some sandy clay streaks.
20.65 - 21.50 m	dark green, very hard clay with a rather high content of fine sand, much fine mica (locally very much mica), much glauconite.
21.50 - 26.00 m	dark green, hard, locally soft clay with a high content of fine sand, rather much mica, much glauconite.
26.00 - 29.00 m	dark brown, very hard clay with a low content of fine sand, little glauconite, much fine mica.
29.00 - 30.00 m	blackish, very hard clay with traces of very fine sand, little glauconite, much fine mica.

30.00 - 31.00 m	blackish, very hard clay with a trace of very fine sand, little glauconite, much fine mica; partly more soft clay, dark green in colour, with a high content of fine sand and with mica.
31.00 - 33.00 m	dark green, rather soft clay with a low content of fine sand, rather little glauconite, rather much mica.
33.00 - 35.00 m	dark green, rather soft clay with a rather high content of fine sand, little glauconite, rather much mica.
35.00 - 38.00 m	dark green, rather soft clay with a rather high content of fine sand, rather little glauconite, much mica.
38.00 - 40.00 m	dark greenish black, very hard clay with a low content of fine sand, rather little glauconite, very much fine mica (clay glitters when freshly broken), locally the clay is almost black in colour.

Regional aspects — Although the Eibergen Member is known from Twente, no good sections that might serve as reference sections are available in that region. Furthermore the impression exists that in Twente the top of the member is removed by erosion during the deposition of the Zenderen Member.

The Eibergen Member is especially well-known in the region around Eibergen and Groenlo and also in the hamlet Haart in Aalten, and near Bocholt and Dingden in western Germany. The sections described above are situated in that area.

Although no complete and thoroughly sampled sections are available, it is supposed that the sedimentation of the Eibergen Member starts with a several metres thick, sandy deposit, containing some glauconite, deposited on top of the Aalten Member. Upwards the sand content decreases markedly, although always some sand is still found. In the higher part of the member the sand content increases again, whilst the clay usually becomes more greenish in colour and some glauconite occurs. Still higher even clayey sands, dark green in colour, are deposited.

Most of the vertebrate remains were found in the lower half of the member. This part was exploited by several brick-works. Some finds of shark-teeth in the higher parts suggest that the faunal composition in the lower part is slightly distinct from the one in the upper part.

Little is known with certainty about the original thickness of the Eibergen Member. In boring 28G.3-1 at Delden a thickness of 3 m was measured. Here, it can be supposed that the top sediments have been removed by erosion: the Zenderen Member was deposited discordantly on top of the Eibergen Member with a thin basal gravel. In boring 34B.3-1, north-west of Neede where the Eibergen Member was reached at 68.50 m below surface, presumably no hiatus occurs.

In the borings 41B.2-8, 41B.2-6 and 41E.3-39 around Groenlo and Aalten the Eibergen Member is discordantly covered by the Delden Member, so here a distinct hiatus is present. In this region a rather distinct basal gravel — containing reworked whale bones, shark-teeth, phosphorite concretions and clay balls — is generally found on the surface of discordance. Therefore, here too, a part of the Eibergen Member could have been removed by erosion. In the area of Groenlo, Eibergen, Aalten and Winterswijk a thickness of 25 - 35 m is normal for the Eibergen Member. In deep-boring Lochem (ten Dam, 1945) a thickness of 19 m was measured, but it is possible that a part of the overlying sediments should be differently interpreted, therefore here a greater thickness remains possible for this member.

Stratigraphical aspects — Correlation of the Eibergen Member with other deposits is hardly possible because of the absence of molluscs and foraminifera. The remains

of whales can not yet be used for this purpose; in the first place they have for the greater part not yet been studied, while, on the other hand, their stratigraphical distribution is not known elsewhere. However, a correlation is possible by means of the many shark-teeth collected at several places. This will be treated in more detail in the palaeontological chapter below.

Presumably the base of the Eibergen Member was deposited in rather deep water; the upwards increase of the glauconite content might indicate a regressive character of the member. It is certain that sedimentation was rather rapid, under quiet circumstances, since most of the whale fossils are represented by more or less complete skeletons; unfortunately these have never been collected as such.

AFZETTING VAN ZENDEREN (ZENDEREN MEMBER), NEW MEMBER

General concept — This member consists of fine quartz sands, usually very silty and dark green in colour, with fine glauconite. The grain size increases upwards. Locally, soft and extremely sandy clay streaks occur. Grain size usually varying between 75 and 100 μm. Molluscs and foraminifera are found when the sediments are not decalcified, usually concentrated in one or more horizons. The member also yields rather many fish remains. Locally, but mainly at the top some valves of the brachiopod *Lingula* are found.

This lithological unit is introduced here as a member named after the municipality of Zenderen, where the stratotype is situated. The member can not with certainty be recognized in the literature. The deposits in the former moulding-sand pit in the "Needse Berg" were generally classified as "Boven-Mioceen". The member was included in the "Laag van Delden" by van den Bosch & Janssen (1965).

Stratotype — Boring 28G.172 was made by the Rijks Geologische Dienst (by order of Rijkswaterstaat) in May 1971, south-west of Zenderen, near the "Retraitehuis", municipality of Zenderen, depth 16.50-23.46 m below surface; map-sheet 28G, co-ordinates X = + 90.520, Y = + 18.240, height of surface c. 12.20 m + N.A.P. Boring method: bailer-sampling. Samples are kept in the collection of the RGD, duplicate samples in the RGM collection (RGM 184 505 to RGM 184 538). Locality map see fig. 14, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 11.

0.00 - 6.00 m	Quaternary: sand.
6.00 - 16.50 m	Delden Member, reference section, see p. 46.
	Zenderen Member, stratotype section:
16.50 - 18.00 m	fine dark green, very silty sand, very much fine glauconite, fine mica, some fragments of *Lingula*.
18.00 - 19.00 m	as above, with some shell grit.
19.00 - 19.50 m	as above, without shell grit.
19.50 - 21.00 m	as above, with little shell grit.
21.00 - 22.00 m	as above, with little shell grit and small fish remains.
22.00 - 22.50 m	as above, some shell grit.
22.50 - 23.46 m	as above, without shell grit.
23.46 - 23.71 m	Eibergen Member: dark brown, hard clay.

The stratotype was selected in the region of Zenderen because in that area the

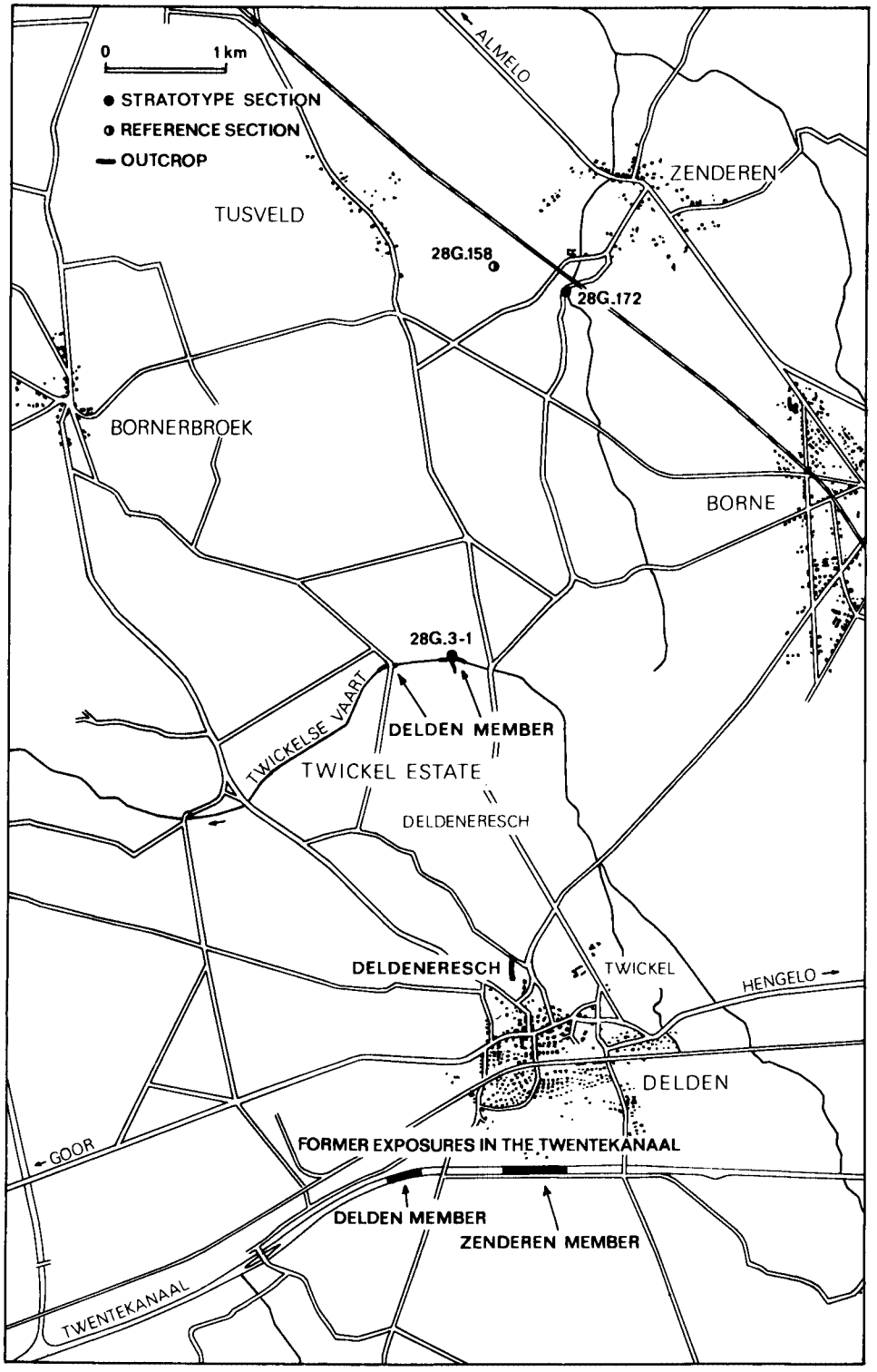

Fig. 14. Map showing the type-localities of the Zenderen Member (boring 28G.172) and the Delden Member (boring 28G.3-1).

member is present at a rather large scale and rather undisturbed. Many borings in this area have demonstrated the Zenderen Member.

Reference sections — Boring 28G.158 made by the Rijks Geologische Dienst (by order of Rijkswaterstaat) in November 1970, south-west of Zenderen and east of Tusveld, municipality of Zenderen, depth 15.95-23.90 m below surface; map-sheet 28G, co-ordinates X = + 89.960, Y = + 18.930, height of surface c. 11.50 m + N.A.P. Boring method: bailer-sampling. Samples are kept in the collection of the RGD. Locality map see fig. 14, grain size analysis see fig. 15.

0.00 - 3.10 m	Quaternary: clay and sand.
3.10 - 15.95 m	Delden Member, reference section, see p. 47.
	Zenderen Member, reference section:
15.95 - 16.20 m	fine dark green sand, very silty, with fine glauconite and mica, thin sandy clay streaks.
16.20 - 23.90 m	fine dark green sand, silty, with fine glauconite and very much fine mica.
23.90 - 24.05 m	Eibergen Member: dark brown, hard clay.

The grain size of the sediments of the Zenderen Member starts at the base with an average of 75 μm and a lutum content of approximately 8.5%, upwards the average grain size increases to somewhat over 100 μm while the lutum content remains almost the same (see fig. 15).

Boring 28G.3-1, at the Twickel estate, on the Twickelse Vaart, municipality of Delden, depth 7.50-13.00 m below surface; map-sheet 28G, co-ordinates X = + 89.600, Y = + 15.790, height of surface c. 14.50 + N.A.P. See for further information about this boring the description of the Delden Member stratotype. Locality map see fig. 14, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 13.

0.00 - 1.40 m	Quaternary: sand.
1.40 - 7.50 m	Delden Member, stratotype section, see p. 45.
	Zenderen Member, reference section:
7.50 - 8.00 m	greenish grey, fine to rather fine sand, rather silty, much glauconite, little fine quartz gravel, some valves of *Lingula*.
8.00 - 8.50 m	dark green, very fine to fine sand, very silty, much glauconite, a trace of very fine quartz gravel.
8.50 - 9.00 m	as above, without quartz gravel.
9.00 - 10.00 m	as above, with a trace of very fine quartz gravel, some vivianite, a single *Lingula* valve.
10.00 - 10.50 m	dark green, very fine to fine sand, very silty, much glauconite, very little weathered shell grit.
10.50 - 11.00 m	as above, little weathered shell grit, small fish remains.
11.00 - 11.50 m	as above, very little weathered shell grit, little very fine mica, small fish remains.
11.50 - 12.00 m	dark green, very fine to fine sand, very silty, much glauconite, little very fine mica, very little weathered shell grit, some carbonized wood scales, small fish remains.
12.00 - 12.50 m	as above, a single *Lingula* valve, some fine quartz gravel, rather much fine crumbly concretions, small fish remains.

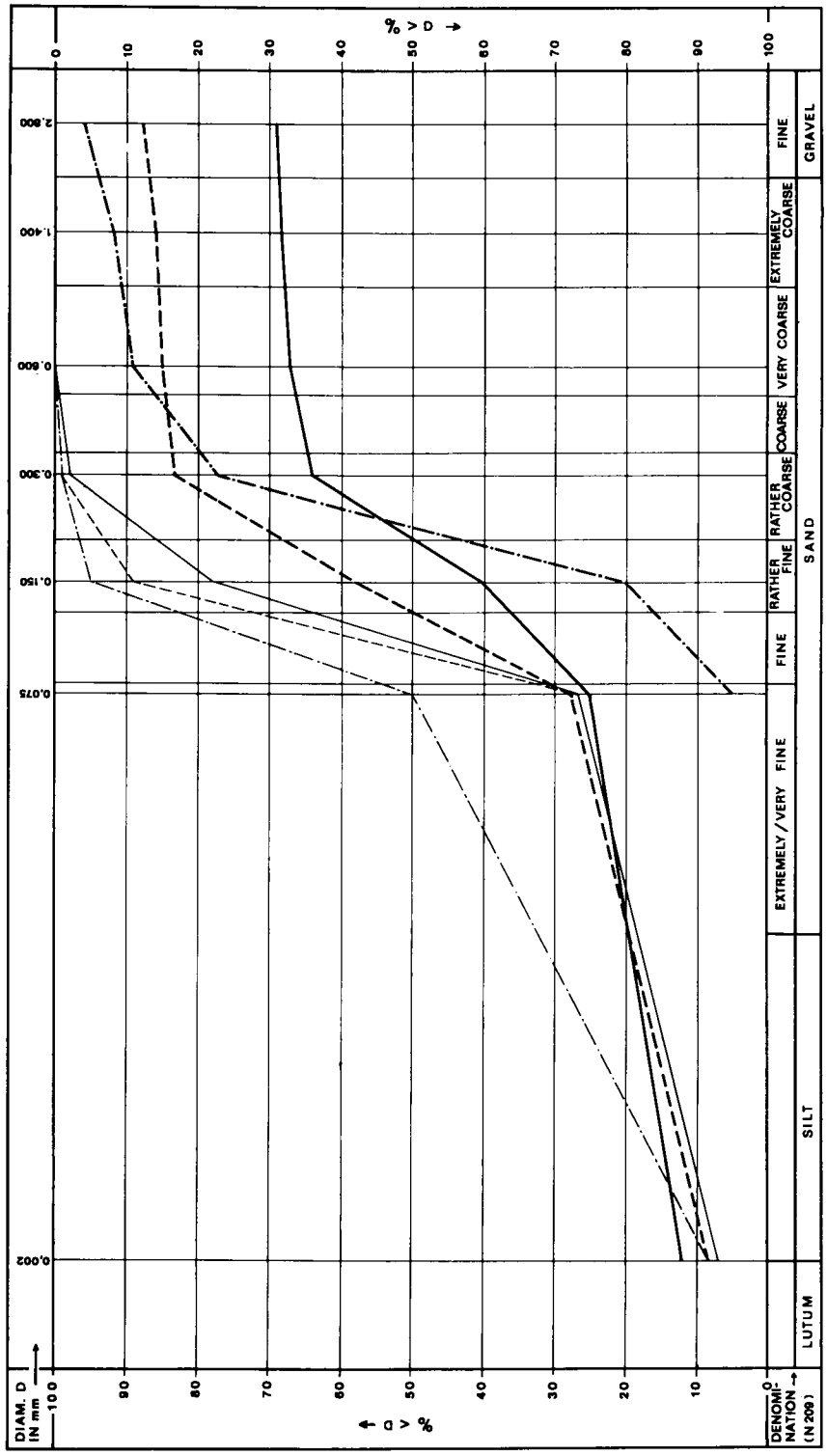

Fig. 15. Grain size analysis of three samples from the Zenderen Member and three samples from the Delden Member, boring 28G.158 at Zenderen (see Fig. 14). This analysis was carried out by the Rijkswaterstaat at Almelo.

12.50 - 13.00 m	dark green, fine sand, very silty, much glauconite, little very fine mica, very little weathered shell grit, small fish remains, some vivianite, some fine quartz gravel, little fine crumbly soft concretions, some reworked clay lumps from the underlying deposits.
	Eibergen Member:
13.00 - 13.50 m	dark brownish black, very hard, heavy clay, not calcareous, much very fine mica, locally some thin burrows filled with sand from the overlying sediment, as well as some larger pockets and cavities (data from undisturbed cores).
13.50 - 15.00 m	dark greenish brown, hard, rather heavy clay with a low content of very fine sand, not calcareous, much very fine mica.
15.00 - 16.00 m	dark greenish grey clay with a high content of very fine sand, somewhat calcareous, much very fine mica, very little fine green glauconite.
16.00 - 21.65 m	Aalten Member, reference section, see p. 30.
21.65 - 35.00 m	Brinkheurne Member, reference section, see p. 13.

Boring 34B.3-1, near the Gelselaars bridge, 1.5 km east of Gelselaar, municipality of Neede, depth 49.50-68.50 m below surface, map-sheet 34B, co-ordinates X = + 79.515, Y = + 1.650, height of surface c. 16.00 m + N.A.P. Boring made by M. van den Bosch, October 1970, in co-operation with the "Waterleiding Mij. Oostelijk Gelderland" and the "Dienst Grondwaterverkenning T.N.O.". Boring method: bailer-sampling with casing 125 mm Ø to 7.25 m, mud-boring 100 mm Ø to 72.50 m. Samples RGM 184 539 to RGM 184 613. Bore hole logs and geothermal logs are available in the RGM files. Locality map see fig. 1, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 12.

0.00 - 27.50 m	Quaternary: sand, clay, sand with gravel.
27.50 - 32.50 m	? Lievelde Member, see p. 55.
32.50 - 49.50 m	Delden Member, reference section, see p. 47.
	Zenderen Member, reference section:
49.50 - 52.50 m	greenish grey, fine, silty sand, rather much glauconite, rather much mica.
52.50 - 55.50 m	greenish grey, fine, silty sand, little glauconite, rather much mica.
55.50 - 60.00 m	greenish grey, fine, silty sand, rather little glauconite, much mica.
60.00 - 61.00 m	as above, some shell grit.
61.00 - 63.50 m	as above, rather little shell grit, fine fish remains.
63.50 - 66.50 m	greenish grey, fine, silty sand, much glauconite, much mica, little shell grit.
66.50 - 68.50 m	as above, some shell grit.
	Eibergen Member:
68.50 - 69.00 m	greenish grey clay with a very high content of fine sand, little glauconite, rather much mica.
69.00 - 70.00 m	as above, less glauconite.
70.00 - 71.50 m	greenish grey clay with a rather high content of fine sand and with streaks of heavy clay, some glauconite, rather much mica.
71.50 - 72.50 m	as above, somewhat less sandy, colour brownish.

Regional aspects — As far as known the Zenderen Member shows little variation in lithological composition. The grain size is on the average 75-100 μm, with a maximum of 250 μm; the sediments are always very silty. Only in the boring 34B.3-1 near the Gelselaars bridge the silt content may be somewhat lower. The sands can not be regarded, however, as a hydrological barrier: in spite of the high silt content the sediments are somewhat permeable.

The member is mainly found in Twente, but the restriction must be made that nothing is known about the occurrence in a more western direction.

Near Zenderen and Delden the Zenderen Member has a thickness of 6.5-8 m. It increases gradually in a western direction: in the boring 34B.3-1 near the Gelselaars bridge a thickness of 19 m was encountered. Furthermore, the member is known from former exposures in the Twentekanaal near Delden, notably from the part east of the St. Anna bridge (Krul, 1950), see fig. 14. The thickness of the sediments in this outcrop, which yielded a large quantity of shark-teeth, is, however, unknown. The member could also be recognized in deposits formerly exposed in the Needse Berg, where it showed a strong glacial deformation. The lithology of the former outcrops in the Twentekanaal and the Needse Berg has not been described in detail and therefore these exposures can not be used as reference sections.

The thickness of the member decreases quickly from Neede to the area of Groenlo and it disappears completely near Lievelde and Winterswijk. This is caused by the fact that the erosion surface (described above for the Eibergen Member, see p. 38) cuts younger sediments in a more southern direction. Near Aalten the discordance is found in the Delden Member. Locally the unconformable deposits contain some basal gravel, usually with some fine gravel and clay lumps originating from the Eibergen Member. It is still uncertain whether the sandy part from 7.35-14.50 m in boring 41D.2-7, south-east of Aalten, can be correlated with the lower part of the Zenderen Member in Twente (see p. 36).

Stratigraphical aspects — Locally the Zenderen Member yields some molluscs which, although in a very weathered and fragmentary condition, give an impression of the fauna. This will be treated in more detail in the palaeontological chapter below. Striking is a horizon with abundant fish remains in the lower part of the member, found in each of the studied sections.

Like the Eibergen Member the Zenderen Member has a regressive character that may be demonstrated by a further increase of the glauconite content. The sediments have presumably been deposited in shallow water; apparently sedimentation took place in a quiet environment with only slight lateral variation.

AFZETTING VAN DELDEN (DELDEN MEMBER) STARING, 1860, EMENDED

General concept — This member consists of rather fine to rather coarse quartz sands containing glauconite and goethite grains, grading to rather coarse goethite sands containing quartz grains, always more or less silty. With an exception for the top and basal sediments of the member numerous hard and soft phosphorite concretions occur that can become very large. Phosphorite is also encountered as continuous beds or slabs that can obtain a considerable thickness. In this phosphorite locally many external and internal moulds of shells are found. Locally, many vivianite crystals are present. The grain size varies from 150-200 μm, with a maximum of c. 1000 μm; locally a considerable quantity of fine gravel forms part of the sediment. The colour can be dark green, dark greenish grey, dark bluish green, grey or blackish, depending from the silt and glauconite content. The whole member is characterized by the abundant occurrence of the brachiopod *Lingula*.

This lithological unit is introduced here as a member named after the municipality of Delden. At the Twickel estate (Delden) the member is well exposed, therefore the stratotype was selected at that locality. The emendation of the name

"Leem van Delden" (Staring, 1860, p. 198) to Delden Member will be discussed in the paragraph on the stratigraphical aspects.

The Delden Member is well-known from the older literature because of its abundant fossils; it was usually reckoned to be Late Miocene. The large phosphorite content has not been mentioned in the literature so far. Van den Bosch & Janssen (1965) followed Staring in using the denomination "Laag van Delden" for the fossiliferous deposits, but they included also the Zenderen Member.

Stratotype — Boring 28G.3-1 at the Twickel estate, on the Twickelse Vaart, municipality of Delden, depth 1.40 - 7.50 m below surface; map-sheet 28G, co-ordinates X = + 89.600, Y = + 15.790, height of surface c. 14.50 m + N.A.P. Boring made by the RGM, 17 to 21 June 1974. Boring method: bailer-sampling with casing 125 mm Ø to 7 m, bailer-sampling with casing 63 mm Ø to 13.75 m (from 13.00 to 13.75 m also undisturbed cores were obtained), wash-boring 50 mm Ø to 35.00 m. Samples RGM 184 614 to RGM 180 663. Locality map see fig. 14, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 13.

0.00 - 1.40 m	Quaternary: sand.
	Delden Member, stratotype section:
1.40 - 2.00 m	dark green, very sandy clay with pockets of Quaternary sand and gravel.
2.00 - 3.00 m	dark greenish grey, clayey sand, fine to rather fine, with many pockets of Quaternary sand and gravel.
3.00 - 3.50 m	dark greenish black, rather fine, slightly silty sand with many coarse grains, very much goethite, rather little soft phosphorite concretions, small vivianite crystals, rather many valves of *Lingula*.
3.50 - 4.00 m	dark greenish grey, rather fine, slightly silty sand, with coarse grains, very much goethite, rather many soft phosphorite concretions with some moulds of shells, small vivianite crystals, many valves of *Lingula*.
4.00 - 4.50 m	dark greenish grey, rather fine, rather silty sand, with few coarse grains and some fine quartz gravel, very much goethite, some soft phosphorite concretions with some moulds of shells, vivianite crystals, many valves of *Lingula*.
4.50 - 5.00 m	dark greenish grey, rather fine, slightly silty sand, very much goethite, many soft phosphorite concretions with some moulds of shells, vivianite crystals, many valves of *Lingula*.
5.00 - 5.50 m	dark greenish black, rather fine, slightly silty sand with few coarse grains, very much goethite, rather many soft phosphorite concretions, vivianite crystals, rather many valves of *Lingula*.
5.50 - 6.00 m	dark greenish grey, rather fine, slightly silty sand with rather many coarse grains and little fine quartz gravel, much goethite and glauconite, rather many soft phosphorite concretions, rather few valves of *Lingula*.
6.00 - 6.50 m	dark greenish grey, rather fine, rather silty sand with rather many coarse grains, some fine quartz gravel, much glauconite and goethite, vivianite cystals, rather many soft phosphorite concretions, rather few valves of *Lingula*.
6.50 - 7.00 m	dark greenish grey, rather fine, slightly silty sand with many coarse grains and little fine quartz gravel, much glauconite and goethite, few soft phosphorite concretions, vivianite crystals, few valves of *Lingula*.
7.00 - 7.50 m	dark greenish grey, rather fine, rather silty sand with some fine quartz gravel, much glauconite and goethite, vivianite crystals, some valves of *Lingula*.
7.50 - 13.00 m	Zenderen Member, reference section, see p. 41.
13.00 - 16.00 m	Eibergen Member, see p. 43.
16.00 - 21.65 m	Aalten Member, reference section, see p. 30.
21.65 - 35.00 m	Brinkheurne Member, reference section, see p. 13.

The stratotype is selected at this locality because the Delden Member is very well exposed in the Twickelse Vaart, this outcrop has been known ever since the 18th century. Staring's description of the "Leem van Delden" was based on this exposure.

The subsurface of the Twickel area, especially the "Deldeneresch", has been deformed to a high degree by glacial action. The sediments in the outcrop on the Twickelse Vaart and in the boring described above have presumably not been affected by this deformation, but the possibility must be kept in mind that the depth of the deposits may have been changed somewhat as a result of this glacial activity.

Reference sections — The outcrop in the Twickelse Vaart at the Twickel estate, north of Delden. This classical exposure runs from c. 200 m upstream of the boring 28G.3-1 (see fig. 14) to c. 250 m downstream of this boring. It shows the same lithological succession as found in the boring 28G.3-1. The soft phosphorite concretions are well-exposed in the banks of the canal as irregular lumps and large slabs, also less cemented phosphorite occurrences are present. Many moulds of shells have been found here.

Boring 28G.172, made by the Rijks Geologische Dienst (by order of the Rijkswaterstaat) south-west of Zenderen, near the "Retraitehuis", municipality of Zenderen, depth 6.00 - 16.50 m below surface. Further information about this boring see the descriptions of the Zenderen Member stratotype. Locality map see fig. 14, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 11.

0.00 - 6.00 m	Quaternary: sand.
	Delden Member, reference section:
6.00 - 7.00 m	green, rather fine, silty sand with coarse grains, some very sandy clay streaks, glauconitic, some soft phosphorite concretions, few valves of *Lingula*.
7.00 - 9.00 m	green, rather fine, silty sand with coarse grains, some very sandy clay streaks, glauconitic, many soft phosphorite concretions with moulds of shells, few valves of *Lingula*.
9.00 - 10.00 m	as above, with goethite, many valves of *Lingula*.
10.00 - 10.50 m	more or less massive bed of phosphorite with goethite sand, abundant valves of *Lingula*.
10.50 - 11.00 m	green, rather fine, silty sand with coarse grains, some very sandy clay streaks, very much goethite, rather many soft phosphorite concretions, rather many valves of *Lingula*.
11.00 - 11.50 m	as above, dark green, many soft phosphorite concretions with moulds of shells, many valves of *Lingula*.
11.50 - 12.00 m	more or less massive bed of phosphorite with goethite sand, many valves of *Lingula*.
12.00 - 13.00 m	dark green, rather fine, silty sand with coarse grains and some very sandy clay streaks, very much goethite, few soft phosphorite concretions, few valves of *Lingula*.
13.00 - 13.50 m	more or less massive bed of phosphorite containing goethite sand, with moulds of shells, abundant valves of *Lingula*.
13.50 - 14.50 m	green, rather fine, silty sand with goethite, some soft phosphorite concretions, few valves of *Lingula*.
14.50 - 16.50 m	green, rather fine, silty sand with a downwards decreasing content of goethite and an increasing amount of glauconite, some valves of *Lingula*.
16.50 - 23.46 m	Zenderen Member, stratotype section, see p. 39.
23.46 - 23.71 m	Eibergen Member, see p. 39.

Boring 28G.158, made by the Rijks Geologische Dienst (by order of the Rijkswaterstaat) south-west of Zenderen, east of Tusveld, municipality of Zenderen, depth 3.10-15.95 m below surface. Further information about this boring see reference sections of the Zenderen Member. Locality map see fig. 14, grain size analysis see fig. 15. Description adapted from the RGD files.

0.00 - 3.10 m	Quaternary: clay and sand.
	Delden Member, reference section:
3.10 - 4.50 m	greenish grey, rather fine, very silty sand with some dry silty clay streaks, containing glauconite and goethite.
4.50 - 6.30 m	grey, rather fine, silty sand with many thin sandy clay streaks, containing glauconite and goethite, thin phosphorite streaks.
6.30 - 7.15 m	laminated complex of dry clay, phosphorite and sand, very stiff.
7.15 - 7.50 m	dark greenish grey, rather fine, somewhat silty sand with very silty dry streaks.
7.50 - 9.50 m	greyish green, rather fine, silty sand with very sandy dry clay streaks, much goethite and many soft phosphorite concretions.
9.50 - 15.95 m	as above, dark green.
15.95 - 23.90 m	Zenderen Member, reference section, see p. 41.
23.90 - 24.05 m	Eibergen Member, see p. 41.

(The occurrence of *Linguia* valves was not mentioned in the description).

From the grain size analysis (fig. 15) it can be read that the Delden Member may be distinguished from the Zenderen Member by the quickly increasing grain size of the sand fraction, which in this boring starts at the base with an average of 125 μm, coarsening upwards to over 250 μm. Striking is also the percentage of fine quartz gravel (to over 2 mm) which is 7% at the base of the Delden Member and increases upwards to more than 30%. The lutum content is the same as in the sediments of the Zenderen Member: 8-12%.

Boring 34B.3-1, near the Gelselaars bridge, 1.5 km east of Gelselaar, municipality of Neede, depth 32.50-49.50 m below surface. Further information about this boring see reference sections of the Zenderen Member. Locality map see fig. 1, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 12.

0.00 - 27.50 m	Quaternary: sand, clay, sand with gravel.
27.50 - 32.50 m	? Lievelde Member, see p. 55.
	Delden Member, reference section:
32.50 - 33.50 m	greenish grey, hard, phosphorite layer with rather fine sand, silty, little glauconite and goethite, rather little mica.
33.50 - 34.50 m	greenish grey, rather fine, silty sand, little glauconite and goethite, rather little mica, from 33.70 to 34.15 cemented to a massive layer.
34.50 - 36.50 m	dark green, somewhat brownish, rather fine to rather coarse, silty sand, much goethite, rather little mica, hard phosphorite concretions in levels, fragments of *Lingula*.
36.50 - 37.50 m	dark green, somewhat brownish, rather fine, silty sand, much goethite, rather little mica, little shell grit.
37.50 - 38.50 m	as above, rather much fine shell grit.
38.50 - 39.50 m	dark greenish black, rather fine to rather coarse, silty goethite sand, little mica, rather much fine shell grit, *Lingula*.

39.50 - 41.50 m	dark greenish black, rather fine to rather coarse, silty goethite sand (consisting for 2/3 of goethite and for 1/3 of quartz), little mica, rather little fine shell grit, *Lingula, Ditrupa,* sometimes cemented to massive phosphorite layers.
41.50 - 42.50 m	as above, cemented to a massive phosphorite layer.
42.50 - 43.50 m	dark green, rather fine to rather coarse, silty goethite sand, little mica, rather little shell grit (Pectinidae, *Arctica*), *Lingula, Ditrupa.*
43.50 - 45.50 m	as above, somewhat more shell grit.
45.50 - 46.50 m	dark greenish grey, rather fine to rather coarse, silty sand, rather much goethite, little mica, little shell grit, *Lingula.*
46.50 - 47.50 m	greenish grey, rather fine, silty sand, rather much glauconite and goethite, little mica, rather little shell grit (Pectinidae), *Lingula, Ditrupa.*
47.50 - 48.50 m	greenish grey, rather fine, silty sand, rather much glauconite, rather little mica, some shell grit, *Lingula.*
48.50 - 49.50 m	greenish grey, rather fine, silty sand, rather little glauconite, rather much mica, some shell grit.
49.50 - 68.50 m	Zenderen Member, reference section, see p. 43.
68.50 - 72.50 m	Eibergen Member, see p. 43.

In this boring at least 7 m highly concentrated goethite sand is present, mainly between 38.50 and 45.50 m below surface, besides another 5 m less concentrated goethitic sand is found above and below this horizon. Furthermore, massive phosphorite layers exist with a total thickness of 3.50 m. Apart from these massive layers many phosphorite concretions are found over a thickness of another 2 m. Many of the unconsolidated phosphorite layers and concretions will not have been noticed in this mud-boring; also the occurrence of small vivianite crystals may have been overlooked. The most important phosphorite horizons occur from 32.50 to 36.50 m and from 39.50 to 42.50 m below surface, which results in a total thickness of 7 m. These two layers are quite distinct on the bore logs of the "Dienst Grondwaterverkenning T.N.O.". The highest goethite content roughly agrees with the lower phosphorite horizon.

Boring 34D.4-4, west of Groenlo, depth 10.90-15.30 m below surface, mapsheet 34D, co-ordinates X = + 83.420, Y = – 12.280, height of surface c. 24.50 m + N.A.P. This boring was made by M. van den Bosch on 3 August 1964. Boring method: bailer-sampling with casing 63 mm Ø to final depth. Samples RGM 184 664 to RGM 184 676. Locality map see fig. 16, geological cross section see fig. 17, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 14.

0.00 - 3.40 m	Quaternary: sand, gravel.
3.40 - 10.90 m	Lievelde Member, reference section, see p. 53.
	Delden Member, reference section:
10.90 - 11.70 m	greenish grey, rather fine sand with many coarse grains and some fine gravel, very silty, streaks of soft, dark green clay, rather little glauconite and goethite, pieces of greenish phosphorite.
11.70 - 12.80 m	dark green, rather fine, very silty sand, rather little glauconite and goethite, little mica, traces of shell grit, *Lingula,* some soft phosphorite concretions.
12.80 - 13.60 m	dark green, rather fine, very silty sand, many goethite grains, little mica, rather many clay lumps and soft phosphorite concretions, some fragments of *Lingula.*
13.60 - 14.25 m	as above, with some shell grit.
14.25 - 15.30 m	dark green, rather fine, slightly silty sand, little mica, many glauconite and goethite grains, much shell grit (*Arctica*), *Lingula,* rather many fish remains.

Zenderen Member:

15.30 - 16.60 m dark green, very fine, very silty sand, much fine glauconite, rather much fine mica, little shell grit.

16.60 - 17.00 m dark green, extremely fine to fine, very silty sand, much fine glauconite, rather much fine mica, traces of shell grit.

Eibergen Member:

17.00 - 17.20 m dark green clay with a high content of very fine sand, much fine mica, glauconitic.

Boring 41B.2-6 on the railway Zutphen-Winterswijk at Lievelde, municipality of Lichtenvoorde, depth 9.00-15.70 m below surface; map-sheet 41B, co-ordinates X = + 83.800, Y = – 15.700, height of surface c. 30 m + N.A.P. Further information about this boring see stratotype section of the Lievelde Member, p. 55. Locality map see fig. 16, geological cross section see fig. 17, boring section and estimated grain sizes of the sediments see enclosure 1, fig. 15.

0.00 - 0.15 m Quaternary: black earth.

0.15 - 9.00 m Lievelde Member, stratotype section, see p. 55.

Delden Member, reference section:

9.00 - 10.00 m greenish grey, sandy clay with some streaks of fine sand, little coarse mica, glauconite and goethite grains.

10.00 - 10.25 m light greenish grey, rather stiff, rather sandy clay, with glauconite and goethite grains, rather little mica, a fragment of *Lingula*.

10.25 - 11.40 m greenish grey, rather fine to rather coarse sand, rather silty, little sandy clay streaks, rather much glauconite and goethite grains, little mica, little soft phosphorite concretions.

11.40 - 11.50 m massive phosphorite layer with glauconite and goethite grains.

11.50 - 12.00 m greenish grey, very sandy clay with little sand streaks, some mica, few coarse glauconite and goethite grains.

12.00 - 13.00 m green, very sandy clay with many sand streaks, some fine mica, many coarse glauconite and goethite grains.

13.00 - 14.00 m green, rather fine sand with some coarse grains, very silty, rather many sandy clay streaks, many glauconite and goethite grains, some shell fragments (*Dentalium*), *Lingula*, fish remains, shark-teeth, soft phosphorite concretions with moulds of shells.

14.00 - 15.00 m greenish grey, fine sand, very silty, many coarse glauconite and goethite grains, very little fine mica, fish remains, shark-teeth, fragments of *Lingula*, some clay lumps, some soft phosphorite concretions.

15.00 - 15.70 m as above, little fine mica, many small fish remains.

15.70 - 40.00 m Eibergen Member, reference section, see p. 37.

Boring 41E.3-39 near the wood "'t Klooster" at the Schaarsheide, municipality of Aalten, depth 3.35-5.35 m below surface; map-sheet 41E, co-ordinates X = + 85.035, Y = – 20.640, height of surface c. 39.00 m + N.A.P. Further information about this boring see the description of the Eibergen Member reference sections, p. 36. Locality map see fig. 16, geological cross section see fig. 17.

0.00 - 3.35 m Quaternary: boulder clay, glacially deformed Tertiary deposits.

Delden Member, reference section:

3.35 - 3.80 m dark greenish grey, rather fine, very silty, sand, with rather many coarse grains, little very fine gavel, little glauconite and goethite, traces of mica, abundant hard phosphorite concretions.

3.80 - 4.40 m	dark greenish grey, fine to rather fine, very silty sand with few coarse grains, rather many glauconite and goethite grains, some mica, few soft phosphorite concretions.
4.40 - 4.45 m	dark greenish grey, fine to rather fine sand, extremely silty, a trace of very fine quartz gravel, some mica, rather many glauconite and goethite grains, laminated with some very thin sandy clay streaks.
4.45 - 4.70 m	greenish grey, fine sand, extremely silty, rather many coarse quartz grains, some mica, rather many glauconite and goethite grains, many thin streaks of greyish green, sandy clay.
4.70 - 4.85 m	dark greyish green, massive phosphorite layer with rather much glauconite and goethite.
4.85 - 5.00 m	green, rather fine sand with rather many coarse grains, very silty, many glauconite and goethite grains, some mica, few phosphorite concretions, some lumps of sandy clay.
5.00 - 5.20 m	dark green, fine to rather coarse, slightly silty sand, a trace of very fine quartz gravel, many glauconite and goethite grains, a trace of mica, few soft phosphorite concretions, a fragment of a whale bone, a bone-fish tooth.
5.20 - 5.35 m	dark greenish grey, massive phosphorite layer, with black hard phosphorite concretions, containing much fine mica, and shell remnants.
5.35 - 15.00 m	Eibergen Member, reference section, see p. 36.

Outcrop in the small brook running through the wood "'t Klooster", 50-200 m downstream reckoned from the boring 41E.3-39, described above, see also fig. 16. The sequence in the exposure roughly agrees with this boring (see also van den Bosch, 1966b). Massive phosphorite layers with moulds of shells are well exposed. The occurrence is rather irregular. In between the phosphorite layers and the Eibergen Member usually a thin sandy deposit is found, containing reworked phosphorite concretions, whale bones, shark-teeth, and valves of *Lingula,* thus showing distinct characters of a basal gravel.

Regional aspects — The concretions so frequently found in the Delden Member were investigated by Dr P. C. Zwaan of the RGM by means of X-ray powder photographs, with the purpose to obtain a correct mineralogical identification. Eight samples from boring 28G.3-1 at Twickel, from the former moulding-sand pit in the Needse Berg and from the outcrop in the wood "'t Klooster" were studied. Each of these samples showed a mixture of quartz and apatite, general formula $Ca_5 (PO_4)_3 (OH, F, Cl)$, in which some PO_4 may have been substituted by CO_3. Therefore all the concretions found in the member have been regarded as phosphorite deposits. Other concretions have not been encountered.

Although the characteristic phosphorite layers, the goethite grains and *Lingula* valves are found almost everywhere, lateral differences do occur. In Twente the member contains rather fine to rather coarse sands, rich in goethite, with little silt and only locally some clay streaks. Around Groenlo, Lievelde and Aalten the grain size shows a small decrease and the sands become relatively more silty and also more clay streaks are found, especially near the top of the member (if not removed by erosion). The goethite content is also less important here. The occurrence of coarse quartz sand or even quartz gravel remains noteworthy; the quartz content shows local differences.

In the phosphorite layers and in the sand containing phosphorite concretions fossils have disappeared by decalcification, only moulds of calcareous fossils are preserved. The phosphate valves of *Lingula* have, of course, not been attacked by the process of decalcification. X-ray powder photographs taken from two samples indicate that these valves contain apatite.

In between the phosphorite layers, sands are found which occasionally

(borings 34B.3-1, 34D.4-4) contain shells. The member — except the topmost sediments — yields many fish remains, although notably less than the Zenderen Member. Moreover, many of these fish remains are reworked. This can be connected with an unconformity at the base of the member in the Gelderse Achterhoek.

In Twente the base of the Delden Member can not sharply be separated from the top of the Zenderen Member. The boundary is drawn at the level where the grain size suddenly increases and where goethite grains appear (see the grain size analysis of fig. 15). Near Lievelde and Aalten, however, the Zenderen Member is absent and the Delden Member discordantly overlies the Eibergen Member. Here, a basal gravel is found containing transported phosphorite concretions of different composition, clay lumps, whale bones and shark-teeth. In the wood "'t Klooster" this basal gravel is well exposed.

A higher concentration of reworked fish remains was noticed in the basal part of the member in the boring 41B.2-6 at Lievelde, also carbonized remains of wood and small seeds of trees were found here.

The thickness of the Delden Member is not always the same. At the type locality Twickel near Delden (28G.3-1) an important part is removed by erosion, a thickness of 6.10 m still remains. In boring 28G.172 at Zenderen a thickness of 10.50 m was encountered and 12.85 m in the boring 28G.158; here too, the top sediments are diminished by Quaternary erosion. In boring 34B.3-1 an apparently complete section is present with a thickness of 17 m. In the Gelderse Achterhoek the thickness decreases quickly: boring 34D.4-4 at Groenlo (apparently complete section) 5.40 m, boring 41B.2-6 (apparently complete section) 6.70 m and boring 41E.3-39 only 2.00 m, but here the top sediments have been eroded.

At places where the top sediments have not been removed during the Quaternary, and where the overlying Lievelde Member is still present (see below), uninterrupted sedimentation from the Delden Member to the Lievelde Member did not always take place. In the neighbourhood of boring 41B.2-6 at Lievelde several borings have been made (not treated in detail here) demonstrating that continuous sedimentation does occur, but also sharp boundaries bewteen both members. In the latter case the sands of the Lievelde Member have cut several metres into the Delden Member; presumably stream channels were formed.

Stratigraphical aspects — The sediments of the Delden Member have for a long time past been known for its numerous moulds of molluscs. Van den Bosch & Janssen (1965) gave a historical review of the nomenclature of these sediments. They decided to denominate the deposit "Laag van Delden", adapting the name "Leem van Delden" of Staring (1860). However, the deposit is known much better now. It does not seem desirable to maintain the lithological denomination "Laag van Delden Staring, 1860" or "Leem van Delden Staring, 1860" without an adequate definition of its contents. Staring had not designated a type locality. The exposure in the Twickelse Vaart, as well as "het Kleigat" and a well-digging on the Twickel estate have been mentioned by him. Especially the attribution of this latter locality is highly uncertain, because this well may even have been dug in early Tertiary sediments. Still one gets the impression that Staring had especially the sediments containing phosphorite concretions and shell moulds in mind. The lithological limitations have not been defined by Staring, nor by van den Bosch & Janssen either. In the present paper the upper and lower boundaries of the Delden Member are defined and a boring on the Twickelse Vaart, at the exposure mentioned by Staring, is designated as the stratotype.

Corresponding to the trend indicated in the Zenderen Member and continued by the Lievelde Member the Delden Member shows a regressive character. Finds of drift-wood and seeds of trees support this supposition. The origin of the sudden deposition of large quantities of phosphorite, goethite and vivianite remains, however, uncertain.

AFZETTING VAN LIEVELDE (LIEVELDE MEMBER), NEW MEMBER

General concept — This member consists of fine to rather fine quartz sands, rather silty to almost free of silt, locally with some fine angular quartz gravel or glauconite, with a low content of mica. At the base om the member sometimes thin clay streaks occur. Also streaks with drifted fine plant remains are sometimes found. The sediment has an average grain size between 100 and 175 μm, with maxima of 250 to 1500 μm. Colour whitish, light grey, light yellowish grey or light greenish grey. Except for the plant remains no fossils have been found.

This lithological unit is introduced here as a member named after the village of Lievelde, on the railway Zutphen - Winterswijk, in the municipality of Lichtenvoorde.

In the literature these sands have occasionally been mentioned as Pliocene or Miocene. Usually, however, they have not been recognized as Tertiary sediments.

Stratotype — Boring 41B.2-6 on the railway Zutphen - Winterswijk at Lievelde, municipality of Lichtenvoorde, depth 0.15 - 9.00 m below surface; map-sheet 41B, co-ordinates X = + 83.800, Y = – 15.700, height of surface c. 30 m + N.A.P. This boring was made by M. van den Bosch, on 10 to 15 July 1965. Boring method: auger-boring 70 mm Ø to 3.00 m, bailer-sampling with casing 63 mm Ø to 21.50 m, mud-boring with excentrical chisel 80 mm ⌀ to 38.00 m, bailer-sampling without casing to 40.00 m. Samples RGM 184 458 to RGM 184 504. Locality map see fig. 16, geological cross section see fig. 17, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 15.

0.00 - 0.15 m	Quaternary: black earth.
	Lievelde Member, stratotype section:
0.15 - 0.55 m	light rusty brown sand (oxidated).
0.55 - 0.80 m	yellowish, fine quartz sand.
0.80 - 1.40 m	light yellowish, fine quartz sand, somewhat silty, with a trace of fine glauconite, some mica, at 1.40 m very thin streaks of heavy clay.
1.40 - 2.00 m	light yellowish green, rather fine quartz sand, somewhat silty, some glauconite, some mica; some hard, finely laminated pieces of sandstone with the same composition.
2.00 - 3.00 m	light greenish yellow, rather fine quartz sand, slightly silty, some glauconite, some mica.
3.00 - 4.00 m	light yellowish white, rather fine quartz sand, many coarse grains, some glauconite, traces of mica.
4.00 - 5.00 m	dark yellow, rather fine quartz sand, oxidated, many coarse grains, a trace of very fine gravel, somewhat silty, some glauconite, a trace of mica.
5.00 - 6.00 m	light greenish grey, fine quartz sand, somewhat silty, some coarse grains, a trace of very fine gravel, little glauconite, little coarse mica.
6.00 - 7.00 m	light greenish grey, very fine to fine quartz sand, rather silty, some coarse grains, some very fine gravel, little glauconite, little mica, some greenish grey clay streaks.
7.00 - 8.00 m	light greenish grey and light brownish grey, laminated, very fine quartz sand, some coarse grains, rather silty, little glauconite, little mica, some

	sandy clay streaks, a calcareous concretion, a quartz pebble of 3 cm.
8.00 - 9.00 m	light brownish grey, very fine quartz sand, rather silty, little glauconite, much coarse mica, some sandy clay streaks, some carbonized wood remains.
9.00 - 15.70 m	Delden Member, reference section, see p. 49.
15.70 - 40.00 m	Eibergen Member, reference section, see p. 37.

The stratotype was selected at this place because in the railway cutting near the stratotype (figs. 16 and 17) the Lievelde Member is exposed. Furthermore the member occurs close to the surface in this region; sometimes it is temporarely exploited in sand-pits for road constructions. These sand-pits are indicated on the locality map (fig. 16), only the easternmost sand-pit was exploited during the years 1973 and 1974.

Reference sections — Railway cutting at Lievelde on the Zutphen - Winterswijk railway, continuing 350 m in the direction of Lievelde from the level-crossing in the Pastoor Schepersstraat. The Lievelde Member can be seen on both sides of the railway cutting in small excavations and in the southern bank of the road. The sediments in the outcrop agree with the upper part of the stratotype section. Locally they are overlain by Quaternary sand and gravel.

Gravel-pit on the road Winterswijk - Lichtenvoorde, near the Dwarsdijk, municipality of Lichtenvoorde; map-sheet 41E, co-ordinates X = + 85.350, Y = – 19.000, height of surface c. 36 m + N.A.P. (fig. 16). This pit, in which Quaternary gravels are exploited, is not continuously at work. Occasionally the Lievelde Member is exploited for the acquisition of moulding-sand for an iron foundry. The member is covered by coarse Quaternary sand and gravel, containing erratic blocks to over 2000 kg. The Lievelde Member consists at this place of almost white, very fine, powder-like sand with only a very slight pollution of glauconite and mica. The sand is almost free of silt.

Boring 34D.4-4, west of Groenlo, depth 3.40 - 10.90 m below surface; map-sheet 34D, co-ordinates X = + 83.420, Y = – 12.280, height of surface c. 24.50 m + N.A.P. Further information about this boring see reference sections of the Delden Member. Locality map see fig. 16, geological cross section see fig. 17, boring section and estimated grain sizes of the sediment see enclosure 1, fig. 14.

0.00 - 3.40 m	Quaternary: sand, gravel.
	Lievelde Member, reference section:
3.40 - 4.50 m	grey, rather fine to rather coarse quartz sand, some fine gravel, some greenish silt.
4.50 - 9.60 m	light yellowish grey, rather fine quartz sand with at the top some coarse grains, little glauconite, mica content increasing slowly downwards.
9.60 - 10.00 m	yellowish grey, rather fine quartz sand with coarse grains, little glauconite, some mica.
10.00 - 10.90 m	light greenish grey, rather fine quartz sand with few coarse grains and some very fine gravel, somewhat silty, rather little glauconite, a trace of mica.
10.90 - 15.30 m	Delden Member, reference section, see p. 48.
15.30 - 17.00 m	Zenderen Member, see p. 49.
17.00 - 17.20 m	Eibergen Member, see p. 49.

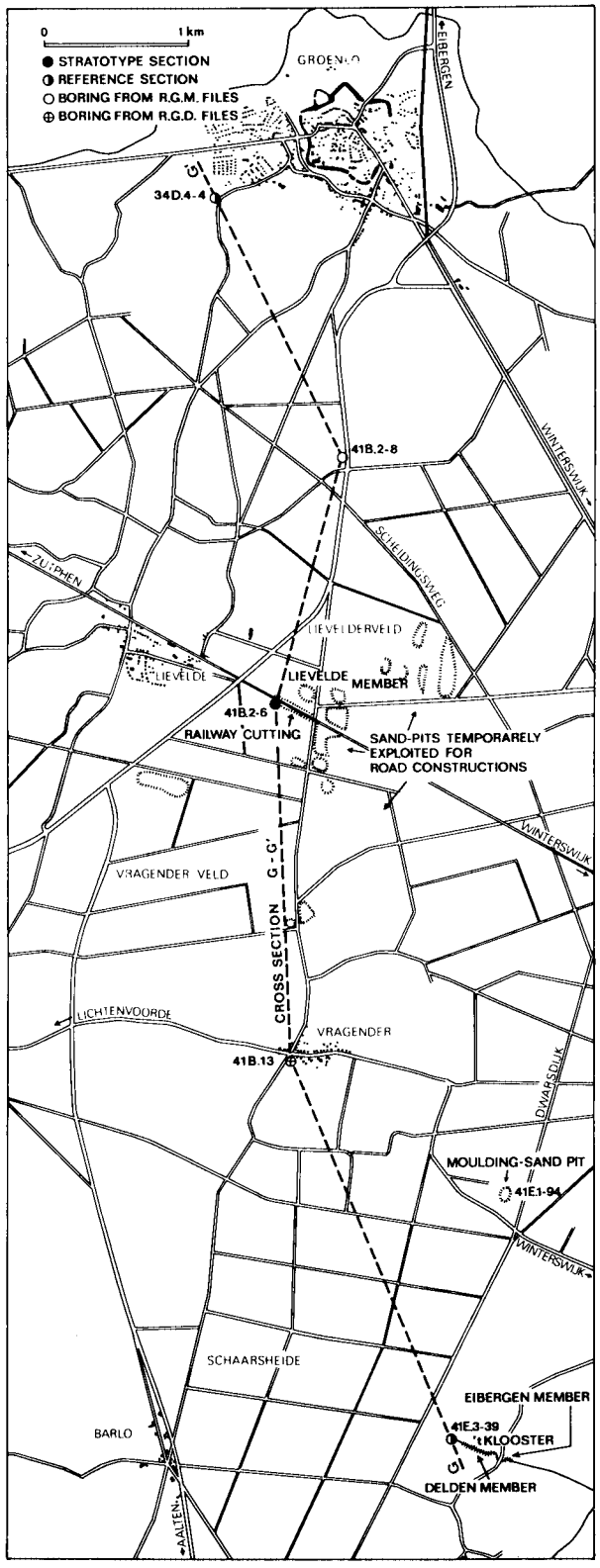

Fig. 16. Map showing the type-locality of the Lievelde Member (boring 41B.2-6). For cross-section G - G' see Fig. 17.

Regional aspects — The Lievelde Member is well-known now from the area between Groenlo, Lievelde, Vragender and Barlo. On the eastern side the occurrence is bordered by the Dwarsdijk and the Scheidingsweg (see fig. 16). In this region, comprising some 20 km², the sediments occur close to the surface. The sand looks nearly always the same as in the outcrop of the Lievelde railway cutting. Occasionally, however, the sands are still finer and then usually light grey or whitish in colour, almost without glauconite, as e.g. in the moulding-sand pit 41E.1-94. In a boring (not described in the present paper) 700 m east of the stratotype, below sands of the usual type a fine whitish quartz sand — containing streaks with drifted plant-remains and some reworked clay lumps — was found. This white sand proved to be the filling of a stream channel, cut to a depth of several metres into the top of the Delden Member.

Between the Delden Member and the Lievelde Member sedimentation was generally continuous, though apparent local unconformities may be found due to stream channels. In the area investigated the usual thickness of the member is c. 10 m but a considerable part might have been removed by erosion all over the area. It is very likely that the Lievelde Member has a much larger distribution than indicated above. In a more western direction the member will undoubtedly be present at places where the Quarternary erosion has not removed much of the sediment. Also in Twente (Vriezenveen, Wierden) the member will probably occur, but from these regions insufficient data are available.

In boring 34B.3-1 near the Gelselaars bridge (see fig. 1 and enclosure 1, fig. 12) a part of the section can presumably be correlated with the Lievelde Member. A description of this section is given here. For further information about this boring see reference sections of the Zenderen Member.

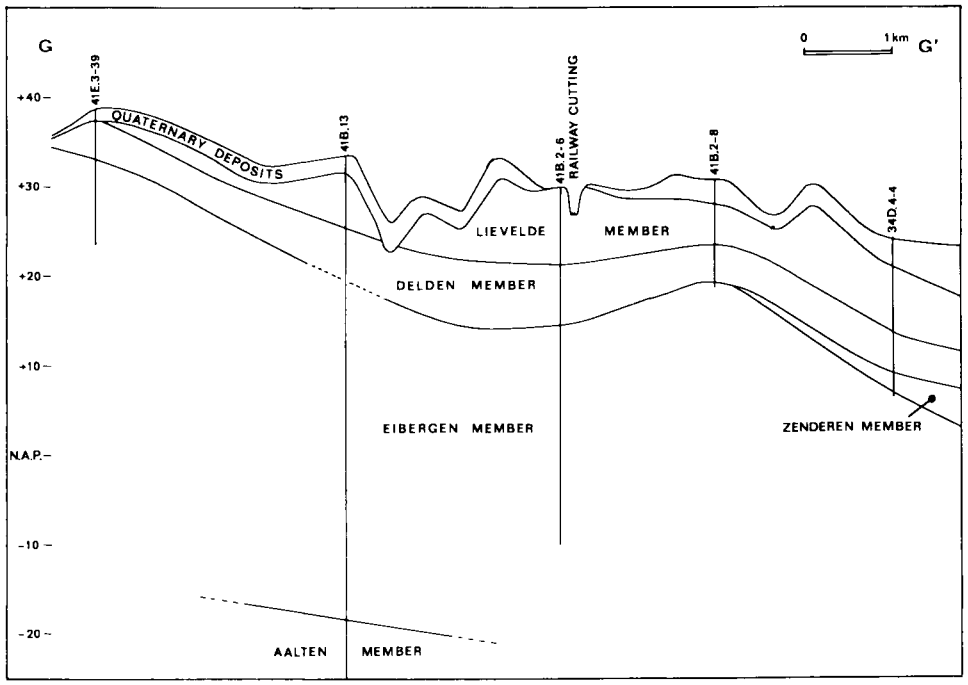

Fig. 17. Geological cross-section of the Lievelde Member stratotype (boring 41B.2-6). For a locality map see Fig. 16.

0.00 - 27.50 m	Quaternary: sand, clay, sand with gravel.
	? Lievelde Member:
27.50 - 31.50 m	light grey, rather fine quartz sand, little glauconite, rather much coarse mica.
31.50 - 32.50 m	light grey, rather fine to rather coarse quartz sand, little glauconite, rather little coarse mica.
32.50 - 49.50 m	Delden Member, reference section, see p. 47.
49.50 - 68.50 m	Zenderen Member, reference section, see p. 43.
68.50 - 72.50 m	Eibergen Member.

Stratigraphical aspects — Up to now it has not been possible to correlate the Lievelde Member by means of palaeontological data. Apart from indeterminate plant-remains no fossils have been found and there is no indication that they have ever been present in these sands. It is certain, however, that the member is a continuation of the sedimentary cycle Zenderen Member - Delden Member. At places where the sedimentary sequence is continuous no sharp boundary can be drawn between the Lievelde Member and the Delden Member.

The Lievelde Member demonstrates the continuous regression already clearly shown by the Delden Member. It can not yet be decided whether the deposits originated in a shallow marine environment or if they should be regarded as fluvio-marine or fluviatile. The glauconite in the deposits could have been reworked. Correlations with other deposits from the same period have not yet been made.

Faunas and biostratigraphy

GENERAL REMARKS

From the above described deposits in the Gelderse Achterhoek and Twente, a large number of mainly unstudied samples is stored in the RGM collections and in several other official and private collections. On the one hand this material consists of numerous boring samples principally kept as reference material, but in many cases they can be used for palaeontological investigation. In general these small quantities of sediment are insufficient for a study of the macrofauna, for micropalaeontological research, however, they are suitable. In some cases, if the fossil content of a deposit made such action desirable and if the sediment made this possible, considerably larger samples have been collected from some levels during the boring procedure by making the sediment well up in the casing as a result of the difference in pressure, obtained by removal of water from the casing.

Several members are well-known from natural outcrops and clay-pits, where larger samples could be collected. It has also been possible to dig temporary exposures in some deposits that occur close to the surface (to a depth of 4.50 m at the most). Especially this latter method has yielded large quantities of fossil material from several localities (Winterswijk-Miste, Eibergen-Ticheloven, Dingden) for further investigation.

As still much research remains to be done on the greater part of the available material, it has not been possible to describe the encountered faunas in detail

			Ratum Member	Brinkheurne Member	Winterswijk Member	Aalten Member		Eibergen Member	Zenderen Member	Delden Member	Lievelde Member
						Miste Bed	Stemerdink Bed				
Foraminifera			-	c	r	cc	cc	-	r	rr	-
Annelida	*Ditrupa* sp.		-	rr	-	c	rr	-	rr	c	-
	Serpula sp.		-	c	-	r	r	-	-	-	-
	other		-	c	r	r	r	-	-	r	-
Anthozoa			-	-	r	c	c	-	-	-	-
Mollusca	Amphineura		-	-	-	rr	-	-	-	-	-
	Bivalvia		-	c	r	cc	cc	-	c	cc	-
	Scaphopoda		-	r	r	cc	c	-	-	-	-
	Gastropoda		-	c	r	cc	cc	-	-	r	-
	Cephalopoda		-	rr	-	rr	rr	-	-	-	-
Brachiopoda			-	rr	r	r	r	-	r	cc	-
Bryozoa			-	r	-	c	c	-	-	rr	-
Echinodermata			-	c	-	c	c	-	-	-	-
Crustacea	Decapoda		-	r	r	c	c	-	-	-	-
	Ostracoda		-	r	-	c	c	-	-	-	-
	Cirripedia		-	-	-	cc	r	-	r	c	-
Vertebrata	Pisces	Elasmobranchii	r	r	rr	c	r	r	c	r	-
		Teleostei	rr	c	r	cc	c	rr	cc	r	-
	Reptilia		-	-	-	rr	-	rr	-	-	-
	Mammalia		-	-	-	r	r	c	r	rr	-
Plantae	drift-wood		-	rr	-	r	r	c	c	c	-
	other		-	-	-	?	-	-	-	c	c

Table 1. Review of fossil groups encountered in the Tertiary sediments (Oligocene - Pliocene) of the Gelderse Achterhoek and Twente. cc = very common, c = common, r = rare, rr = very rare.

here. This would also have gone beyond the scope of this paper. For two important groups of fossils, molluscs and vertebrates (mainly shark-teeth), the investigations are advanced to such a degree that they can be treated here in some detail. Both groups will be discussed in the palaeontological review below.

In the literature only scattered information can be found on other fossil groups. The most important among them are memorized here. Also the fossil groups encountered in the lithological units described in this paper are indicated (see also Table 1).

Foraminifera — Foraminifera are found in not decalcified marine deposits, mainly in the Brinkheurne Member and the Aalten Member. The faunas are usually rich in species. Ten Dam & Reinhold (1942) treated the foraminifera of Oligocene and Miocene deposits from some localities in the Gelderse Achterhoek and Twente.

Batjes (1958) studied the foraminiferal content of some samples of the Brinkherne Member. A sample from the Aalten Member (Miste Bed) of Winterswijk-Miste was investigated for foraminifera by Boekschoten (1969a); this author also made some remarks about the palaeoecology of this fauna. Indans (1971) investigated 54 samples from the boring Dingden-Königsmühle in western Germany. The stratigraphy obtained by studying the foraminiferal content of the Miocene part of the deposits is correlated by her with the stratigraphy published by Janssen (1967). The fossiliferous part of the Oligocene deposits is assigned to the Late Oligocene (Chattien), a more detailed correlation has not been possible.

Annelida — Naturally, only remains of annelids that secrete calcareous tubes are found. Few authors have mentioned annelids so far; Boekschoten (1963a) mentioned *Spirorbis* sp., *Serpula* sp. and *Ditrupula* sp. from the Brinkheurne Member (possibly also from the Winterswijk Member). The species *Serpula septaria* Giebel, so important for the biostratipraphy of the Brinkheurne Member, will be treated in the discussion of the fauna of this member.

Anthozoa — The coral fauna of the Oligocene deposits in the Gelderse Achterhoek and Twente can be neglected. Only a few specimens of *Flabellum* sp. have been found in the Winterswijk Member. Miocene corals from the area concerned have been studied by de Gruyter (1944) and Chevalier (1964). They are only known from the Miste Bed and the Stemerdink Bed in the Aalten Member. Since the appearance of Chevalier's paper a considerable quantity of corals was collected that has been studied only partly by him. Generally, corals are much rarer in the clayey deposits of the Stemerdink Bed than in the more sandy sediments of the Miste Bed. The occurrence of the species *Flabellum pompeckji* Krejci, 1926, however, seems to be restricted to the *Limopsis aurita* Acme Zone of the Stemerdink Bed. In the area investigated the following species are only known from the Miste Bed: *Stephanophyllia nysti* Milne-Edwars & Haime, 1958 and *Sphenotrochus intermedius* (Goldfuss). The latter is characteristic for the *Astarte radiata* Acme Zone and the *Hiatella arctica* Acme Zone. *Eupsammia praelonga* (Michelotti, 1838) is rare in the Stemerdink Bed (Dingden) and in the lower parts of the Miste Bed. However, this species was commonly found in a horizon of limited thickness at Dingden (Janssen, 1967). This level belongs to the upper part of the Miste Bed and forms part of the *Spisula* sp. Acme Zone. All these coral species are ahermatypical.

Mollusca — No complete survey has appeared as yet in the literature on the molluscs. Mollusca from the Brinkheurne Member have been described by Boekschoten (1954), Cadée (1961) and Bosch (1967). Cadée (1969b) has listed the mollusc fauna of the Winterswijk Member. Von Koenen (1872, 1882) studied some Miocene molluscs from Eibergen that are still kept in the collections of the RGM ("Staring collection"). In more recent time the investigation of de Vogel (1970, 1971) has been especially important for the biostratigraphy of the Miocene in the eastern part of the Netherlands. Papers by Anderson (1964) and Janssen (1967, 1969) described the mollusc fauna systematically. Nordsieck (1972) studied a sample from the Miste Bed of Winterswijk (Miste); he expressed curious views with regard to the stratigraphy and many of his determinations are incorrect. Further information about the mollusc fauna is given below in the discussion of the palaeontology of the members.

Brachiopoda — Small numbers of brachiopods have been found in the Brinkheurne Member (Cadée, 1961, p. 33, pl. 3, fig. 46) and in the Winterswijk Member. These specimens have not yet been identified with certainty. In several levels of the Aalten Member a *Terebratulina* sp. and a *Discina* sp. have been found. This *Discina* sp. has been mentioned in the literature also as a gastropod under the name of *Acmaea? deurnensis* Glibert, 1957. In the upper part of the Zenderen Member and in the Delden Member frequently valves of the inarticulate brachiopod *Lingula* sp. are found. This species will be discussed below.

Bryozoa — Pyritized bryozoa are sometimes found in wash-residues of samples from the Brinkheurne Member. In the Aalten Member, especially, lunulitiform bryozoa are frequently encountered, but also incrustating forms are found. Janssen (1966) mentioned an imprint of a bryozoan colony from a shell mould of the Delden Member.

Echinodermata — Spines of regular and irregular sea-urchins have been found in the Brinkheure Member and especially in the Aalten Member. Only very rarely more or less complete specimens occur, as for example a mould with shell fragments of a specimen with a length of about 4 cm from Winterswijk-Miste, originating from the bed of phosphorite concretions in situ. Small specimens of *Echinocyamus* sp. were encountered in Dingden (Miste Bed) and Winterswijk-Miste (Miste Bed), always, however, in small numbers. Spines, especially smaller ones from irregular sea-urchins, are sometimes quite common. Asterozoan skeleton fragments have locally been found in the Aalten Member. All this material has not yet been studied. Boekschoten (1963a) mentioned comatulid fragments from the Brinkheurne Member.

Boring 41E.4-387 at the Stemerdink farmyard at Brinkheurne, Winterswijk. Collected by M. van den Bosch RGM 168 803 - 168 848	Aalten Member							
	Miste Bed							
	Astarte radiata Acme Zone							
	12.00 - 13.00	13.00 - 13.50	13.50 - 14.00	14.00 - 15.00	15.00 - 16.00	16.00 - 17.00	17.00 - 18.00	18.00 - 19.00
Costa tricostata (Reuss, 1850)	x	-	-	-	-	-	-	-
Cytheridea pernota Oertli & Keij, 1955	x	-	x	x	x	x	x	x
Echinocythereis asperrima (Reuss, 1850)	x	-	x	x	x	-	-	-
Echinocythereis hirsuta (Lienenklaus, 1894)	-	-	x	-	-	-	-	-
Echinocythereis hispida (Speyer, 1863)	-	x	-	-	-	-	-	-
Echinocythereis hystrix (Reuss, 1850)	x	-	-	x	-	-	-	-
Eucytheridea curvata (Lienenklaus, 1900)	-	x	x	x	x	-	-	-
Eucytheridea fissodentata (Lienenklaus, 1894)	x	x	x	x	x	x	x	x
Pontocythere lithodomoides (Bosquet, 1852)	-	-	-	x	x	-	-	x
Pterygocythereis prolongata Bassiouni, 1962	x	-	-	-	-	-	-	-
Quadracythere nodoreticulata Bassiouni, 1962 s.s.	x	x	x	x	x	-	-	-
Urocythereis latimarginata (Speyer, 1863)	x	x	x	x	x	x	x	x

Table 2. Ostracode species, kept in the RGM, from the Aalten Member (Miste Bed) of boring 41E.4-387 at Stemerdink, Winterswijk, indentified by Mrs E. J. Noordermeer-Perreijn.

Boring 41D.2-7 at Aalten collected by M. van den Bosch RGM 168 858 - 169 008	40.50 - 41.00	42.00 - 42.50	43.00 - 43.50	43.50 - 44.00	44.00 - 44.50	44.50 - 45.00	45.00 - 45.50	45.50 - 46.00	46.00 - 46.50	46.50 - 47.00	47.00 - 47.50	47.50 - 48.00	48.00 - 48.50	48.50 - 49.00	49.00 - 49.50	49.50 - 50.00	50.00 - 50.50	50.50 - 51.00	51.00 - 51.50	51.50 - 52.00	52.00 - 53.00
	A A L T E N M E M B E R																				
	Stemerdink Bed										Miste Bed										
	Limopsis aurita Acme Zone										*Spisula* sp. Acme Zone				*Astarte radiata* Acme Zone						
Bairdia subdeltoidea (von Münster, 1830)	—	—	—	—	—	—	—	—	×	—	×	—	—	—	×	×	×	×	×	—	—
? *Bosquetina pectinata* (Bosquet, 1852)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—
Costa tricostata (Reuss, 1850)	—	—	—	—	×	—	×	×	×	—	—	—	×	—	×	—	×	—	—	—	—
Cytherella beyrichi (Reuss, 1851)	—	—	—	—	—	—	—	—	×	—	—	—	×	—	—	×	×	—	—	—	—
Cytheretta tenuipunctata (Bosquet, 1852)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—
Cytheridea pernota Oertli & Keij, 1955	×	×	—	×	×	×	—	×	×	—	×	×	×	×	×	×	×	×	×	—	—
Cytheropteron steinmanni Kuiper, 1918	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—
Echinocythereis asperrima (Reuss, 1850)	—	×	×	×	×	—	—	×	—	×	—	×	×	×	×	×	×	×	×	—	—
Echinocythereis hispida (Speyer, 1863)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	×	—	—
Echinocythereis hystrix (Reuss, 1850)	—	—	—	×	—	×	—	×	—	—	—	—	—	—	—	—	—	—	×	×	—
Echinocythereis ? *variolata* (Egger, 1858)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—
Eucytheridea curvata (Lienenklaus, 1900)	—	×	—	—	×	—	—	—	—	—	—	×	×	×	×	×	×	×	—	×	—
Eucytheridea fissodentata (Lienenklaus, 1894)	—	—	×	×	×	—	—	×	—	—	—	—	×	×	×	×	×	×	—	—	—
Eucytheridea rostrata Bassiouni, 1962	×	×	×	×	×	×	×	×	×	×	—	—	×	×	×	—	×	×	—	—	—
Krithe pernoides (Bornemann, 1855)	—	—	—	—	—	—	—	—	×	—	×	—	—	—	—	—	—	—	—	—	—
Loxoconcha kuiperi Keij, 1957	—	×	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Loxoconcha cf. *subovata* (von Münster, 1830)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—
Loxoconcha variolata Brady, 1878	—	—	×	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—
Paracytheridea bilacunosa miocaenica Bassiouni, 1962	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	—	—
Pontocythere ? *angustata* (von Münster, 1830)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—
Pterygocythereis prolongata Bassiouni, 1962	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	×	—	—	—	—
Pterygocythereis sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—
Quadracythere excancellata (Neviani, 1928)	—	×	—	—	—	—	—	—	—	—	—	—	—	—	×	×	×	—	—	×	×
Quadracythere nodoreticulata Bassiouni, 1962 s.s.	—	—	—	—	—	—	—	×	×	—	×	×	×	×	×	×	×	×	×	×	×
Schizocythere hollandica Triebel, 1950	—	—	—	—	—	—	—	—	—	—	×	—	×	—	—	—	×	—	—	—	—
Tetracytherura angulosa (Seguenza, 1880)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—
Urocythereis latimarginata (Speyer, 1863)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	—

Table 3. Ostracode species, kept in the RGM, from the Aalten Member of boring 41D.2-7 at Aalten, identified by Mrs. E. J. Noordermeer-Perreijn.

Outcrop near the "Königsmühle", at Dingden, western Germany. Collected by A. W. Janssen. RGM 169 232 - 169 246, 169 387 - 169 470	"Glimmerton"	"Feinsand"
Bairdia subdeltoidea (von Münster, 1830)	-	x
Bairdia sp.	-	x
Bosquetina sp.	-	x
Buntonia sp.	-	x
Costa tricostata (Reuss, 1850)	x	x
Cuneocythere sp.	x	x
Cytherella beyrichi (Reuss, 1851)	x	x
Cytheridea acuminata Bosquet, 1852	-	x
Cytheridea diversilacunata Bassiouni, 1962	x	x
Cytheridea paracuminata Kollmann, 1960 s.s.	x	x
Cytheridea perforata Kuiper, 1918	-	x
Cytheropteron steinmanni Kuiper, 1918	-	x
Cytheropteron sp.	x	x
Echinocythereis asperrima (Reuss, 1850)	x	x
Echinocythereis cf. *asperrima* (Reuss, 1850)	-	x
Echinocythereis hirsuta (Lienenklaus, 1894)	x	x
Eucythere sp.	x	x
Eucytheridea fissodentata (Lienenklaus, 1894)	x	x
Eucytheridea lienenklausi (Kuiper, 1918)	x	x
Eucytheridea rostrata Bassiouni, 1962	-	x
Eucytheridea sp.	x	x
Krithe pernoides (Bornemann, 1855)	x	x
Muellerina latimarginata (Speyer, 1863)	x	x
Occultocythereis sp.	x	x
Paracytheridea bilacunosa miocaenica Bassiouni, 1962	x	x
Parakrithe cf. *ariminensis* Ruggieri, 1967	-	x
Parakrithe sp.	-	x
Pontocythere lithodomoides (Bosquet, 1852)	-	x
Pterygocythereis prolongata Bassiouni, 1962	x	x
Pterygocythereis cf. *subcoronata* (Speyer, 1863)	x	x
Pterygocythereis sp.	x	x
Quadracythere excancellata (Neviani, 1928)	x	x
Quadracythere nodoreticulata Bassiouni, 1962 s.s.	x	x
Schizocythere hollandica Triebel, 1950	x	x
Xestoleberis obtusa Lienenklaus,1900	x	x
Gen. et sp. indet.	x	-

"Glimmerton" = Aalten Member, Stemerdink Bed, *Limopsis aurita* Acme Zone ("Dingdener Schichten, Dingdener Glimmerton" of the german stratigraphy)

"Feinsand" = Aalten Member, Miste Bed, *Limopsis aurita* Acme Zone and *Spisula* sp. Acme Zone ("Dingdener Schichten, Dingdener Feinsand of the german stratigraphy)

Table 4. Ostracode species, kept in the RGM, from the Miocene deposits at Dingden (Köningsmühle), western Germany, identified by Mrs E. J. Noordermeer-Perreijn.

Crustacea — Decapod remains are mainly known from the Brinkheurne Member and the Aalten Member; in both deposits several species occur. Most finds consist of parts of the pincers, only rarely (e.g. in phosphorite concretions) parts of the thorax or other parts of the skeleton are found in connection. Material from Dutch localities has not yet been studied. Posthumus (1923) mentioned the crab *Coeloma balticum* Schlüter, 1879, from the Ratum Member in Twente. It is very likely, however, that this species — preserved as phosphorite concretions — originated from the Eocene. In Belgium, however, representatives of the same genus have been found in the Boom Clay.

Balanidae are especially common in the lower part of the Miste Bed, which is a further argument for the near-shore character of that fauna. This group of fossils has not yet been studied either. As a second group of the Cirripedia representatives of the family Lepadidae are found, of which a species of *Scalpellum* is not very rare in the lower part of the Miste Bed. This species was pictured by Nordsieck (1972, p. 46, pl. 11, fig. 81 left) as a fragment of the bivalve *Lyonsia norvegica* (Gmelin, 1790).

Ostracoda are known from the Brinkheurne Member and Aalten Member. Keij (1957) has investigated the ostracodes from several samples of the Brinkheurne Member. In the RGM collection a number of ostracode samples from four different localities of the Aalten Member are kept. These samples have been studied by Mrs E. J. Noordermeer-Perreijn. As this material has not yet been published we list here the ostracode species (see tables 2-5).

Outcrop nr. 34G.4-5 at "Beuting", Ellewicker Feld, municipality of Ellewick, western Germany. Sample collected by H. Krul, about 3.00 m below surface. RGM 168 849 - 168 857.
Cytherella beyrichi (Reuss, 1851)
Cytheridea pernota Oertli & Keij, 1955
Eucytheridea curvata (Lienenklaus, 1900)
Eucytheridea fissodentata (Lienenklaus, 1894)
Loxoconcha kuiperi Keij, 1957
Pontocythere lithodomoides (Bosquet, 1852)
Pterygocythereis prolongata Bassiouni, 1962
Schizocythere hollandica Triebel, 1950
Urocythereis latimarginata (Speyer, 1863)

Table 5. Ostracode species, kept in the RGM, from the Miocene deposits of "Beuting", Ellewicker Feld, Ellewick, western Germany, identified by Mrs E. J. Noordermeer-Perreijn.

Vertebrata — The shark and ray fauna is of great importance for the stratigraphical correlation. This fauna will be discussed below, separately for each member. Remains of these animal groups, as well as skeleton parts of bone-fishes are known from almost each of the members discussed. At several localities otoliths were found in not decalcified deposits. They are in the course of investigation and will be published in future.

Remains of reptilia are very rarely found, such as bony shell plates of a turtle. A short note about a turtle from the clay-pit near the water-tower of Eibergen (Eibergen Member) has been published by Roding (1961).

From the same deposit, in the F.O.W. clay-pit at Eibergen, the RGM collections contain many whale fossils and a fragmentary skeleton of *Halitherium* sp. Also marine carnivora are known from the Eibergen Member. These fossils are treated in more detail in the discussion of the Eibergen fauna (see p. 97).

Plantae — As far as we know palynological investigations and research on dinoflagellates, calcareous nannoplankton, etc. have not yet been carried out in the area concerned. Several samples from the Brinkheurne Member are subject of a palynological investigation at the RGM at this moment. Also the larger plant remains (seeds) have not yet been studied.

FAUNA OF THE RATUM MEMBER

In the Ratum Member autochthonous shark-teeth are found among the reworked Eocene phosphorite concretions occurring in the basal part of the member. These shark-teeth are the only fossils known from this member up to now that can serve for a stratigraphical correlation.

Such shark-teeth have been found in situ for example at Ootmarsum (Kuiperberg), Rossum, boring on the tramway Oldenzaal-Denekamp and at Oldenkotte (Rekken near Eibergen). In the region around Winterswijk no shark-teeth have been found in the Ratum Member. In the papers of van de Geyn (1937, p. 232) and van den Bosch (1964b. p. 68) the following species are mentioned from the Ratum Member (RGM collections, about 150 teeth).

Odontaspis acutissima Agassiz, 1844 — common
Odontaspis cuspidata le Hon, 1871
Lamna rupeliensis (le Hon, 1871)
Isurus gracilis (le Hon, 1871)
Isurus flandricus (Leriche, 1910)
Galeorhinus latus (Storms, 1894)

This fauna belongs without any doubt to the Rupelian. It differs only slightly from the fauna found in the Brinkheurne Member. Each of the species mentioned is also known from the Boom Clay of the Rupel area in Belgium and from the Sands of Berg at its type locality Berg, municipality of Spouwen, Belgium.

The shark-teeth that are reworked from the Eocene, found in large quantities in the phosphorite deposits at the base of the Ratum Member in Twente, do not belong to the autochthonous fauna of this member. The reworked shark fauna has been described by Leriche (1936), van de Geyn (1937) and van den Bosch (1964b).

FAUNA AND BIOSTRATIGRAPHY OF THE BRINKHEURNE MEMBER

Especially during the last 30 years, much fossil material has been collected from the clay-pits that have been exploited in the Brinkheurne Member. The absence of fossils in some clay-pits was striking. The faunal composition can differ markedly in the various clay-pits (Krul, 1948; Boekschoten, 1963a; Bosch, 1967). The faunal differences between the excavations at the Kuiperberg near Ootmarsum and the clay-pits of the brick-works "de Vlijt" and "te Siepe" at Winterswijk, which are the localities where most of the fossil material was collected, are especially striking. Also in the Boom Clay of Belgium differences in the faunas were observed (Cadée, 1969a).

From the sequence at the Kuiperberg (Bosch, 1971) it is clear that only the lower part of the Brinkheurne Member is exposed in those clay-pits, as also the Ratum Member is present beneath it. The recent extention in a western direction of the clay-pits "de Vlijt" and "te Siepe" near Winterswijk proved that the upper parts of the Brinkheurne Member are present here, because it is overlain by the Winterswijk Member (Cadée, 1969b; van Hinsbergh, 1972).

The differences in the faunal composition lead to the introduction of two new biozones in the Brinkheurne Member.

Cyclocardia kickxi – Astarte kickxi Assemblage Zone, new biozone

General concept — The *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone of

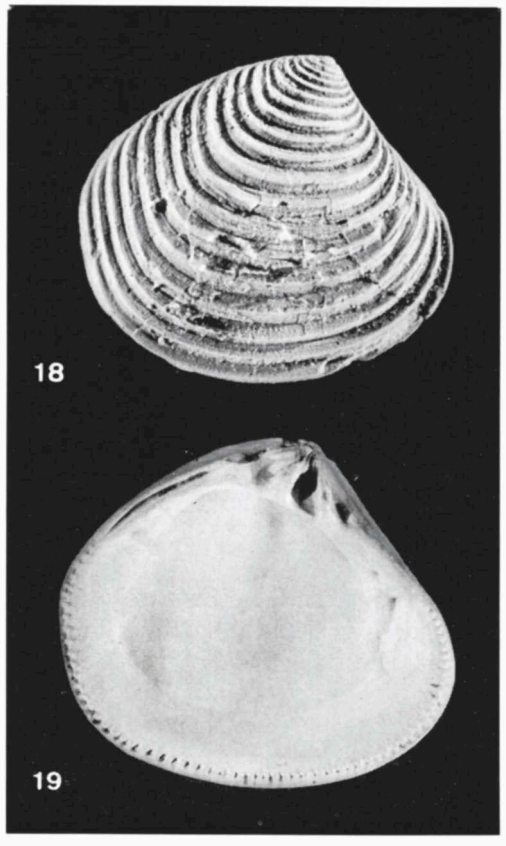

Fig. 18-19. Typical species of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone. Fig. 18. *Astarte (? Astarte) kickxi* (Nyst, 1835), right valve. Clay-pit of the Scholten brick-works at the Kuiperberg, Ootmarsum. RGM 184 793. Height 14.7 mm. Fig. 19. *Astarte (? Astarte) kickxi* (Nyst, 1835), left valve. Clay-pit at Niel, Belgium (Rupel area). RGM 184 794. Height 17.6 mm.

the Brinkheurne Member is characterized by the joint occurrence of the bivalves *Cyclocardia kickxi* (Nyst & Westendorp, 1839) and *Astarte (? Astarte) kickxi* (Nyst, 1835), see figs. 18-21. The marine mollusc fauna is relatively poor in species and individuals.

The two typical species belong to the most common species in this biozone and their vertical distribution is limited to this biozone of the Brinkheurne Member. Descriptions of both species can be found in the literature (see Glibert, 1957a).

The most frequent mollusc species of this assemblage zone are listed in Table 6.

Some less frequent species, probably restricted to the *Cyclocardia kickxi* - *Astarte kickxi* Assemblage Zone, are (see pl. 6):

Pycnodonte paradoxa (Nyst, 1835)
Spaniorhinus cf. *striatulus* (Nyst, 1845)
Galeodea depressa (von Buch, 1831)
Neptunea erratica (de Koninck, 1838)

Data for the above lists have been adopted from Bosch (1967), Tangerding (private communication) and personal observations. Material in several collections from the

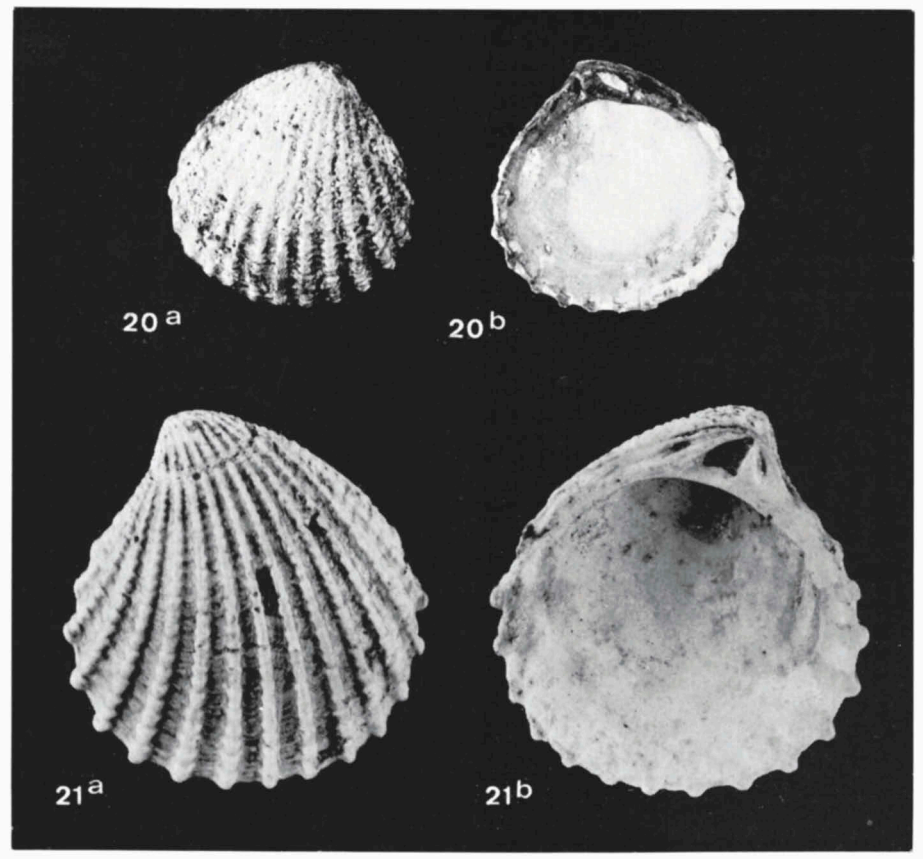

Fig. 20-21. Typical species of the *Cyclocardia kickxi* - *Astarte kickxi* Assemblage Zone. Fig. 20. *Cyclocardia kickxi* (Nyst & Westendorp, 1839), right valve. Clay-pit of the Scholten brick-works at the Kuiperberg, Ootmarsum. RGM 184 795. Height 10.9 mm. Fig. 21. *Cyclocardia kickxi* (Nyst & Westendorp, 1839), left valve. Clay-pit at Niel, Belgium (Rupel area). RGM 184 796. Height 12.2 mm.

clay-pits at the Kuiperberg near Ootmarsum and from Rhedebrügge (western Germany) has been studied. The mollusc fauna of this assemblage zone has been described in detail by Bosch (1967).

Typical reference section, boundaries and lithology — The mollusc-bearing part of the Brinkheurne Member in the former clay-pits of the Scholten brick-works at the Kuiperberg in the municipality of Ootmarsum (also being a reference section of the Brinkheurne Member) is designated here as the typical reference section of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone. Further information about this locality and the lithology of the sediments can be found in Bosch (1967).

Apart from a slight difference in the colour of the clay this biozone can lithologically not be distinguished from the *Serpula septaria - Ancistrosyrinx volgeri*

Annelida	A	B
Serpula septaria Giebel, 1864	-	cc
Mollusca		
Nucula (Lamellinucula) duchasteli Nyst, 1835	c	c
Nuculana (s.lat.) *deshayesiana* (Nyst, 1835)	cc	cc
? *Portlandia* (s.lat.) *sphaerica* (von Koenen, 1868)	-	c
Bathyarca saxonica (von Koenen, 1893)	-	c
Thyasira nysti (Philippi, 1846)	c	cc
Cyclocardia kickxi (Nyst & Westendorp, 1839	cc	-
Astarte (? Astarte) kickxi Nyst,1835	c	-
Corbula (Varicorbula) gibba gibba (Olivi, 1792)	c	-
Dentalium (s.s.) *kickxi* Nyst, 1845	cc	-
Solariella speyeri (von Koenen, 1867)	-	c
Mathilda crispula (Sandberger, 1863)	-	c
Aporrhais speciosa (Schlotheim, 1820)	c	rr
Euspira helicina (Brocchi, 1814)	c	-
Euspira sp.	-	cc
Phalium (Semicassis) rondeleti (Basterot, 1853)	-	r
Charonia (Sassia) flandrica (de Koninck, 1838)	c	rr
Typhis (Lyrotyphis) fistulosus schlotheimi (Beyrich, 1854)	r	c
Hexaplex (Paziella) pauwelsi (de Koninck, 1837)	r	c
Aquilofusus waeli (Nyst, 1852)	rr	c
Aquilofusus rotatus (Beyrich, 1856)	-	c
Aquilofusus multisulcatus (Nyst, 1845)	c	c
Streptochetus (Streptodyction) cheruscus elongatus (Nyst, 1845)	c	cc
Fusinus elatior (Beyrich,1856)	r	c
Brachitoma behmi (von Koenen, 1867)	-	c
Turricula (Surcula) regularis (de Koninck, 1838)	cc	c
Turris (Fusiturris) selysi (de Koninck, 1838)	cc	r
Turris (Fusiturris) duchasteli (Nyst, 1838) s.s.	r	c
Epalxis (Bathytoma) crenata (Nyst, 1845)	cc	cc
Ancistrosyrinx volgeri (Philippi, 1851)	-	c
Spiratella umbilicata (Bornemann, 1855)	rr	cc

Table 6. Distribution of several invertebrate species in the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone (column A) and the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone (column B) of the Brinkheurne Member. cc = very common, c = common, r = rare, rr = very rare. As fossils are in general rare in these clays, these indications refer to the relative frequency of the species mentioned.

Assemblage Zone and from the clay occurring in between both assemblages zones that is presumably not fossiliferous.

The lower boundary of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone coincides with the lithological boundary of the Brinkheurne Member and the Ratum Member. The upper boundary is defined at the level where the two typical species do no longer occur together in the Brinkheurne Member.

The maximal thickness of this biozone in the Gelderse Achterhoek and Twente is at least 5 m, but will presumably reach a total of some 10 m. The *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone is not directly overlain by the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone described below. In between both biozones a part of the Brinkheurne Member is most probably not fossiliferous. These barren clays are probably exposed in clay-pits at Ellewick (western Germany) and Oldenkotte (Rekken near Eibergen).

Facies and climatic significance — The fauna of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone is not very rich in species. Bosch (1967) mentioned some 20 mollusc species. Later observations at other localities in this region have hardly increased this number. The large number of carnivorous gastropods and the relatively large number of taxodont bivalves are striking in this fauna.

The faunal and the lithological characters suggest for this assemblage zone deposition in a quiet sea with the coast at a great distance. The depth of the sea is difficult to estimate. A depth of more than 100 m does not seem very probable. An extensive study on the palaeoecology of the Brinkheurne Member has been published by Boekschoten (1963a). The fauna indicates a tropical to subtropical sea.

Geologic age and correlation — Through the frequent occurrence of the bivalve *Nuculana deshayesiana* (Nyst) the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone can be referred to the Rupelian.

At this moment the biozone is known with certainty from the following localities in the area investigated: Rossum (clay-pit on the former tramway Oldenzaal-Denekamp), clay-pit at Rhedebrügge (western Germany), and an outcrop in the Willinkbeek at Ratum, municipality of Winterswijk (reference section of the Brinkheurne Member, see p. 13).

Outside the region concerned the assemblage zone is known from the Boom Clay, exposed in a vast area of the Rupel district in Belgium (Niel, Boom, Rumst, Steendorp, Tielrode, Rupelmonde a.o.). The faunas from these localities have been described by Glibert (1957a). More to the north, in the surroundings of Antwerp (Belgium), the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone is covered by younger sediments (Cadée, 1969a).

Because of the fact that the exposures in the Belgian Rupel area are much more extensive than those in the Netherlands and also because they are still accessible it seems useful to mention here some common mollusc species from this assemblage zone, known from the Rupel area only (see pl. 7):

Hilberia hoeninghausi (Defrance, 1825)
Cancellaria (Merica) evulsa (Solander, 1766)
Gemmula (Oxytropa) koninckí (Nyst, 1845)
Tornatellaea simulata (Solander, 1766)

Some less frequent species that seem to be restricted to the *Cyclocardia kickxi* -

Astarte kickxi Assemblage Zone, but only known from this biozone in the Rupel area up to now, are:

Barbatia decussata (Nyst & Westendorp, 1839)
Pecten rupeliensis von Koenen, 1868
Typhis (Lyrotyphis) cuniculosus (Nyst, 1836)
Northia (Searlesia) konincki (Nyst, 1845)
Aquilofusus deshayesi (de Koninck, 1837)
Asthenotoma bicingulata (Sandberger, 1863)

The faunistical data mentioned here originate from Glibert (1957a) and from personal observations. The correlation of this biozone with the German Oligocene is discussed in the description of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone.

Serpula septaria – Ancistrosyrinx volgeri Assemblage Zone, new biozone

General concept — The *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone of the Brinkheurne Member is characterized by the joint occurrence of the two typical species, accompanied by a marine mollusc fauna relatively rich in species and individuals.

The two typical species (see figs. 22-24), the annelid *Serpula septaria* Giebel, 1864 and the gastropod *Ancistrosyrinx volgeri* (Philippi, 1851) are both in the Brinkheurne Member restricted to this biozone. For a description of *Serpula septaria* see Albrecht & Valk (1943) and of *Ancistrosyrinx volgeri* see von Koenen (1867).

Ancistrosyrinx perspirata (von Koenen), mentioned by Boekschoten (1954) and Cadée (1961) from the Brinkheurne Member, has proven to be incorrectly identified. *A. perspirata* is a species from Early Oligocene deposits. It differs from *A. volgeri* by a finer crenulation of the carina and by the occurrence of an extra spiral ridge above the periphery. Von Koenen (1867), Harder (1913) and Glibert

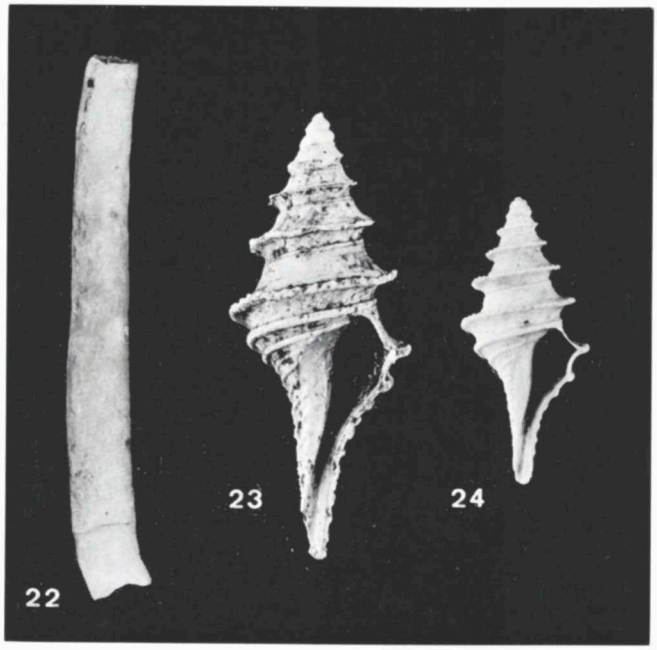

Fig. 22-24. Typical species of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone. Fig. 22. *Serpula septaria* Giebel, 1864, calcareous tube, with slightly eroded surface. Clay-pit complex of the brick-works "de Vlijt" and "te Siepe" at Winterswijk. RGM 184 797. Height 34.5 mm. Fig. 23-24. *Ancistrosyrinx volgeri* (Philippi, 1851). Locality as in fig. 22. Collection M. C. Cadée. Height resp. 19.0 mm and 12.2 mm.

(1957a) named this species correctly *A. volgeri;* also Boekschoten (1963a) used this name, however, without a motivation.

The most frequent mollusc species from this assemblage zone are listed in Table 6. *Euspira* sp., mentioned in Table 6, is a common gastropod figured by Janssen (1969, pl. 5, fig. 15). A correct name for this species, differing distinctly from *E. helicina* (Brocchi), is not yet available. Some rare species restricted to the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone are:

Similipecten hauchecornei (von Koenen, 1884)
Thyasira obtusa (Beyrich, 1848) (see pl. 8)
Cuspidaria clava (Beyrich, 1848)
Alvania (?*Arsenia*) *rupeliensis* Tembrock, 1964
Turriscala rudis (Philippi, 1843) (see pl. 8)
Eocypraea (s.s.) *beyrichi* (von Koenen, 1867)
Aquilofusus biformis (Beyrich, 1856) (see pl. 8)
Babylonella fusiformis (Cantraine, 1836) (see pl. 8)
Crenilabium elatior (von Koenen, 1868) (see pl .8)
Aturia sp. (see pl. 9)

The faunistical data mentioned here were adopted from Cadée (1961, 1965) and personal observations. The clay-pits of the brick-works "de Vlijt" and "te Siepe" at Winterswijk have yielded all the material mentioned here.

The nautiloid cephalopod *Aturia* sp. from the Rupelian of the North Sea Basin can be found in the literature under the denominations *Aturia ziczag,* (Sowerby, 1812), *Aturia koeneni* Gagel, 1928, *Aturia basteroti* Benoist, 1888 or *Aturia aturi* Basterot, 1825. *A. ziczag* is in reality an Eocene species known from the London Clay in England. *A. koeneni* was described from so-called Eocene clays near Jatznick (G.D.R.). Von zur Mühlen & Udluft (1929), however, have pointed out that this clay is of Oligocene age. Bentz (1930) used the name *A. aturi* for specimens of Winterswijk and Gagel (1928) mentioned *A. basteroti* from Rupelian clays of Itzehoe. Von Koenen (1882) mentioned *A. aturi* from Miocene and Oligocene deposits of the North Sea Basin.

We prefer to use the denomination *Aturia* sp., as a specific identification will require a profound study of all the material available.

Typical reference section, boundaries and lithology — The part from 2.55 to 7.55 m below surface of the section in the southwestern part of the clay-pit complex of the brick-works "de Vlijt" and "te Siepe" at Winterswijk (41E.3-143), also a part of a reference section of the Brinkheurne Member, is designated here as the typical reference section of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone. For a description of the lithology see p. 15.

The upper boundary of this biozone coincides with the lithological boundary of the Brinkheurne Member and the Winterswijk Member. The lower boundary of this assemblage zone is not known exactly but it is defined at the level where *Serpula septaria* and *Ancistrosyrinx volgeri* occur together in the Brinkheurne Member for the first time. The total thickness of this biozone will be some 5-10 m, but this can not exactly be ascertained because of the lack of good exposures.

Facies and climatic significance — The mollusc fauna of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone is less poor in species than the fauna of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone, even if the fauna of the latter biozone is extended with species only known from the Belgian Rupel district.

The greater part of the gastropods seems to have been carnivorous (Boekschoten, 1963a). Striking is the common occurrence of the planktonic gastropod *Spiratella umbilicata* in this biozone. The number of species as well as the number of individuals of the taxodont bivalves have increased as compared to the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone. Also the more frequent occurrence of the bivalve *Thyasira nysti* is noteworthy.

The environmental circumstances during the deposition of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone will have been almost the same as for the lower biozone of the Brinkheurne Member, but obviously conditions have been somewhat more favourable for a number of species. The mollusc fauna indicates a tropical to subtropical sea.

Geologic age and correlation — The occurrence of the bivalve *Nuculana deshayesiana* in this biozone indicates a Rupelian age. In Twente and the Gelderse Achterhoek no exposures are known in which the fauna of this biozone occurs, except for the typical reference section. Still it is problable that the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone is present at a large scale in the area. Wherever the Winterswijk Member is encountered on top of the Brinkheurne Member the biozone can be expected in the upper part of the underlying clay. The find of *Serpula septaria* in the Brinkheurne Member of boring 41E.4-177 at "Stemerdink" (van den Bosch, 1969b, p. 35-38) seems to support this thesis. In general, however, the biozones of the Brinkheurne Member can not be determined by means of boring samples because of the rare occurrence of molluscs. Usually rather extensive exposures will be necessary to obtain a sufficient quantity of faunal elements.

In Belgium in the area around Antwerp, the lower boundary of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone was just reached in temporary excavations for the construction of the Kennedy tunnel in the E 3 highway south of Antwerp (1965) and for the tunnel under the first harbour dock near Kallo, west of Antwerp (1974). In these excavations the upper part of the Boom Clay was exposed, containing already many specimens of *Serpula septaria* and rarely *Ancistrosyrinx volgeri* (see Cadée, 1969a). *Cyclocardia kickxi* and *Astarte kickxi* have not been found at those localities, nor have they been found in the clay-pit at Kruibeke, south west of Antwerp, either (1974, personal observation). In the latter clay-pit, however, the two typical species of the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone have not been found together. Also the fauna of this locality shows notable differences with the faunal composition of the two assemblage zones described here.

The basal conglomerate of the Edegem Sands ("Burcht Gravel"), overlying the Boom Clay in the excavation for the Kennedy tunnel, and also the basal deposits of the Kattendijk Sands, covering the Boom Clay in the excavation near Kallo (Janssen, 1974), contain many reworked calcareous septaria and other components from the Boom Clay. Therefore it is very likely that a considerable part of the upper Boom Clay has been removed there by erosion.

In Germany the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone has not been recognized with certainty. Many species, that occur frequently in this biozone are known from several localities, e.g. Söllingen, Hermsdorf, Freienwalde and Joachimsthal (von Koenen, 1867). From each of these localities, however, also the bivalve *Astarte kickxi* is mentioned, so a better knowledge of these exposures will be necessary before any correlations can be elaborated.

The "Ratinger Ton" from the surroundings of Düsseldorf in western Germany, can not be compared with the biostratigraphical subdivision described in this paper. Only few fossils are known from that clay. Harder (1913) described Middle and Late Oligocene sediments from Aarhus (Denmark). Of these, the Late Oligocene clay contains a fauna that has a number of species in common with the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone, but it also yielded so many typical Late Oligocene elements that a correlation is not possible. The Middle Oligocene fauna of Aarhus, collected according to Harder from a fine sandy sediment at the same place, shows some similarity with the fauna of the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone. Probably due to the fine sandy character of the sediment, however, so many other species occur that, here too, a correlation is not possible.

Vertebrata of the Brinkheurne Member

Only in two clay-pit complexes an interesting fauna has been collected, viz. at the Kuiperberg near Ootmarsum and in de clay-pits "de Vlijt" and "te Siepe" near Winterswijk. The fauna consists of shark-teeth, bone-fish otoliths and other skeleton parts of fishes. Reliable names are at this moment only available for the shark-teeth.

From the lower part of the Brinkheurne Member (*Cyclocardia kickxi - Astarte kickxi* Assemblage Zone) at the clay-pit on the Kuiperberg at Ootmarsum the following species are known (6 teeth in the RGM collection):

Lamna rupeliensis le Hon, 1871 (see pl. 20)
Isurus gracilis (le Hon, 1871) (see pl. 20)
Galeorhinus latus (Storms, 1894)

From the upper part of the Brinkheurne Member (*Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone) much more material is available. In the clay-pits of the brick-works "de Vlijt" and "te Siepe" a good fauna was collected that has already partly been published by van de Geyn (1937, p. 238). Van den Bosch (1961, p. 37) gave a more extensive list of this fauna. The following faunal list can be adopted from these two papers (some 500 teeth in the RGM collections):

Squalus alsaticus Andreae, 1892
Squatina angeloides van Beneden, 1873
Hexanchus primigenius (Agassiz, 1843)
Odontaspis acutissima Agassiz, 1844 — common (see pl. 20)
Odontaspis cuspidata Agassiz, 1844
Lamna rupeliensis (le Hon, 1871) (see pl. 20)
Isurus gracilis (le Hon, 1871) (see pl. 20)
Isurus flandricus (Leriche, 1910)
Cetorhinus parvus Leriche, 1908
Galeorhinus latus (Storms, 1894)

Regularly also teeth of the bone-fish *Trichiurides delheidi* Leriche, 1908 have been found. This faunal composition is typical for the Rupelian. Each of the species mentioned above is also known from the Boom Clay in the Belgian Rupel district (type locality of the Rupelian), from the Sands of Berg in the type locality Berg, municipality of Spouwen (Belgium), and from the "Unteres Meeressand" and the "Septarienton" of the Mainz Basin in western Germany.

A number of very small species has been discovered lately in the Brinkheurne Member. The research is still in progress.

FAUNA OF THE WINTERSWIJK MEMBER

Fauna of the basal deposits

Many fossils have been collected from the basal deposit (2.30-2.55 m) of the Winterswijk Member stratotype. This material, concentrated here as a result of a short interruption of the sedimentary process (perhaps accompanied by a slight erosion), has probably originated for the greater part from the upper sediments of the Brinkheurne Member. Partly, however, it can be autochthonous. From several hundredweights of clay many molluscs, several thousands very small shark-teeth and many fine skeleton parts and otoliths of bone-fishes have been collected. Research on this material is still in progress. The mollusc fauna has not yet been studied thoroughly. The preservation of the fossils is excellent and transport over a long period can therefore be excluded. Although the mollusc fauna contains also elements of the Winterswijk Member, the main part of the molluscs seems to have been washed out from the top of the Brinkheurne Member. *Euspira fissurata* (von Koenen), a typical gastropod of the Winterswijk Member, has never been found in this basal deposit.

The following Elasmobranchii can be listed here anticipating a future paper. The material (some 5000 teeth of sharks and rays) is kept in the RGM and in private collections.

Squalus alsaticus Andreae, 1892 — extremely common (see pl. 20)
Squatina angeloides van Beneden, 1873
Hexanchus primigenius (Agassiz, 1843)
Odontaspis acutissima Agassiz, 1844 — fragments rather common
Isurus gracilis (le Hon, 1871)
Cetorhinus parvus Leriche, 1908
Galeus sp. (= *"Pristiurus"* sp.)
Orectolobidae sp. — common
Galeorhinus latus (Storms, 1894)
Carcharhinus elongatus (Leriche, 1910)
Raja sp. div. — common
Dasyatis sp.

This fauna differs apparently from the Brinkheurne Member fauna, but this can not yet been determined with certainty because from the Brinkheurne Member an insufficient quantity of small fossils is at hand yet for comparison. Furthermore, only very few larger specimens are found at the base of the Winterswijk Member and therefore a comparison based on the larger species is also impossible.

The common species may point to a rather shallow sea with an abundant benthonic fauna that supplied the food for these fishes. The frequent occurrence of *Raja* may indicate rather shallow water with a rich bottom vegetation, necessary for these fishes to attach the egg capsules. The representatives of Orectolobidae indicate a tropical to subtropical climate. *Cetorhinus* prefers subtropical to moderate latitudes.

Autochthonous fauna of the Winterswijk Member

Although the sediments overlying the basal deposits of the Winterswijk Member have yielded only few molluscs it is clear that the faunal composition differs markedly in some respects from the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone. The most frequent species is the small gastropod *Euspira* sp., also

common in the upper biozone of the Brinkheurne Member. The autochthonous fauna of the Winterswijk Member is characterized, however, by the rather common gastropod *Euspira fissurata* (von Koenen), of which some 20 specimens have been collected (private collections). Although this species is also known from Early Oligocene deposits in Germany, it can certainly be assumed that *Euspira fissurata* is characteristic for the Winterswijk Member in the area investigated.

Because of the still rather frequently occurring bivalve *Nuculana deshayesiana* the Winterswijk Member can also be regarded as Rupelian.

The mollusc species most commonly encountered in this part of the Winterswijk Member are:

Nuculidae sp. (see pl. 8)
Nuculana (s. lat.) *deshayesiana* (Nyst, 1835)
?Portlandia (s. lat.) *sphaerica* (von Koenen, 1868)
Limopsis (Pectunculina) retifera Semper, 1861 (see pl. 8)
Thyasira nysti (Philippi, 1846)
Abra sp.
Solariella speyeri (von Koenen, 1867)
Euspira fissurata (von Koenen, 1891) (see pl. 8)
Euspira sp.
Aquilofusus waeli (Nyst, 1852)
Aquilofusus rotatus (Beyrich, 1856)
Streptochetus (Streptodictyon) cheruscus elongatus (Nyst, 1845)
Fusinus elatior (Beyrich, 1856)
Epalxis (Bathytoma) crenata (Nyst, 1845)
Brachytoma behmi (von Koenen, 1867)
Ancistrosyrinx volgeri (Philippi, 1851)

Euspira fissurata seems to prefer sandy sediments. Harder (1913) mentioned this species from the Middle Oligocene fine-sandy deposits of Aarhus (Denmark), under the denomination of *Natica dilatata* (non Philippi). For an exhaustive discussion of this species see Janssen (1972c). This gastropod is also known from Westeregeln and Itzehoe in Germany, but nothing is known about the sedimentary circumstances at these localities. Besides, with regard to the mollusc fauna the Middle Oligocene deposits of Aarhus differ considerably from the Winterswijk Member.

Some typical, but rare species from the Winterswijk Member are:

Solemya obovata von Koenen, 1868 (see pl. 8)
Propeamussium (Parvamussium) impar (Speyer, 1864)
Melanella (s. lat.) sp.

Since only a small number of specimens has been collected from the Winterswijk Member, it remains possible that species mentioned in the first list will appear to be less common, and vice versa. The fauna from the Winterswijk Member has not yet been studied in detail, a provisional list of species has been given by Cadée (1969b). The bivalves Nuculidae sp. and *Thyasira nysti* are common, but the specimens are usually squeezed. Only pyritized fossils can be collected.

The mollusc fauna mentioned here has been collected from the stratotype of the Winterswijk Member at the clay-pits "de Vlijt" and "te Siepe" at Winterswijk. Mollusc specimens can only be obtained from unweathered sediment: through the oxidation of pyrite and the good permeability of the sediment weathering proceeds quickly. The material, mainly kept in private collections, has chiefly been collected at the time that the clay-pit complex was regularly excavated in a western

direction (1969-1972); clean exposures of the Winterswijk Member were always present at that time. Nowadays this clay-pit is in a neglected condition and fossil collecting in the Winterswijk Member is practically impossible.

FAUNA OF THE AALTEN MEMBER

Reworked faunas of the basal deposits

Decalcified fauna in the reworked phosphorite concretions — A large number of hard, black phosphorite concretions with distinct signs of transport are found at the base of the Aalten Member at many places (see pl. 11). In these concretions, that are externally completely decalcified, moulds of fossils — mainly molluscs — can regularly be found. These mouds are interesting because on the base of this fauna conclusions can be drawn with regard to the origin of these concretions. Large quantities of these concretions remain still unstudied in the RGM collections. A preliminary list of the fossils found in these concretions has been composed after a provisional study of a part of the material collected from the temporary excavations at Winterswijk (Miste). At this locality the concretions are found in the basal sediments of the Miste Bed, belonging to the *Hiatella arctica* Acme Zone, that overlie the Winterswijk Member. The species encountered are listed in Table 7. It can be expected that a future more thorough research of this material, and also of material from other localities, will reveal many additional species.

From the occurence of the species *Laevicardium tenuisulcatum, Callista beyrichi, Haustator goettentrupensis,* and *Cominella bolli* (see pl. 11) it can be concluded with certainty that the fauna preserved in the phosphorite concretions originated from deposits of a Late Oligocene (Chattien) age, that is, if it is accepted that all the concretions are reworked from the same stratigraphical level.

Reworked vertebrates — Among the reworked phosphorite concretions also many black shark-teeth and whale bone fragments, all of them with clear signs of transport, were found. The whale bone fragments are usually so badly preserved and broken that it will most probably be impossible to identify them. Of the Elasmobranchii, however, many species are known, the most important ones being mentioned below. These have for the greater part been collected at "Ticheloven" near Eibergen (temporary exposure near boring 34G.1-24), Rekken near Eibergen ("Dieters", 34G.4-2) and from temporary exposures at Miste near Winterswijk. Similar material is also known from several borings. Some 500 teeth are kept in the RGM collections.

Hexanchus primigenius (Agassiz, 1843)
Odontaspis acutissima Agassiz, 1844
Odontaspis cuspidata Agassiz, 1844
Odontaspis vorax le Hon, 1871
Odontaspis molassica Joleaud, 1912 (non Probst, 1879)
Lamna cattica (Philippi, 1846)
Isurus desori (Agassiz, 1844) — common (see pl. 20)
Isurus hastalis (Agassiz, 1843) narrow type (see pl. 20)
Isurus benedeni (le Hon, 1871) large type
Isurus retroflexus (Agassiz, 1843)
Procarcharodon sp.
Scyliorhinus distans (Probst, 1879)

Galeocerdo aduncus Agassiz, 1843
Carcharhinus priscus (Agassiz, 1843)
Scoliodon taxandriae Leriche, 1926
Squatina subserrata von Münster, 1846
Raja sp.
Dasyatis sp.
Rhinoptera cf. *studeri* Agassiz, 1838
Aetobatis arcuatus Agassiz, 1843

This reworked fauna shows much resemblance to the fauna from the Basal Con-

Foraminifera (fam. Lagenidae)	1
Nucula (*Nucula*) sp.	1/2
Nuculana (*Saccella*) *westendorpi* (Nyst, 1839)	6/2
Glycymeris (s.s.) *lunulata baldii* Glibert & van de Poel, 1965	10/1 + 9/2
Arcoperna sp.	4/2
Mytilus (s.s.) aff. *acutirostris* Sandberger, 1863	12/1 + 3/2
Pectinidae sp. div.	25/2
? *Diplodonta* sp.	2/2
Cyclocardia sp.	13/2
Astarte (? *Astarte*) *gracilis* von Münster, 1837	6/2
Parvicardium sp.	1/2
Laevicardium (*Habecardium*) *subturgidum* (d'Orbigny, 1852)	3/2
Laevicaedium (*Habecardium*) *tenuisulcatum* (Nyst, 1836)	17/2
Ensis sp.	1/2
Glossus (s.s.) sp.	2/1
Venus (*Ventricoloidea*) *multilamella* (Lamarck, 1818)	1/2
? *Pelecyora* (*Cordiopsis*) sp.	4/1
Callista beyrichi (Semper, 1861)	2/1 + 5/2
Corbula (*Varicorbula*) *gibba gibba* (Olivi, 1792)	45/2
Hiatella arctica (Linné, 1767)	2/2
Panopea sp.	6/1
Pholadomya sp.	1/2
Thracia sp.	1/2
Dentalium sp.	31
Solariella sp.	2
Haustator goettentrupensis (Cossmann, 1899)	6
Turritellidae sp.	2
Naticidae sp.	6
Hinia sp.	1
Cominella bolli (Beyrich, 1854)	1
Turridae sp.	2
Ringicula sp.	1
Bryozoa (lunulitiform species)	11

Table 7. Invertebrate fossils in reworked decalcified phosphorite concretions from the base of the Aalten Member (Miste Bed), temporary excavations at Winterswijk-Miste near the stratotype of the Miste Bed. The number of specimens is mentioned to obtain an indication about the frequency of the species. For the Bivalvia x/1 means internal moulds and x/2 means external moulds (x is the number of specimens).

glomerate of Elsloo (Netherlands, province of Limburg, see van de Geyn, 1937 and van den Bosch, 1964c) and with the fauna from the Burcht Gravel at the base of the Sands of Edegem at Antwerp (Belgium), where a similar reworked fauna has been collected by staff members of the RGM. These shark-teeth are Late Oligocene to Early Miocene in age, as is especially demonstrated by the frequent occurrence of *Isurus desori*, some specimens of an early form of *Isurus hastalis*, and furthermore by some teeth of *Procarcharodon* with distinct accessory teeth next to the main crown (private collections).

Up to now the sediments from which the fossil-bearing phosphorite concretions and the shark-teeth have originated have not been traced in situ with certainty. In the Late Oligocene sediments of the boring Dingden (Königsmühle) a tooth of *Carcharhinus priscus* and a black phosphorite concretion of the same type as found at the base of the Aalten Member have been found.

Not decalcified reworked fauna — Mainly at the base, but also in the higher part of the section of the temporary exposures at Winterswijk (Miste) — even still in the horizon containing phosphorite concretions — a large number of mollusc shells was encountered that show clear signs of transport. The larger part of these shells belongs to species that are regular constituents of the autochthonous fauna. Since these deposits — belonging to the *Hiatella arctica* Acme Zone — represent the most shallow environment (see p. 32), it is very likely that a part of the autochthonous shells will be worn as a result of wave action or currents.

A minor part of these species, however, is reworked from other, probably older, deposits for they are not encountered in the autochthonous fauna. The most important species in this respect are (see pl. 10):

Pecten (Pecten) brummeli Nyst, 1864
Pycnodonte (s.s.) *navicularis* (Brocchi, 1814)
Arctica islandica (Linné, 1767)
Dentalium (s.s.) aff. *seminudum* auct. non Deshayes, 1860
Haustator goettentrupensis (Cossmann, 1899)
Ecphora wiechmanni (von Koenen, 1860)

Several of these species — *Pecten brummeli, Pycnodonte navicularis* and *Arctica islandica* — have a continuous vertical distribution that includes lateral equivalents of the Aalten Member. So, these species give no indication about the source of this fauna. The remaining three species can give direct information about the origin of at least a part of the not decalcified reworked fauna. *Haustator goettentrupensis* is known from Late Oligocene and Early Miocene deposits. The specimens frequently found at Winterswijk-Miste reach a considerable size. They resemble the specimens pictured by Gripp (1914, p. 12, pl. 2, fig. 8-11) from the Early Miocene of Itzehoe closely. The gastropod *Ecphora wiechmanni* is generally considered a typical representative of Early Miocene deposits, although occasionally a specimen is mentioned from Late Oligocene sediments. *Dentalium* aff. *seminudum* is a species insufficiently known from the North Sea Basin. Seifert (1959, p. 24) mentions this species (if indeed it is the same!) from Middle and Late Oligocene deposits in western Germany. The specimens found at Miste — admittedly rather badly preserved — reach considerably larger dimensions than the specimens discussed by Seifert. Similar forms are apparently unknown from the Late Oligocene or Early Miocene of the Lower Rhine area. Both *Dentalium* aff. *seminudum* and *Haustator goettentrupensis* were in Miste found together in a small, not decalcified,

phosphorite concretion. It can safely be supposed therefore, that at least these two species of the reworked fauna did belong to one and the same fauna. The age of the deposit from which this fauna has been derived is difficult to establish; the previous discussion points to a Late Oligocene to Early Miocene age; an Early Miocene age seems to be the most probable.

Among the reworked shark-teeth some specimens of *Isurus retroflexus* (Agassiz, 1843) (see pl. 20) have been found that differ from the other reworked teeth by their somewhat lighter colour. Their preservation, however, distinctly indicates that they do not belong to the autochthonous fauna. Perhaps they belonged to the same fauna as the reworked not decalcified mollusc fauna.

Vertebrate fauna of the Aalten Member

Vertebrata of the Miste Bed — In the Miste Bed not reworked vertebrate remains are found rather frequently. Apart from large quantities of bone-fish otoliths and other skeleton parts of fishes also some bones of whales have been found that, however, have not yet been studied. Also rather many teeth of sharks (Elasmobranchii) have been found, representing a rich fauna. Important quantities of shark teeth have been collected from the Miste Bed, e.g. in the clay-pit of the brick-works Scholten at the Kuiperberg near Ootmarsum, at temporary exposures near the "Ticheloven" farm at Eibergen (close to boring 34G.1-24), at temporary exposures at Winterswijk (Miste) close to boring 41E.3-75, at temporary exposures near the Königsmühle at Dingden ("Dingdener Feinsand") and from several borings. The most important species of this fauna are (some 1200 teeth in the RGM collections) (see pl. 21):

Hexanchus primigenius (Agassiz, 1843) — rather common
Odontapsis acutissima Agassiz, 1844 — rather common
Odontaspis vorax le Hon, 1871 — rather common
Odontaspis molassica Joleaud, 1912 (non Probst, 1879)
Lamna cattica (Philippi, 1846)
Isurus hastalis (Agassiz, 1843) narrow type - rather common
Isurus retroflexus (Agassiz, 1843)
Isurus benedeni Menesini, 1969 (non le Hon, 1871)
Procarcharodon megalodon (Agassiz, 1843)
Cetorhinus sp.
Scyliorhinus distans (Probst, 1879)
Galeocerdo aduncus Agassiz, 1843
Paragaleus sp.
Galeorhinus sp.
Scoliodon taxandriae Leriche, 1926 — rather common
Squalus sp.
Squatina subserrata von Münster, 1846
Squatina biforis le Hon, 1871
Raja sp. div.
Dasyatis sp. div.
Rhinoptera sp.
Aetobatis arcuatus Agassiz, 1843

This fauna agrees fairly well with the faunas known from the "Hemmoor Stufe" of the Dutch Peel area a preliminary list of which has appeared (van den Bosch, 1964c, p. 22).

Also from the Sands of Antwerp from the neighbourhood of Antwerp (Belgium) — horizons 12 to 17 of the section of Janssen & van der Mark, 1968 — a

similar fauna has been collected (RGM collections).

Concerning a correlation over a larger distance similarity has been noticed with the fauna described by Cappetta (1970) from Loupian (France, department of Hérault) and with the fauna of "Pietra leccese" (Italy, province of Puglia, see Menesini, 1969). Possibly the fauna of the Miste Bed is somewhat younger than the Loupian fauna. Especially the narrow type of *Isurus hastalis* agrees with the specimens from Puglia and also the form of *Isurus benedeni* Menesini (1969, p. 21, pl. 3, fig. 8-11) looks very much like the specimens from the Miste Bed. The faunas of the French and Italian localities mentioned here are correlated with the Helvetian by Cappetta and Menesini, respectively.

The fauna indicates — by the occurrence of *Isurus* and *Carcharodon* — a subtropical climate and a shallow sea — rich in food — with an open connection to the Atlantic Ocean.

Vertebrata of the Stemerdink Bed — Also in the Stemerdink Bed many vertebrate fossils occur. The number of otoliths and other skeleton parts of bone-fishes is also rather large. In the upper part of the Stemerdink Bed already, complete skeletons of whales are rather often found (old clay-pit of the F.O.W. brick-works at Eibergen, 34G.3-1). According to recent information it is certain that finds in the F.O.W. clay-pit complex from before 1945 originate from the lower part of the Eibergen Member. The remains of the Cetacea will be discussed below in the description of the Eibergen Member fauna (see p. 96).

Although the clayey sediments make collecting in the Stemerdink Bed rather difficult, still a rather extensive collection of shark teeth is available, e.g. from an exposure in the small river Berkel, south of the "Ticheloven" farm at Eibergen, from the old clay-pit of the F.O.W. brick-works at Eibergen, from "de Giffel" near Meddo, Winterswijk and from the "Dingdener Glimmerton" in the classical outcrop near the Königsmühle at Dingden in western Germany.

The most important species of Elasmobranchii from the Stemerdink Bed are listed here (some 75 teeth in collections of the RGM and private collections).

Hexanchus primigenius (Agassiz, 1843)
Odontaspis acutissima Agassiz, 1844
Odontaspis vorax le Hon, 1871
Isurus hastalis (Agassiz, 1843) — common at the top of the Stemerdink Bed
Procarcharodon megalodon (Agassiz, 1843) (see pl. 22)
Cetorhinus sp.
Sphyrna aff. *laevissima* (Cope, 1867) (see pl. 22)
Isistius sp.
Squatina biforis le Hon, 1871
Raja sp.
Dasyatis sp.

This fauna is only a poor reflection of the rich Miste Bed fauna. Many species seem to have disappeared. Some new elements, however, attract attention: *Sphyrna* aff. *laevissima* and *Isistius* sp. They have not been found in the large material from the Miste Bed. These species indicate a strong southern (tropical) influence. In the case of *Isistius* one can hardly imagine that this species belonged to the autochthonous fauna; it is more likely that an animal has lost its way (only one tooth has been found!).

The teeth of *Isurus hastalis* are already less narrow than those from the Miste

Bed; the specimens found in the Stemerdink Bed of the old clay-pit F.O.W. (34G.3-1) at Eibergen compare rather closely with the teeth from the Eibergen Member.

Although the Miste Bed and the Stemerdink Bed might partially have been deposited contemporaneously a rather large difference in age must be supposed between the lowermost and the uppermost deposits of the Aalten Member in the area of Dingden and the Gelderse Achterhoek.

Mollusc fauna of the Aalten Member

Sediments of the Aalten Member generally contain a mollusc fauna rich in species Little attention, however, has been paid to the faunas in the literature, until recently. This is especially the case for the Dutch localities, the classical outcrop at Dingden has been known for a long time and its mollusc fauna has been treated in several papers (e.g.: von Koenen, 1872, 1882; Lehmann, 1885, 1892, 1893; Schilder, 1929; ten Dam, 1934; Anderson, 1964; Janssen, 1967, 1969).

Von Koenen, in his two papers on the Miocene molluscs of northern Germany, also studied a number of gastropods from Dutch localities (indicated by him as "Eibergen"). Spaink (1960) gave a list of Miocene mollusc species from Dutch localities in the collection of the Rijks Geologische Dienst at Haarlem. He also mentioned material from borings and outcrops in the Gelderse Achterhoek. Boekschoten (1967a) described a fauna preserved in decalcified phosphorite concretions in situ from the Miste Bed of the Kuiperberg at Ootmarsum (Twente).

Janssen (1967) examined the quantitative mollusc content of a series of samples from the Miocene part of the boring Dingden (Königsmühle). Partly in consequence of the results obtained at Dingden de Vogel (1970, 1971) investigated quantitatively a large number of samples, practically all collected from borings in the Gelderse Achterhoek. In this way it proved possible to obtain an impression of the vertical variation in the frequency of the mollusc species. Maxima of several common species could be correlated from one place to another within the area investigated (see fig. 25). Although the species in question are common in the complete sequence of shell-bearing Miocene deposits in the Gelderse Achterhoek and adjacent areas the maxima obtained are so characteristic and can so easily be found by means of a simple counting method (described by de Vogel, 1970, p. 66) that we introduce here four new biozones in the Aalten Member, based on this method.

BIOSTRATIGRAPHY OF THE AALTEN MEMBER

Because the biozones are based on maxima in the vertical distribution of mollusc species they should be indicated as acme zones (International Subcommission on Stratigraphic Classification, 1972, p. 307). Within the Aalten Member we distinquish the following four acme zones:

Limopsis aurita Acme Zone, new biozone
Spisula sp. Acme Zone, new biozone
Astarte radiata Acme Zone, new biozone
Hiatella arctica Acme Zone, new biozone

With the help of the counting method mentioned the four biozones can not be

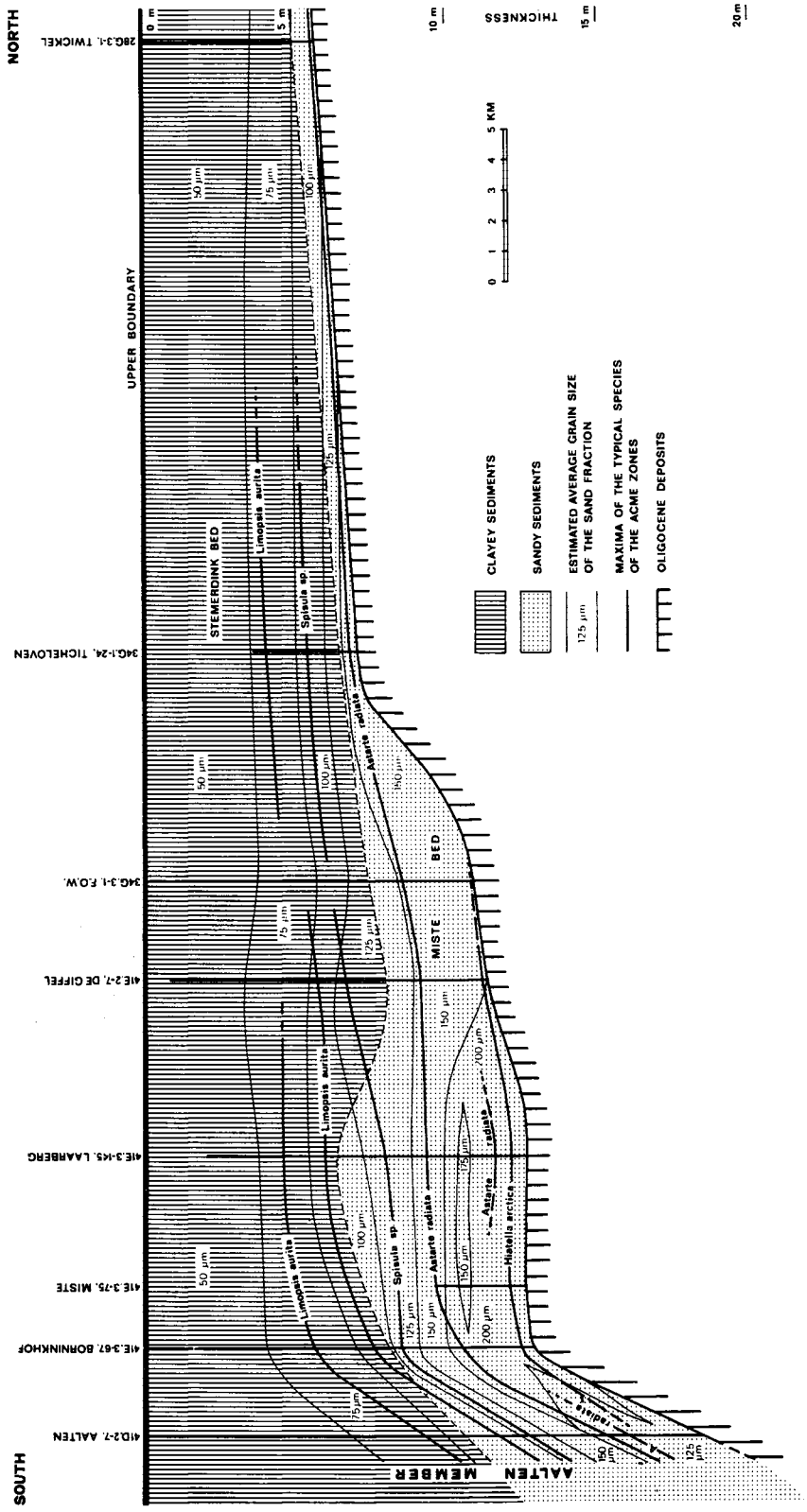

Fig. 25. Schematic south-north cross-section through the Aalten Member. The upper boundary of the Aalten Member is represented by a horizontal line. Thicknesses are plotted vertically. The boundary between the Miste Bed and the Stemerdink Bed is indicated by a broken line. The boundaries between the estimated average grain sizes of the sand fraction of the sediment are indicated by thin lines. Heavy lines connect the maxima of the typical species of the acme zones. Note the existence of two maxima of *Astarte radiata* and *Limopsis aurita* in the southern part of the section, and the fact that the lines connecting the maxima of the typical species cut the lithological boundaries.

separated sharply from each other because the changes in the fauna are gradual, which is, indeed, a distinguishing character of acme zones. A striking phenomenon is that the biozones do not coincide with the lithological subdivision, but appear to cut it obliquely (see fig. 25). In the description of the biozones this will be discussed in more detail.

Hiatella arctica Acme Zone, new biozone

General concept — The *Hiatella arctica* Acme Zone of the Aalten Member is characterized by a relative maximum in the vertical distribution of the bivalve *Hiatella arctica* (Linné, 1767), figs. 26-29, and by the presence of an accompanying marine mollusc fauna very rich in species and individuals. A description of the typical species can be found in the literature (e.g. Glibert, 1945, p. 209, pl. 11, fig. 7a-d; Jakubowski, 1972, p. 105, pl. 10, fig. 1-36, textpl. 10, fig. 1-36).

This biozone is known at this moment from a more or less north - south running strip between Eibergen (Rekken), Winterswijk and Aalten.

For a rough survey of the mollusc species commonly occurring in this biozone the reader is referred to de Vogel (1971). The ten most common species encountered (more or less in order of frequency) are:

Hiatella arctica (Linné, 1767) (see fig. 26-29)
Ringicula (Ringiculina) buccinea (Brocchi, 1814)
Amyclini facki (von Koenen, 1872) (see pl. 16)
Aporrhais alata (von Eichwald, 1830)
Naticidae sp. div.
Cadulus (Gadila) gadus (Montagu, 1803)
Portlandia (Yoldiella) pygmaea (von Münster, 1837)

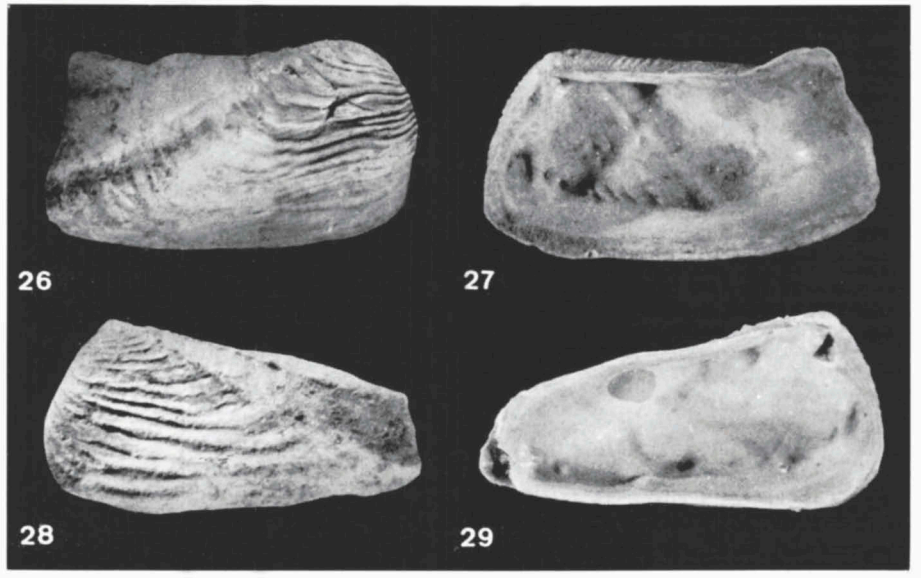

Fig. 26-29. Typical species of the *Hiatella arctica* Acme Zone. Fig. 26. *Hiatella arctica* (Linné, 1767), right valve. Temporary exposure at Winterswijk-Miste near the stratotype of the Miste Bed. RGM 184 798. Height 3.0 mm. Fig. 27. *Hiatella arctica* (Linné, 1767), right valve. Locality as in Fig. 26. RGM 184 799. Height 3.2 mm. Fig. 28. *Hiatella arctica* (Linné, 1767), left valve. Locality as in Fig. 26. RGM 184 800. Height 2.2 mm. Fig. 29. *Hiatella arctica* (Linné, 1767), left valve. Locality as in Fig. 26. RGM 184 801. Height 3.0 mm.

Laevicardium (Habecardium) subturgidum (d'Orbigny, 1837)
Astarte (? A.) gracilis (von Münster, 1835) s.lat.
Cavilucina droueti (Nyst, 1861)

These data were adopted from de Vogel (1971). None of these species is restricted to this biozone. The *Hiatella arctica* Acme Zone can be distinguished from the *Astarte radiata* Acme Zone, apart from the frequency of the typical species, by the occurrence of a number of rare to very rare species that have not yet been found in the other biozones of the Aalten Member (see pl. 12):

Lembulus emarginatus (Lamarck, 1819)
Bucardium sp.
Morum sp.
Fasciolariidae sp. (see Janssen, 1972, p. 35)
Ancillarina sp.
Trigonostoma planispira (Nyst, 1845)
Trigonostoma sp.
Terebridae sp.

Further investigation of the material available from this biozone will certainly result in an extension of this list. Unfortunately, all these species are so rare that they will only be found after thorough inspection of large samples. Consequently they will hardly ever be found in boring samples. In the *Hiatella arctica* Acme Zone a number of species occurs, however, that — like the typical species — are much more common in this zone than in the other biozones of the Aalten Member. The most important species (in systematical order) are (see pl. 13-14):

Lutraria cf. *latissima* Deshayes, 1830
Cyrtodaria angusta (Nyst & Westendorp, 1839)
Dentalium (Antalis) dumasi Cossman & Peyrot, 1916
Architectonica (s.s.) *carocollata* (Lamarck, 1822)
Haustator eryna (d'Orbigny, 1852)
Crepidula (Janacus) crepidula (Linné, 1766)
Neverita josephinia olla (des Serres, 1829)
Euspira gottschei (Kautsky, 1925)
Bursa (Lampasopsis) austriaca (Hoernes & Auinger, 1884)
Chicoreus aquitanicus (Grateloup, 1833)
Pterynotus (Pterochelus) angustifolius (Kautsky, 1925)
Hadriania coelata (Dujardin, 1837)
Kelletia (Boreokelletia) hosiusi (Beyrich, 1856)
Hinia (s.s.) *schroederi* (Kautsky, 1925)
Trigonostoma behmi (Beyrich, 1856)
Trigonostoma ornatissima (Zilch, 1935)
Clavatula (s.s.) *boreointerrupta* Kautsky, 1925
Vaginella depressa Daudin, 1800

Haustator eryna is the most usefull of the species mentioned in this list, as this gastropod occurs frequently in the *Hiatella arctica* Acme Zone and is only locally found in the *Astarte radiata* Acme Zone, only at such places where the *Hiatella arctica* Acme Zone has presumably never been present. This can be explained by the assumption that the occurrence of *Haustator eryna* is limited to a certain period rather than to the special environmental conditions of the *Hiatella arctica* Acme Zone. This could be an explanation for the occurrence of *H. eryna* in the *Astarte radiata* Acme Zone which is supposed to be deposited at least partially at the same time as the *Hiatella arctica* Acme Zone, but in somewhat deeper water. A frequent

occurrence of *H. eryna,* however, is always indicative for the *Hiatella arctica* Acme Zone.

Typical reference section, boundaries and lithology — The section from 3.25 to 4.10 m below surface of the boring 41E.3-75 at Winterswijk-Miste (being also a part of a reference section of the Miste Bed) is designated as the typical reference section of the *Hiatella arctica* Acme Zone.

The lower boundary coincides, known so far, always with the lower boundary of the Miste Bed. This biozone, if present, is always found in the lower part of the Miste Bed. The upper boundary can not be drawn sharply, but it can be estimated by quantitative counts of samples from short vertical intervals. The boundary is then placed somewhere between the relative maxima of *Hiatella arctica* and *Astarte radiata.*

For a description of the lithology the reader is referred to the chapter on the lithostratigraphy (see p. 22). Fig. 25 shows the relation of the *Hiatella arctica* Acme Zone to the lithology. So far this biozone nowhere exceeds a thickness of 2 m.

Facies and climatic significance — The composition of the mollusc fauna of the *Hiatella arctica* Acme Zone points to a rather shallow, marine environment. Among the four biozones described here the *Hiatella arctica* Acme Zone shows most clearly near-shore characteristics (de Vogel, 1971, p. 123, fig. 2 "fine sands of Hemmoor type"). It is difficult to estimate the climatic conditions, but subtropical to moderate subtropical conditions are the most likely.

Geologic age and correlations — There can be no doubt about the Miocene age of this fauna. It agrees to a large degree with the fauna of the "Hemmoor Stufe" in northern Germany, especially with that of the "unteres Hemmoor" of Hinsch, 1955 (Behrendorf). See also the remarks on p. 86 in the description of the *Astarte radiata* Acme Zone.

The absence of good mollusc faunas in the corresponding sediments makes correlation with Belgian Miocene deposits less easy. It can be assumed that the horizons 9 to 15 (included) of the subdivision of Janssen & van der Mark (1968, p. 78, fig. 1) correspond more or less with the lower part of the Miste Bed. A small collection of molluscs, preserved in calcitic concretions, is kept in the RGM collections. It has been collected in a temporary excavation alongside the E 3 highway trace at Antwerp (Berchem, near to the "Grote Steenweg"). The level from which this material has been collected corresponds with horizon 11 of the subdivision of Janssen & van der Mark and has been denominated "Kiel Sands" by Hooyberghs & de Meuter (1972). The thickness of this horizon 11 is said to be about 4 m by Janssen & van der Mark; according to Hooyberghs & de Meuter, however, this should be some 10 m. This fauna contains *Haustator eryna,* which gastropod has not been found in other parts of the Miocene in the Antwerp area. Horizon 14 of the above mentioned section yielded many specimens of a large Turritellid gastropod that might be a local form of *H. eryna.*

In the so-called "Hemmoor Stufe" of the Dutch Peel area (province of Noord Brabant) and in the Sands of Houthalen in Belgium, most certainly faunas occur that can at least partially be correlated with the *Hiatella arctica* Acme Zone, but accurately sampled sections that are essential for a detailed correlation have not been available to us.

Historical review — The recent discovery of the surprisingly rich fauna of the *Hiatella arctica* Acme Zone has been recorded by van den Bosch (1968, p. 43) and provisionally indicated as "Hemmoor Stufe". Further investigations on the fauna were done by de Vogel (1970, 1971), Boekschoten (1969a) and Nordsieck (1972). The samples of the latter author included probably also material from the *Astarte radiata* Acme Zone.

Astarte radiata Acme Zone, new biozone

General concept — The *Astarte radiata* Acme Zone of the Aalten Member is characterized by a relative maximum in the vertical distribution of the bivalve *Astarte (? Astarte) radiata* Nyst & Westendorp, 1839 (fig. 30-31) and by the presence of an accompanying marine mollusc fauna rich in species and individuals. A description of the typical species can be found in the literature (see for example Anderson, 1964, p. 149, pl. 3, fig. 35a-c).

This biozone is known at this moment from a large number of borings and exposures in a strip more or less running north - south (Ootmarsum-Delden-Eibergen-Winterswijk-Aalten-Dingden).

For a rough survey of the common mollusc species of this biozone the reader

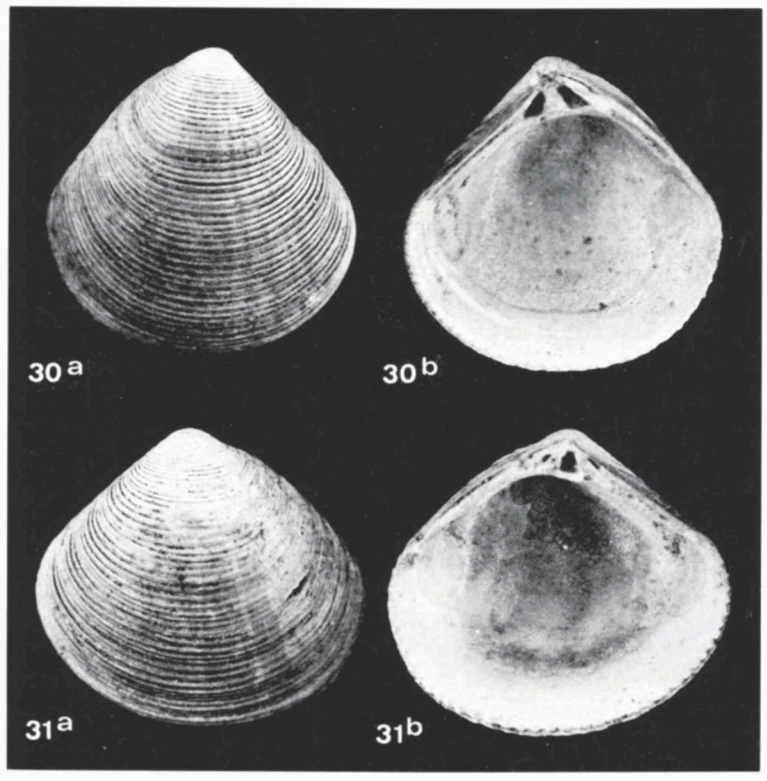

Fig. 30-31. Typical species of the *Astarte radiata* Acme Zone. Fig. 30. *Astarte (? Astarte) radiata* Nyst & Westendorp, 1839, right valve. Temporary excavation north-east of the Ticheloven farm at Eibergen-Loo, near boring 34G.1-24. RGM 184 802. Height 9.7 mm. Fig. 31. *Astarte (? Astarte) radiata* Nyst & Westendorp, 1839, left valve. Locality as in Fig. 30. RGM 184 803. Height 9.5 mm.

is referred to de Vogel (1971). The species most frequently found in the samples investigated (more or less in order of frequency) are:

Ringicula (Ringiculina) buccinea (Brocchi, 1814)
Astarte (? Astarte) radiata Nyst & Westendorp, 1839 (see figs. 30-31)
Portlandia (Yoldiella) pygmaea (von Münster, 1837)
Corbula (Varicorbula) gibba gibba (Olivi, 1792)
Spisula sp.
Parvicardium straeleni (Glibert, 1945)
Goodallia (s.s.) *angulata* (Lehmann, 1885)
Limopsis (s.s.) *aurita* (Brocchi, 1814)
Yoldia (s.s.) *glaberrima* (von Münster, 1835)
Hiatella arctica (Linné, 1767)
Dentalium (s.s.) *mutabile* Hoernes, 1856

None of these species is restricted to this biozone. In the *Astarte radiata* Acme Zone a number of species occurs, however, that like the typical species are markedly more common in this biozone than in each of the other biozones distinguished in the Aalten Member, these are (see pl. 15):

Glycymeris (s.s.) *lunulata baldii* Glibert & van de Poel, 1965
Crenella (Rhomboidella) rhombea (Berkeley, 1815)
Erycinella chavani (Glibert, 1945)
Astarte (? Astarte) waeli Glibert, 1945
Arctica islandica (Linné, 1767)
Venericardia (Glans) aculeata ronchetti Glibert & van de Poel, 1970
Clausinella scalaris (Bronn, 1831)
Pelecyora (Cordiopsis) polytropa nysti (d'Orbigny, 1852)
Lepetella compressiuscula (Karsten, 1849)
Ringicula (Ringiculina) ventricosa (Sowerby, 1824)
Roxania (s.s.) *paucistriata* (Ravn, 1907)

In the area investigated the occurrence of these species is usually a useful indication for the *Astarte radiata* Acme Zone. Most of these species, however, also occur in the *Hiatella arctica* Acme Zone, although generally in much smaller quantities. Of the species mentioned only *Venericardia aculeata ronchetti* and *Roxania paucistriata* have also been found in the *Spisula* sp. Acme Zone, both of them being extremely rare there. Also the small coral *Sphenotrochus intermedius* (Goldfuss) (see pl. 15) should be mentioned here as a typical species for the two lower biozones of the Aalten Member.

Typical reference section, boundaries and lithology — The section from 3.50 to 4.15 m below surface of the boring 34G.1-24 at "Ticheloven" near Eibergen (also a reference section of the Miste Bed) is designated here as the typical reference section of the *Astarte radiata* Acme Zone. Here, the lower boundary of the biozone coincides with the lithological lower boundary of the Miste Bed (overlying here the Brinkheurne Member) and the upper boundary coincides with the boundary between the Miste Bed and the Stemerdink Bed. Elsewhere, however, where the *Hiatella arctica* Acme Zone is found below the *Astarte radiata* Acme Zone and/or the *Spisula* sp. Acme Zone on top of it, the boundaries can only be found by a quantitative investigation of the mollusc fauna. The fact that in the typical reference section the upper boundary of the *Astarte radiate* Acme Zone coincides with the lithostratigraphical boundary is accidental.

A striking phenomenon is the fact that the *Astarte radiata* Acme Zone is

found in the neighbourhood of Eibergen at the very top of the Miste Bed (and occurs locally perhaps even in the lower part of the Stemerdink Bed as in boring 41E.2-7 at "de Giffel" near Eibergen) but occurs lower in the Miste Bed in southern direction. At the same time the *Spisula* sp. Acme Zone moves down from the base of the Stemerdink Bed into the top of the Miste Bed. At the southernmost places (boring 41D.2-7 at Aalten, and especially also at Dingden, see Janssen, 1967, p. 119) even the *Limopsis aurita* Acme Zone occurs partially in the Miste Bed (see fig. 25).

For further details on the lithology of this biozone the reader is referred to the chapter on the lithostratigraphy, see p. 29. The thickness of this biozone increases roughly from the north to the south. In the section of boring Dingden (Königsmühle) the part from 8.50 to 14.00 m below surface can be reckoned to this biozone. Locally two distinct maxima of the typical species are found in the *Astarte radiata* Acme Zone (as for example in boring 41E.3-145 at "Laarberg", Winterswijk, see fig. 25).

Facies and climatic significance — The mollusc fauna of the *Astarte radiata* Acme Zone suggests a deposition in a rather deep marine environment. The fauna seems to indicate a somewhat deeper sea than that of the *Hiatella arctica* Acme Zone. This is in agreement with the transgressive character of the Miste Bed, as indicated above (see also de Vogel, 1971, p. 123, fig. 2). This supposition is supported by the fact that the *Astarte radiata* Acme Zone was found in several borings and exposures at the very base of the Miste Bed (e.g. at Delden, see Janssen, 1972b; in boring 41D.2-7 at Aalten and in the boring Dingden-Königsmühle) while there is not the slightest indication that the *Hiatella arctica* Acme Zone has ever been present at those places and has later been removed by erosion. At the start of the sedimentation of the Aalten Member the sea was very probably already to deep at those places for the faunal association of the *Hiatella arctica* Acme Zone. Therefore, it can be safely assumed that the fauna of the *Astarte radiata* Acme Zone and of the *Hiatella arctica* Acme Zone have lived at different places at the same time. As a result of the progressing transgression the *Astarte radiata* Acme Zone is in a later stage deposited on top of the *Hiatella arctica* Acme Zone.

The fauna indicates a subtropical to moderate subtropical climate.

Geologic age and correlations — The mollusc fauna proves that the *Astarte radiata* Acme Zone is of Miocene age.

This biozone can easily be correlated with Miocene faunas in the region of Antwerp (Belgium) that are excellently known now from a number of magnificent exposures in recent time. The fauna of horizon 17 of the subdivision of Janssen & van der Mark — especially its lower part — has so many species in common with the *Astarte radiata* Acme Zone that both faunas can be regarded as very similar. The fauna of this horizon 17 differs, of course, to a certain degree from the *Astarte radiata* Acme Zone, so for example the bivalve *Glycymeris lunulata baldii* occurs in enormous quantities in the Belgian deposits. The distance between both regions makes such differences not surprising.

The *Astarte radiata* Acme Zone is not known from the Dutch Peel area nor from the Houthalen deposits in Belgium, but it remains possible that this biozone can be demonstrated by a quantitative investigation of the mollusc fauna if carefully sampled sections of those deposits become available.

Correlation with the Miocene of north western Germany is rather difficult.

Hinsch (1972b, p. 98) has correleated the *Astarte radiata* Acme Zone of the Netherlands ("Laag van Ticheloven") with the Hemmoor Stufe in marine facies as it is found in the western part of Schleswig-Holstein and northern Niedersachsen in Germany, and he based this correlation especially on the frequent occurrence of *Astarte radiata.* A possible correlation with the Reinbek Stufe was denied by him.

A number of mollusc species mentioned by Anderson (1964, table 1) from the Reinbek deposits of northern German, however, is not known from the two upper biozones of the Aalten Member (which should agree with the Reinbek Stufe, according to Hinsch), but they are known from the *Hiatella arctica* Acme Zone and the *Astarte radiata* Acme Zone. Therefore we are inclined to correlate the shell-bearing part of the Reinbeker Schichten of northern Germany with the *Astarte radiata* Acme Zone of the eastern part of the Netherlands and adjacent German areas. Especially the following species are of importance here (revised nomenclature):

Glycymeris (s.s.) *lunulata baldii* Glibert & van de Poel, 1965 (see pl. 15)
Limatula sulcata (Brown, 1827)
Meiocardia harpa (Goldfuss, 1840) (see pl. 16)
Arctica islandica (Linné, 1767) (see pl. 15)
Diplodonta (s.s.) *rotundata* (Montagu, 1803)
Pelecyora (Cordiopsis) polytropa nysti (d'Orbigny, 1852) (see pl. 15)
Solariella marthae Kautsky, 1925
Ficus simplex (Beyrich, 1854) (see pl. 16)
Amyclina facki (von Koenen, 1872) (see pl. 16)
Crenilabium terebelloides (Philippi, 1843)

It should be noticed here again that we do not wish to express any chronostratigraphical opinions here; when speaking of "correlation" we mean correlation in a litho- and biostratigraphical sense only.

It is very doubtful, however, whether it is really possible to correlate the faunal associations of north-western Germany, so strongly influenced by trans- and regressions, with the biostratigraphical subdivision of the Aalten Member in the Netherlands, where a regular transgressive sedimentation took place. Further quantitative research on the Miocene sections of north-werstern Germany might possibly throw light upon this problem.

Historical review — Although already von Koenen (1872, 1882) very probably has studied molluscan material from this biozone, only in recent times (Janssen, 1967) attention was drawn to the special character of this fauna. De Vogel (1970, 1971) did quantitative research on a large number of samples. A large quantity of molluscan material from several borings and exposures waits for further investigation.

Remarks — Hinsch (1972b, p. 97-99) explicitly stated that in north-western Germany the so-called "Hemmoor Stufe" and "Reinbek Stufe" have to be treated as chronostratigraphical units. The boundary between them, verified at the type localities, can according to him be correlated all over the North Sea Basin.

The investigation in the Gelderse Achterhoek and adjacent areas, however, has demonstrated beyond any doubt that the differences between the faunal associations of the various biozones in the Aalten Member have mainly been caused by environmental conditions. The different frequencies in the occurrence of species of the bivalve family Astartidae should, according to Hinsch, be connected with climatic changes over vast areas rather than with environmental modifications on a small scale. Exactly the opposite is demonstrated by the results obtained in the

Gelderse Achterhoek. Also, in the area studied by us, there is a clear difference in age between the lowermost and uppermost sediments of the Aalten Member, as is demonstrated for example by differences in the shark-fauna and by the planktonic gastropods. It is also clear, however, that chiefly environmental changes, interpreted in this paper as a progressive transgression, caused the obvious differences in the faunal associations. Consequently the resemblance between the *Astarte radiata* Acme Zone and the fauna of horizon 17 of the Sands of Antwerp should be considered an indication of similar environments rather than an indication of synchronism. The planktonic gastropods, as well as the sharks, indicate after all that the difference in age can not be very considerable.

So, if the Hemmoor Stufe and the Reinbek Stufe at their stratotypes are considered to be chronostratigraphical units, the probability has really to be kept in mind that these units will show an overlap.

No perfect chronostratigraphical correlations can be made by means of the palaeontological data. In our opinion chronological conclusions based on correct absolute datings would be preferable, if present. Correlations by means of planktonic, and sometimes also of nektonic, faunal elements can give some information about a presumable chronological correlation if absolute datings are not available. Similar remarks, especially concerning the correlation of Miocene deposits within the North Sea Basin, have been made by Boekschoten (1969b), de Vogel (1971), and Janssen (1972a).

Spisula sp. Acme Zone, new biozone

General concept — The *Spisula* sp. Acme Zone of the Aalten Member is characterized by a relative maximum in the quantitative vertical distribution of the bivalve *Spisula* sp. (figs. 32-33) and by the presence of an accompanying marine mollusc fauna rich in species and individuals.

The correct name of the typical species could not yet be ascertained. In the literature this species is usually indicated as *Spisula subtruncata triangula* (Brocchi, 1814). Glibert & van de Poel (1970, p. 16), however, have used the name *Spisula trinacria* (Semper, 1861). Without having seen the type material of these taxa we do not have an opinion about this problem. A description of this species can be found for example in the paper of Anderson (1964, p. 182, pl. 10, fig. 70a-b).

This biozone is known so far from a strip running more or less north-south (Eibergen-Winterswijk-Aalten-Dingden). De Vogel (1971) has studied the quantitative characters of the mollusc faunas in a number of samples. For a rough survey of the mollusc species frequently occurring in this biozone the reader is referred to de Vogel (1971). The most frequent species (more or less in order of frequency) are:

Spisula sp. (see fig. 32-33)
Corbula (Varicorbula) gibba gibba (Olivi, 1792)
Ringicula (Ringiculina) buccinea (Brocchi, 1814)
Astarte (? Astarte) gracilis convexior Anderson, 1959
Limopsis (s.s.) *aurita* (Brocchi, 1814)
Limopsis (Pectunculina) retifera Semper, 1861
Limopsis (Pectunculina) lamellata Lehmann, 1885
Dentalium (s.s.) *mutabile* Hoernes, 1856
Goodallia (s.s.) *angulata* (Lehmann, 1885)
Parvicardium straeleni (Glibert, 1945)

The *Spisula* sp. Acme Zone and the *Limopsis aurita* Acme Zone have a number of species in common that have hardly ever been found in the two lower biozones of the Aalten Member. These are mainly (see pl. 16):

Portlandia (Yoldiella) curvirostris (Lehmann, 1885)
Pycnodonte (s.s.) *navicularis* (Brocchi, 1814)
Abra lehmanni Anderson, 1964
Architectonica (Pseudotorinia) planulata (Grateloup, 1832)
Trivia westfalica Schilder, 1929
Eudolium dingdense Anderson, 1964
Aquilofusus festivus (Beyrich, 1856)
Haedropleura maitreja (von Koenen, 1872)
Magnella andersoni Dittmer, 1960
Thatcheria circumfossa (von Koenen, 1872)
Tornatina bellardii (von Koenen, 1882)

From the *Spisula* sp. Acme Zone a number of species is known that have not yet been found in the other biozones. This can partly be a result of the fact that from this biozone (temporary excavations at Dingden-Königsmühle, see Janssen, 1967) relatively large samples have been inspected for their fossil content. In the following list value should especially be attached to the more common species (marked with an *) (see pl. 17-18):

* *Yoldia* (s.s.) *longa* Bellardi, 1875
Solemya gliberti (Strauch, 1967)
* *Propeamussium (Parvamussium) squamosoreticulatum* (Anderson, 1964)

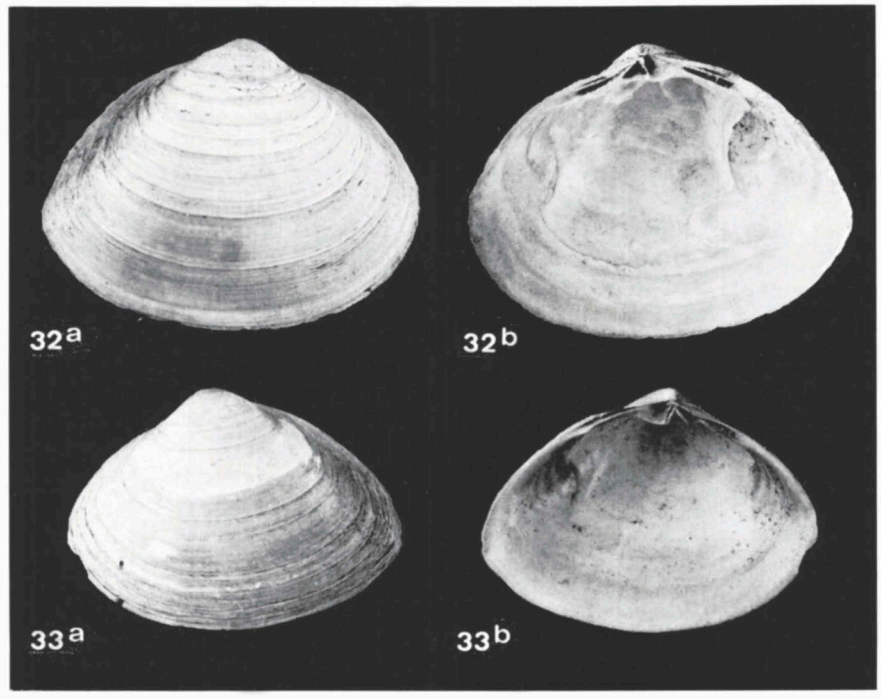

Fig. 32-33. Typical species of the *Spisula* sp. Acme Zone. Fig. 32. *Spisula* sp., right valve. Temporary excavation near the Königsmühle at Dingden, western Germany. RGM 184 804. Height 12.4 mm. Fig. 33. *Spisula* sp., left valve. Locality as in Fig. 32. RGM 184 805. Height 10.5 mm.

Hilberia duwelzi (Nyst, 1861)
Congeria basteroti (Deshayes, 1836)
* *Angulus (Oudardia)* aff. *donacillus* (Wood, 1857)
Xylophaga sp.
Pecchiola argentea (Mariti, 1797)
Solariella formosa Janssen, 1967
Cingula (Chevallieria) pseudoproxima Janssen, 1967
* *Circulus quadricarinatus* Janssen, 1967
* *Teinostoma (? Solariorbis) partimstriatum* Janssen, 1967
Melanopsis (Stilospirula) jansseni (Anderson, 1964)
* *Cirsotrema (Elegantiscala) kimacowiczi* (Zilch, 1934)
Capulus koeneni Anderson, 1964
* *Coralliophila (Pseudomurex) bracteata* (Brocchi, 1814)
Coralliophila (Aldrichia) granifera (Michelotti, 1847)
* *Murex (Tubicauda) spinicosta* Bronn, 1831
* *Amyclina badensis* (Hoernes, 1852)
Amyclina banatica (Zilch, 1934) sensu Anderson, 1964
* *Gemmula* (s.s.) *coronata* (von Münster, 1844)
* *Genota acuticostata* (Kautsky, 1925)
Mitroborsonia debilis (Beyrich, 1856)

These data are mainly based on the fauna collected in the exposures at Dingden-Königsmühle, because no large samples have been examined from other localities.

Typical reference section, boundaries and lithology — The section from 16.00 to 18.00 m below surface of the boring 41E.3-67 at Aalten is designated here as the typical reference section for the *Spisula* sp. Acme Zone. For a description of the lithology see p. 21.

The lower and upper boundary can usually only be estimated by a quantitative investigation of the mollusc fauna. The lower boundary is drawn between the relative maxima of *Astarte radiata* and *Spisula* sp., whereas the upper boundary is found between the maxima of *Spisula* sp. and *Limopsis aurita*. In the typical reference section the upper boundary accidentally coincides with the lithological boundary of the Miste Bed and the Stemerdink Bed. At Dingden the top metre of the Miste Bed belongs already to the *Limopsis aurita* Acme Zone. Further to the north, on the contrary, the *Spisula* sp. Acme Zone is found above this lithological boundary in the base of the Stemerdink Bed (see fig. 25). Hence, it can be concluded that the mutual relation between the composition of the fauna on one side and the lithological characters of the sediment on the other is not so close as is generally supposed. An interesting feature is the fact that from north to south the percentage of *Spisula* sp. in the fauna increases. So, in boring 34G.1-24 at "Ticheloven" near Eibergen a maximum was counted of 12%, in boring 41E.2-7 at "de Giffel" in Winterswijk this was 20%, boring 41E.3-67 at Aalten (Haart) 25% and in boring 41D.2-7 at Aalten even 31% (data from de Vogel, 1971). This phenomenon can not yet be explained at this moment.

This biozone reaches a maximum thickness of about 2 m.

Facies and climatic significance — Fauna and lithology of the *Spisula* sp. Acme Zone indicate clearly a marine environment. Probably the sea was deeper than during the deposition of the *Astarte radiata* Acme Zone. A depth of some 25-30 m seems to be a fair estimate.

In the mollusc material of this biozone collected from the exposures at Dingden (Königsmühle) two species that originate from a more oligohaline environment — *Congeria basteroti* and *Melanopsis jansseni* — have very rarely been

found. It is very likely that these species have been transported from elsewhere. Their apparent absence in the other biozones of the Aalten Member can probably be explained by the fact that from the Dingden locality very large samples have been investigated already. On the other hand they could possibly indicate a change in the geography of the coastal plain.

This fauna too indicates a subtropical to moderate subtropical climate.

Geologic age and correlations — The *Spisula* sp. Acme Zone is certainly of Miocene age. A correlation with faunas from other parts of the North Sea Basin appears to be rather difficult. No faunas are known from north-werstern Germany that, with respect to the species composition, can be compared with the fauna of the *Spisula* sp. Acme Zone. The "Twistringer Schichten", that will be extensively discussed in the description of the *Limopsis aurita* Acme Zone, show the closest relationship.

From Belgium also, no equivalents of the *Spisula* sp. Acme Zone are known. Anderson (1964, p. 111) correlates the Sands of Edegem with the "Reinbek Stufe". This misunderstanding was mainly caused by the fact that a number of bivalve species has erroneously been mentioned from the Sands of Edegem by Glibert (1945, see also Janssen & van der Mark, 1969). Janssen (1972a) gave as his opinion that the Sands of Edegem belong to the oldest known Miocene deposits of the North Sea Basin. Hooyberghs & de Meuter (1972) even reckoned these Edegem Sands to the Late Oligocene.

It is practically certain that the "Bislicher Schichten" (Anderson, 1964) of the German Lower Rhine area correspond partially with the *Spisula* sp. Acme Zone. Which part, however, should exactly be correlated can not be decided because of the lack of a detailed quantitative investigation of the Bislich section. Presumably also the *Astarte radiata* Acme Zone is represented in the "Bislicher Schichten".

Also it can not be checked if parts of the Miocene deposits of the Dutch Peel area and the Belgian Houthalen deposits can be correlated with the *Spisula* sp. Acme Zone, because no detailed quantitative investigations have been carried out there so far.

Historical review — Material from this biozone has hardly been described in the literature, only the Dingden locality has been investigated by several authors. De Vogel (1971) did a quantitative research on the mollusc fauna.

Limopsis aurita Acme Zone, new biozone

General concept — The *Limopsis aurita* Acme Zone of the Aalten Member is characterized by a relative maximum in the vertical distribution of the bivalve *Limopsis* (s.s.) *aurita* (Brocchi, 1814) (see figs. 34-35) and by an accompanying marine mollusc fauna that is relatively poor in species and individuals. A description of the typical species can be found in the literature (e.g. Anderson, 1959, p. 87, pl. 13, fig. 8a-c.)

This biozone is known with certainty from a strip running more or less north-south in the Gelderse Achterhoek and adjacent areas (Eibergen-Winterswijk-Aalten-Dingden). For a rough survey of the common mollusc species of this biozone the reader is referred to de Vogel (1971) who did a quantitative research on the mollusc fauna. The most frequently occurring species in this biozone are (more or less in order of frequency):

Limopsis (s.s.) *aurita* (Brocchi, 1814)
Astarte (? Astarte) gracilis convexior Anderson, 1959
Aporrhais (s.s.) *alata* (von Eichwald, 1830)
Parvicardium straeleni (Glibert, 1945)
Corbula (Varicorbula) gibba gibba (Olivi, 1792)
Hinia (s.s.) *bocholtensis* (Beyrich, 1854)
Dentalium (s.s.) *mutabile* Hoernes, 1856
Cyclocardia (s.s.) *chamaeformis* auct. (non Sowerby)
Nuculana (Saccella) westendorpi (Nyst, 1839)
Yoldia (s.s.) *glaberrima* (von Münster, 1835)

This biozone can be distinguished from the *Spisula* sp. Acme Zone, apart from the frequency of the typical species, by an impoverishment of the mollusc fauna, as a result of which many species occurring in the *Spisula* sp. Acme Zone are no longer found in the *Limopsis aurita* Acme Zone. Also the number of individuals (in relation to the quantity of sediment) is markedly less. As far as is known up to now all the mollusc species found in the *Limopsis aurita* Acme Zone also occur in the *Spisula* sp. Acme Zone. There are, however, a small number of differences in the frequencies. In the *Limopsis aurita* Acme Zone the following molluscs are more common than in the *Spisula* sp. Acme Zone:

Portlandia (Yoldiella) curvirostris (Lehmann, 1885) (see pl. 16)
Limopsis (s.s.) *aurita* (Brocchi, 1814) (see fig. 34-35)
Pycnodonte (s.s.) *navicularis* (Brocchi, 1814) (see fig. 36)
Eudolium dingdense Anderson, 1964 (see pl. 16)

A striking feature is the fact that in several borings two distinct maxima of the bivalve *Limopsis aurita* have been found (see fig. 25).

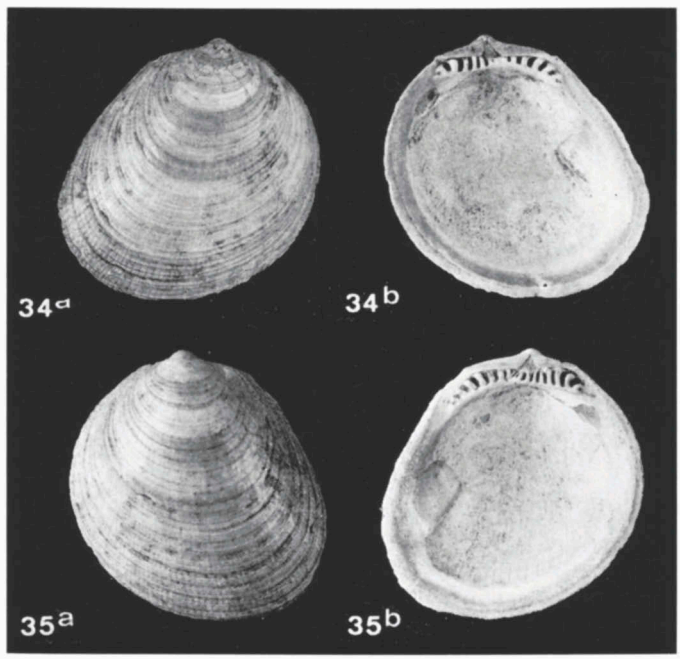

Fig. 34-35. Typical species of the *Limopsis aurita* Acme Zone. Fig. 34. *Limopsis* (s.s.) *aurita* (Brocchi, 1814), right valve. Temporary excavation near the Königsmühle at Dingden, western Germany. RGM 184 806. Height 11.4 mm. Fig. 35. *Limopsis* (s.s.) *aurita* (Brocchi, 1814), left valve. Locality as in Fig. 34. RGM 184 807. Height 11.4 mm.

Typical reference section, boundaries and lithology — The section from 6.00 to 11.00 m below surface of the boring 41E.4-387 at the "Stemerdink" farm at Brinkheurne (Winterswijk), which is also part of a reference section of the Stemerdink Bed, is designated here as the typical reference section of the *Limopsis aurita* Acme Zone. For a description of the lithology see p. 25.

The lower boundary of this biozone has to be traced by a quantitative investigation of the mollusc fauna. The boundary is drawn between the maxima of *Spisula* sp. and *Limopsis aurita*. The upper boundary coincides, as far as is known at this moment, always with the upper boundary of the shell-bearing part of the Aalten Member, at any rate at those places where the deposit has not been affected by erosion and where consequently the base of the Eibergen Member is still present. In the exposure near the Königsmühle at Dingden the upper part of the Stemerdink Bed seems to be eroded. In the former clay-pit of the F.O.W. brick-works at Eibergen (Zwilbroek) the transition between the Stemerdink Bed and the Eibergen Member could be studied very well. The fauna of the upper part of the Aalten Member (Stemerdink Bed) comprises in that clay-pit no more than some 15 mollusc species, among which especially the oyster *Pycnodonte navicularis* (see fig. 36) was common, also very large specimens of *Eudolium dingdense* (up to a size of at least 15 cm) were found. The specimens of this latter species were so badly preserved that it was impossible to collect a single specimen. The shells could exclusively been observed in freshly broken clay as very thin white lines.

The *Limopsis aurita* Acme Zone is practically always found in the clayey sediments of the Stemerdink Bed. Only in the southern part of the area investigated the base of this biozone reaches into the top of the Miste Bed (see fig. 25). At Dingden the lithological boundary of the Miste Bed and the Stemerdink Bed is accompanied by a distinct concentration of the bivalve *Anadara* (s.s.) *diluvii* (Lamarck, 1805) (see Janssen, 1967, fig. 2).

The thickness of this biozone can reach some 10 m in the south and decreases in thickness to the north.

Geologic age and correlations — The *Limopsis aurita* Acme Zone is also certainly of Miocene age.

Apart from the area described here this biozone has presumably also been encountered in the adjacent Lower Rhine area in western Germany (Anderson, 1958, 1964; "Dingdener Schichten").

No similar fauna is known from the Miocene deposits in Belgium, an hiatus is found between the Sands of Antwerp and the Sands of Deurne, instead.

In north-western Germany the fauna of the so-called "Twistringer Schichten" is in many respects similar to the fauna of the *Spisula* sp. Acme Zone and the *Limopsis aurita* Acme Zone of the Aalten Member. Each of these three faunas contains regularly specimens of the gastropod *Aquilofusus festivus* (Beyrich). The best correlation is found between the "Twistringer Schichten" and the *Limopsis aurita* Acme Zone: the faunas are rather poor in specimens and species, *Limopsis aurita* is common to very common, and from Twistringen *Spisula* sp. is hardly known. A large number of the species found in the *Spisula* sp. Acme Zone has not been found in the "Twistringer Schichten", despite the fact that a large quantity of mollusc material has been inspected (Anderson, 1964; Janssen, 1972a). Also the frequency of other species points in the same direction, as for example *Portlandia curvirostris, Parvicardium straeleni, Abra lehmanni, Aporrhais alata, Eudolium dingdense, Hinia bocholtensis,* and other species. Consequently, we suppose

that the deposition of the "Twistringer Schichten" took place in relatively deep water, which is demonstrated, apart from the resemblance with the *Limopsis aurita* Acme Zone, also by the occurrence of many species of the gastropod family Turridae and genera like *Thracia, Pholadomya, Verticordia,* and so on. Recently (January 1975), also several specimens of *Aturia* sp. were found (RGM collection).

The fauna of the "Twistringer Schichten" has yielded a number of species that are more or less typical for the "Hemmoor" faunas. They have most probably been collected from the lower part of the "Twistringer Schichten", but this is not known with certainty for all of them. These species are:

Euthria antwerpiensis Glibert, 1952
Aquilofusus beyrichi (Nyst, 1861)
Hinia (s.s.) *cimbrica* (Ravn, 1907) — very common
Clavus (Elaeocyma) diensti (Kautsky, 1925)

Concluding it can be assumed that the whole section of the "Twistringer Schichten", as described by Cadée & Janssen (1968), is a lateral equivalent deposited in a

Fig. 36. *Pycnodonte* (s.s.) *navicularis* (Brocchi, 1814). Clay-pit of the F. O. W. brick-works at Eibergen (Zwilbroek), 34G.3-1. Upper part of the Stemerdink Bed. RGM 184 808. Height c. 60 mm.

somewhat deeper sea, contemporaneously with the Hemmoor and Reinbek facies that have been laid down elsewhere in a relatively shallower sea. This hypothesis seems to solve a great deal of the correlation problems. In this respect, it is quite interesting to note that the upper part of the "Twistringer Schichten" shows a transition into overlying barren clays, analogue to the transition observed between the Aalten Member and the Eibergen Member (see also Cadée & Janssen, 1968).

Facies and climatic significance — As stated above the *Limopsis aurita* Acme Zone has most probably been deposited in a somewhat deeper sea than the other three biozones of the Aalten Member. In this respect depths of no more than 40 to 50 metres should be considered the most probable. The greater depth of the sea agrees with the transgressive character of the Aalten Member. Of course, this has also influenced the palaeogeography of the coast-lines. This is supported by the shark fauna (see p. 78) in which suddenly southern species appear. The occurrence of the genera *Sphyrna* and *Isistius,* that are usually regarded as typical for tropical faunas, should be explained by palaeogeographical changes rather than by climatic changes. There are no indications for a climatic change during the deposition of this biozone.

The impoverishment of the fauna should be explained by an increasing depth of the sea and by an increased rate of sedimention.

Historical review — The *Limopsis aurita* Acme Zone is the only biozone that can be sampled without excavation at the classical exposure at Dingden. The fauna of this locality has repeatedly been dealt with in the literature. The underlying sandy deposits of the Miste Bed ("Dingdener Feinsand") have at first not been recognized as a separate zone (von Koenen) and have only in recent time (Anderson, 1964; Janssen, 1967) been described in detail.

This biozone is also known from the outcrop "Stemerdinkbrug" near the "Stemerdink" farm at Winterswijk (Brinkheurne). This locality is known for a long time, but it has hardly ever been mentioned in the literature. Spaink (1960) listed all the mollusc species known to him from the Gelderse Achterhoek, but he has not distinguished separate biozones or lithozones.

FAUNA OF THE EIBERGEN MEMBER

Practically all the fossils known from the Eibergen Member are vertebrates, among which numerous remains of marine mammals and large Elasmobranchii. Molluscs and other calcareous fossils have not been found.

Two localities are of interest for the elasmobranchiid teeth: the former clay-pit near the water-tower of Eibergen on the road from Eibergen to Haaksbergen and the clay-pit complex of the F.O.W. brick-works near Zwilbroek at Eibergen. From these clay-pits the following fauna has been collected (some 750 teeth in the RGM collections).

Hexanchus primigenius (Agassiz, 1843)
Hexanchus gigas (Sismonda, 1861)
Odontaspis aff. *cuspidata* Agassiz, 1844
Odontaspis vorax le Hon, 1871
Isurus aff. *retroflexus* (Agassiz, 1843)
Isurus hastalis (Agassiz, 1843) — dominant, more than 80% of the fauna (see pl. 22)
Isurus escheri (Agassiz, 1844) — not rare
Galeocerdo aduncus Agassiz, 1843

Twelve teeth of *Galeocerdo aduncus* belonging to one individual have been found in the F.O.W. clay-pit. A search for smaller fossils has not been successfull. Only very few skeleton parts of bone-fishes have been found. Thus, it should be accepted that smaller species have almost completely been missing in the fauna.

Van Deinse (1959) mentioned a large placoid scale of a ray that was identified by him with some reservation as *Raja aplanata* Probst, 1877. This scale, collected in the old clay-pit of the F.O.W. brick-works at Zwilbroek in Eibergen (34G.3-1) could also have originated from the top of the Stemerdink Bed that was also exposed in this clay-pit. It is kept in the RGM collection (RGM 86 869) and is now identified as *Dasyatis targionii* (Lawley, 1876) (see pl. 22, fig. 1).

As stated in the above list *Isurus hastalis* is by far the most frequent species. It does no longer show the same shape as the specimens of the Miste Bed, it reaches a larger size and is relatively less narrow. A less common species is *Isurus escheri* that appears in the Eibergen Member for the first time. The teeth of *Isurus escheri* are not yet as typical as they are in the Zenderen Member, the crenulation of the crown is usually still rather indistinct. The impression exists that this species is here still in an earlier evolutionary stage. The teeth of *Odontaspis* aff. *cuspidata* differ from those from the Oligocene; likewise the form of the teeth of *Isurus* aff. *retroflexus* differs from the teeth of that species found in the Miste Bed.

The Elasmobranchii found in the Eibergen Member resemble the fauna of the "Langenfelder Stufe" in northern Germany (Kruckow, 1960), but *Procarcharodon megalodon* (Agassiz) mentioned by Kruckow, has not been found in the Eibergen Member.

Correlations over a larger distance can hardly be made. Around the Mediterranean Sea comparable faunas do not occur because of the strongly changed palaeogeography in that area as a result of extensive regressions. Elsewhere comparable faunas have not been found either.

Striking is the fact that the Eibergen Member fauna does not comprise species that feed at the sea bottom. Furthermore most species prefer the open water of a rather deep sea.

Van Deinse (1931, 1953, 1957, 1964) mentioned the following respectable list of marine mammals and some bone-fishes, all of them collected in the clay-pit complex of the F.O.W. brick-works at Zwilbroek, Eibergen (34G.3-1, 34G.3-13). In our opinion this list needs a revision, also because an extensive material has been collected by staffmembers of the RGM from the same locality in recent time.

mammalia:

Squalodon antwerpensis van Beneden
Scaldicetus grandis du Bus
Physeterula dubusi van Beneden
Thalassocetus antwerpensis Abel
Cyrtodelphis sulcatus Gervais
Acrodelphis scheynensis du Bus
Acrodelphis macrospondylis Abel
Eurhinodelphis cocheteuxi du Bus
Eurhinodelphis longirostris du Bus
Eurhinodelphis cristata du Bus
Choneziphius planirostris Cuvier
Mesoplodon longirostris Cuvier
Mioziphius belgicus Abel
Balaenoptera musculoides van Beneden
Balaenoptera borealina van Beneden
Balaenoptera rostratella van Beneden

Megaptera affinis van Beneden
Burtinopsis similis van Beneden
Erpetocetus scaldisensis van Beneden
Plesiocetus brialmonti van Beneden
Plesiocetus dubius van Beneden
Plesiocetus hupschi van Beneden
Plesiocetus verus (van Beneden)
Plesiocetus affinis (van Beneden)
Plesiocetus brevifrons (van Beneden)
Plesiocetus sprangi (van Beneden)
Plesiocetus longirostris (van Beneden)
Plesiocetus laxatus (van Beneden)
Plesiocetus longifrons (van Beneden)
Balaenula balaenopsis van Beneden
Alachtherium sp.
Palaeophoca sp.

pisces:

Brachyrhynchus belgicus Leriche, 1926
Mola pileatus Leriche, 1926

Furthermore a large part of a *Halitherium* skeleton, found during the excavation of a new clay-pit at the F.O.W. clay-pit complex at Eibergen (34G.3-13), is kept in the RGM. It was obtained through the courtesy of Dr F. J. M. Heslinga (Amsterdam).

In the collections of the Natuurhistorisch Museum at Enschede a part of a turtle shell is kept. This reptile has been found in the clay-pit near the water-tower at Eibergen (Roding, 1961).

It is a question whether these animals have really lived at this place or have drifted in from elsewhere as dead specimens and were buried here. Van Deinse (1931) supposed that mass strandings have taken place. This seems rather improbable, however, as the coast-line was not situated at a short distance. The fossils found (Elasmobranchii and marine mammals) originate from very different environments. Many hundreds of teeth of *Isurus hastalis* occur and also specimens of *Halitherium* and *Palaeophoca*. It seems hardly probable that a near-shore sea rich in food has been present with a deep see at a short distance as, in the region of Bocholt, Winterswijk, Eibergen and adjacent regions, the Eibergen Member shows hardly any changes in the lithological composition. So, most certainly there has been a supply of dead animals but an acceptable theory about their origin has not been found yet. Also it can not yet be determined with certainty whether sedimentation of the Eibergen Member took place in a relatively deep or in a relatively shallow sea. A littoral or sublittoral environment seems to be out of the question. With regard to the transgressive character of the Aalten Member and the regressive nature of the deposits succeeding the Eibergen Member a relatively great depth is the most probable, especially for the lower part of the member. Upwards in the Eibergen Member the increasing content of glauconite in the sediment indicates a more regressive character.

We have the impression that most whales have been buried in the sediment as more or less complete skeletons, disconnected in the clay-pit by the digging machines and that only the most solid parts are noticed. Should sedimentation have taken place in shallow coastal waters (less than $\pm$ 15 m deep) the skeleton parts would have been disconnected by wave action.

It has not yet been possible to make use of the marine mammals for stratigraphical correlations. The stratigraphic level of most of the Belgian finds is not exactly known, at least not in such a way that they can be interpreted according to the present stratigraphical concepts.

FAUNA OF THE ZENDEREN MEMBER

Invertebrata — For an investigation of the fauna of the Zenderen Member washresidues of two borings were available. They contain a poor and rather badly preserved fauna that has carefully been analysed.

In the boring 34B.3-1 near the Gelselaars bridge, municipality of Neede (see p. 43), the section from 49.50 to 68.50 m below surface belongs to the Zenderen Member. In almost every sample some fragments of the inarticulate brachiopod *Lingula* have been found. Although the numbers are small (with a maximum of 8 fragments in sample 61.50 - 62.50 m) only two samples did yield no *Lingula*. The following mollusc species have been found. *Nucula* sp. — presumably *N. nucleus* (Linné, 1758) — was found in four samples below 61.50 m, with a maximum of 19 fragments in sample 62.50 - 63.50 m. Rather regularly occurring fragments of Pectinidae can hardly be identified specificly. Especially in the lower part of the member fragments of a *Pseudamussium* sp., presumably *P. clavatum* (Poli, 1795), are not rare. This species is known from the Sands of Deurne and less frequently from the Sands of Kattendijk in Belgium. This species is also found in the "Gram Stufe" of north-western Germany and Denmark. In the "Sylt Stufe" the species is less common. Above 60.00 m some fragments of a pectinid, presumably *Palliolum tigerinum* (Müller, 1776), are present in the smooth form that is frequent in the Sands of Kattendijk in Belgium. Furthermore fragments of *Limatula sulcata* (Brown, 1827) and an *Astarte* sp. have incidently been found. Finally, fragments of Balanidae and of the annelid *Ditrupa* sp. (three fragments of each) have been found. Some irreocognizable remnants of bivalvia, especially from the part below 59.00 m, are disregarded here.

Also in the boring 28G.3-1 at the Twickel estate, municipality of Delden (see p. 41) the brachiopod *Lingula* occurs in almost every sample of the Zenderen Member. Usually it is likewise found in small numbers, but in several residues (about 9.00 and 12.50 m) this species is much more common. In none of the samples, however, the species occurs as frequent as in the Delden Member of the same boring. Except for irrecognizable fragments of bivalvia the following molluscs have been found: Nuculanacea indet., 1 fragment; *Nuculana (Saccella)* cf. *westendorpi* (Nyst, 1839), 1 fragment; Mytilacea, 1 fragment; *Yoldia* sp., 1 fragment; and *Ringicula (Ringiculina) buccinea* (Brocchi, 1814), 1 fragment. Of these species *Nuculana westendorpi* is only known from Miocene deposits.

These faunas suggest a Late Miocene age for the Zenderen Member rather than a Pliocene age. This can, however, hardly be decided with certainty on the base of the poor material available.

It is quite possible that part of the invertebrate material collected from the exposure in the Twentekanaal near Delden (Janssen, 1966) originates from the Zenderen Member. This is more extensively discussed below and in the description of the Delden Member fauna (see p. 101).

Vertebrata — In the Zenderen Member many vertebrate remains are found, mainly of fishes. Also some whale bones have been found, but notably less than in the Eibergen Member. Every boring in the Zenderen Member yielded fish remains, mainly fine skeleton parts, scales and small teeth. Remains of larger fishes, among which also a fauna of Elasmobranchii, and of marine mammals are known from the exposures of the Twentekanaal near Delden, in the part east of the St. Anna bridge, and from moulding-sand pits in the Needse Berg at Neede. The material from the fossiliferous localities in the Twentekanaal, however, has not been kept apart with the result that fossils from the Zenderen Member and the Delden Member have been mixed up. The same happened with material from the Needse Berg, where mainly sediments of the Zenderen Member were exposed, but locally also Delden Member sediments have been observed. In the faunal lists below the data have been interpreted as well as possible.

From boring 28G.172 at Zenderen, boring 34B.3-1 near the Gelselaars bridge, boring 28G.3-1 at the Twickel estate, exposures in the Twentekanaal east of the St. Anna bridge and the moulding-sand pit at the Needse Berg the following fish species are known (see also van den Bosch, 1969a). Some 500 teeth are kept in the RGM collection.

Hexanchus primigenius (Agassiz, 1843)
Hexanchus gigas (Sismonda, 1861)
Odontaspis aff. *acutissima* Agassiz, 1843
Odontaspis vorax le Hon, 1871
Odontaspis aff. *cuspidata* Agassiz, 1843
Lamna sp. van den Bosch, (1969a, p. 27, fig. a-d)
Isurus hastalis (Agassiz, 1843) — dominant (see pl. 23)
Isurus escheri (Agassiz, 1844) — common (see pl. 23)
Cetorhinus maximus (Gunnerus, 1765)
Squalus sp. — common
Raja sp. div. — common
Dasyatis sp.
Rhinoptera sp.

Miothunnus deldenius van Deinse, 1953
Acipenser sturio Linné, 1758

Van den Bosch (1969a) mentioned also the species *Lamna cattica* (Philippi, 1846). This species has wrongly been identified, and is listed above as *Lamna* sp. The same author also mentioned *Oxyrhina benedeni* le Hon, 1871, that is now supposed to originate from Oligocene deposits. It does not occur in the fauna of the Zenderen Member. Furthermore *Oxyrhina desori* (Agassiz, 1844) has been mentioned by van den Bosch. Part of this material, however, is now considered by him to be juvenile specimens of *Isurus hastalis,* another part came from Quaternary deposits.

The fauna of the Elasmobranchii found in the Zenderen Member shows notable differences with the fauna of the Eibergen Member. *Isurus hastalis* is still a common species, but the teeth reach larger dimensions and they are relatively less narrow; *Isurus escheri* becomes a common species in this deposit and the teeth represent a very typical form of this species (van den Bosch, 1969a). Furthermore a number of forms appears that are partly indicative for less deep seas, e.g. *Squalus, Raja, Dasyatis* and *Rhinoptera.* Also, a species of *Lamna* is found that is mentioned by van den Bosch (1969a, p. 27, fig. a-d) but has not been named yet.

The fauna still indicates an open connection with the Atlantic Ocean and is considered to represent a subtropical to moderate climate.

A fauna, closely comparable to the Zenderen Member fauna, has been

acquired by the RGM from the clay-pit of the Gram brick-works at Gram, Denmark. This locality is the stratotype of the Gram Formation (in the sense of Rasmussen, 1956).

There is also a strong resemblance to the fauna known from the Sands of Deurne in the Antwerp region (Leriche, 1926), from which deposit material is kept in the RGM collection.

Outside the North Sea Basin no fauna is known that can be compared with that of the Zenderen Member. In the Mediterranean district extensive regressions took place; also at the Atlantic coast comparable deposits from this period are not amply represented.

Van Deinse (1931) mentioned skeleton parts of marine mammals from the moulding-sand pits of the Needse Berg at Neede that, according to some sediment samples kept in the RGM, have mainly been found in the Zenderen Member. He mentioned the following species:

Scaldicetus caretti du Bus
Choneziphius planorostris Cuvier
Balaenoptera musculoides van Beneden
Balaenoptera borealina van Beneden
Balaenoptera rostratella van Beneden
Burtinopsis minutus van Beneden
Burtinopsis similis van Beneden
Plesiocetus verus (van Beneden)
Plesiocetus affinis (van Beneden)
Plesiocetus brevifrons (van Beneden)
Plesiocetus latifrons (van Beneden)
Balaenula balaenopsis van Beneden

From the former exposures in the Twentekanaal near Delden van Deinse (1964) recorded a find of *Odobenus huxleyi* (Lankester).

This fauna shows differences with that of the Eibergen Member. The remarks made in the description of the Eibergen Member vertebrates hold to a lesser degree also for the Zenderen Member.

FAUNA OF THE DELDEN MEMBER

Invertebrata — From the stratotype of the Delden Member (boring 28G.3-1 at the Twickel estate at Delden, see p. 45, depth 1.40-7.50 m below surface) a small invertebrate fauna has been collected (RGM collection). Fossil-bearing residues are available from 3.00 to 7.50 m below surface. Since the sediments have been decalcified most of the encountered species have been preserved as internal or external moulds. Only the fragments of *Lingula* are present in an apparently unchanged condition. The number of specimens per sample is indicated in Table 8. If only fragments have been found the numbers are underlined.

Among the irrecognizable specimens, indicated with "indet." in Table 8, moulds of gastropods and bivalves are represented, as well as fragmentary moulds presumably of Crustacea (? Decapoda).

Also from the boring 34B.3-1 near the Gelselaars bridge at Neede, in which the part from 32.50 to 49.50 m below surface belongs to the Delden Member (reference section, see p. 47) a small fauna has been collected that is listed in Table 9. This material is also fragmentary, but it is hardly or not decalcified.

Striking in both borings is the frequent occurrence of *Lingula* sp. (see pl. 19). The only deposit in the North Sea Basin (apart from some Early to Middle Miocene deposits in north-western Germany) in which this species is known in comparable quantities are the Sands of Kattendijk of the Scaldisian (the relevant part is also called Kattendijkian) from the Antwerp area in Belgium. According to Glibert (1957c, p. 5) this species — denominated *Lingula dumortieri* Nyst, 1845, by him — is very common in the Sands of Deurne and common in the Kattendijk Sands. However, in recent exposures of the Sand of Deurne near Antwerp this species was hardly ever encountered. In the Kattendijk Sands it occurs very frequently (personal observations at several outcrops). From the boring Oddenrade in north-western Germany (Hemmoor Stufe) the same species has been reported to be common by Dittmer (1959). All other fossils found in the two borings are also known from these Sands of Kattendijk. The Astartid bivalve *Digitaria excurrens* is exclusively known from Pliocene deposits.

Janssen (1966) studied a fauna preserved in phosphorite concretions, collected in the temporary exposures of the Twentekanaal near Delden. This material has been collected at two localities, situated close to each other on the western and eastern side of the St. Anna bridge (Krul, 1950). The greater part of the collection has not been separated per locality. At the place mentioned the Zenderen Member has been exposed as well as the Delden Member. Therefore the fossils could have been collected from both members. It can be assumed, however, that the fossiliferous phosphorite concretions have mainly, if not completely, been

	3.00 - 3.50 m	3.50 - 4.00 m	4.00 - 4.50 m	4.50 - 5.00 m	5.00 - 5.50 m	5.50 - 6.00 m	6.00 - 6.50 m	6.50 - 7.00 m	7.00 - 7.50 m
plant remains	-	-	2	17	-	-	-	-	-
foraminifera	-	-	-	1	-	-	-	-	-
Vitrupa sp.	28	1	5	34	8	7	3	6	-
Portlandia (Yoldiella) sp.	8	2	5	3	-	5	2	1	-
Glycymeris sp.	1	-	-	-	-	-	-	-	-
Pectinidae indet.	-	1	3	2	1	-	-	-	-
Limatula sulcata (Brown, 1827)	5	-	-	-	-	1	-	1	-
Digitaria excurrens (Wood, 1853)	-	-	-	-	-	-	-	1	-
Carditidae/Cardiidae	17	1	3	11	1	2	3	1	-
Hiatella arctica (Linné, 1767)	-	-	-	-	-	1	-	-	-
Corbula gibba gibba (Olivi, 1792)	-	-	1	-	-	-	-	-	-
Lingula sp. (numbers estimated)	600	400	600	2500	300	650	700	300	22
Decapoda	-	-	-	-	1	-	-	-	-
Balanidae sp.	-	-	-	2	-	1	-	-	-
indet.	78	-	32	89	7	42	17	9	-

Table 8. Invertebrate fossils of boring 28G.3-1 at the Twickel estate, municipality of Delden, depth 3.00 - 7.50 m below surface (Delden Member). Underlined numbers mean that only fragments have been found.

	32.50 - 33.50 m	33.50 - 34.50 m	34.50 - 35.50 m	35.50 - 36.50 m	36.50 - 37.50 m	37.50 - 38.50 m	38.50 - 39.50 m	39.50 - 40.50 m	40.50 - 41.50 m	41.50 - 42.50 m	42.50 - 43.50 m	43.50 - 45.50 m	45.50 - 46.50 m	46.50 - 47.50 m	35.00 - 47.50 m	47.50 - 48.50 m	48.50 - 49.50 m
Ditrupa sp.	-	-	-	-	-	-	-	22	4	4	5	8	-	1	1	-	-
Nucula (Nucula) sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Modiolula phaseolina (Philippi, 1844)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Arcoperna sericea (Bronn, 1831)	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Pseudamussium tigerinum (Müller, 1776)	-	-	-	-	-	-	-	16	5	58	42	72	6	26	65	-	-
Limatula sulcata (Brown, 1827)	-	-	-	-	-	-	-	-	1	9	4	3	-	2	-	-	-
Digitaria excurrens (Wood, 1853)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Goodallia (s.s.) cf. *triangularis* (Montagu, 1803)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Corbula gibba gibba (Olivi, 1792)	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Panopea sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Bivalvia sp.	-	-	-	-	-	-	6	28	24	30	13	23	8	18	c	2	4
Epitonium (Spiniscala) frondiculum (Wood, 1848)	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Lingula sp.	9	11	99	1	7	16	29	160	171	129	132	173	30	87	179	6	2
spines of regular sea-urchins	-	-	-	-	-	-	-	6	1	2	-	-	-	1	-	-	-
Balanidae sp.	-	-	-	-	-	-	3	4	-	-	-	7	1	4	35	1	-

Table 9. Invertebrate fossils from boring 34B.3-1 near the Gelselaars bridge at Needе, depth 32.50 - 49.50 m below surface (Delden Member). Underlined numbers mean that only fragments have been found.

collected from the Delden Member. This fauna is important because it is considerably richer in species than the fauna of the two borings mentioned above. Janssen (1966, p. 116) concluded that the invertebrate fauna of the Twentekanaal can approximately be correlated with the Belgian "Deurnian" (Sands of Deurne). This conclusion, however, seems to be more or less contestable nowadays. Not only are some of the identifications questionable, but since the publication of that paper the Sands of Deurne have been studied near Antwerp in temporary excavations for the E 3 highway around Antwerp, resulting in an improved knowledge of the fauna of this deposit. Janssen & van der Mark (1969) have corrected the faunal lists of the Sands of Deurne, given in the literature. The bivalve *Pygocardia rustica* (Sowerby, 1818) does not occur in the Sands of Deurne. This species, mentioned from the Twentekanaal (see pl. 19), is known — in a number of forms — from the Sands of Kattendijk and younger deposits. The conclusion, also on the base of the fossil content of the two borings mentioned above, should be obvious: the Delden Member should be placed without any doubt in the Pliocene. However, several other species mentioned by Janssen (1966) from the Twentekanaal are exclusively known from the Miocene. In this respect especially the bivalve *Panopea menardi* Deshayes (see pl. 19) and the gastropod *Scaphella bolli* (Koch) (see pl. 19) should be mentioned. The question arises whether the specimens in the material from the Twentekanaal that have been assigned to these species do not belong to *Panopea faujasi* Ménard de la Groye, and *Scaphella lamberti* (Sowerby) respectively, or to transitional forms. A revision of the material will be necessary to allow a definite conclusion in this matter.

In the RGM and in several other collections (especially the one of the Natuurhistorisch Museum at Enschede) mollusc material, preserved as moulds and resembling the material from the Twentekanaal, is available from several other localities, e.g. Vasse, the Twickelse Vaart near Delden, the Needse Berg at Neede, an outcrop in the wood "'t Klooster" at Aalten, etc. Unfortunately much of this material, especially in the older collections, has been collected disregarding the exact stratigraphic position. Nevertheless, a study of the complete available material seems to be very promising. Superficially this material is similar by the frequent occurrence of the bivalves *Arctica islandica* (Linné) and *Panopea* sp. In the collection of the Needse Berg, on the contrary, many gastropods occur *(Scaphella* sp., ? *Galeodea* sp.), as well as many specimens of the bivalve *Glossus* sp.

Because of the incompleteness of the Belgian sequence it will be very difficult to obtain an accurate correlation. For the present the most acceptable conclusion, not contradicted by the vertebrate fauna (see below), seems to be that the Delden Member must be correlated with deposits of a very young Miocene or early Pliocene age.

Deposits in north-western Germany and Denmark can only with great difficulty be compared since they have been developed in different facies. The mollusc fauna of the "Sylt Stufe", as represented in the Morsum Kliff of the island of Sylt, still has a Miocene character. Due to the difference in facies it is, however, quite possible that the "Sylt Stufe" and the Sands of Kattendijk differ only slightly in age, or even overlap each other. This is also indicated by the results of the study of the vertebrates (see below). A study of the otoliths of the Sylt Stufe may perhaps throw some new light on this matter. A paper on this subject is in preparation by P. A. M. Gaemers and W. Schwarzhans.

Vertebrata — Many vertebrate fossils are found in the Delden Member, mainly

teeth of Elasmobranchii but also skeleton parts of Teleostei and remains of marine mammals, which have, however, not yet been identified. These fossils show usually slight signs of transport, but as far as known they have not been reworked from older deposits. Transport, probably by wave action, has presumably taken place in a horizontal direction only.

Comparable material has been collected from the boring Twickel (28G.3-1), from exposures on the Twickelse Vaart, from the Twentekanaal near Delden, from the boring Gelselaars bridge (34B.3-1), from the boring Lievelde (41B.2-6), as well as from the outcrop in the wood "'t Klooster" at Aalten. Many teeth in the collection have phosphorite concretions or fragments of these on the roots. From the localities mentioned the most important species are listed below, some 2000 teeth are kept in the RGM collection.

Hexanchus primigenius (Agassiz, 1843)
Odontaspis aff. *acutissima* Agassiz, 1843
Odontaspis vorax le Hon, 1871
Lamna sp. van den Bosch, (1969a, p. 27, fig. a-d) (see pl. 23)
Isurus hastalis (Agassiz, 1843) — rather rare (see pl. 23)
Isurus escheri (Agassiz, 1844) — rare
Cetorhinus maximus (Gunnerus, 1765) — rather common
Scyliorhinus sp. div.
Carcharhinus sp.
Galeocerdo sp.
Galeorhinus cf. *galeus* (Linné, 1758)
Squalus sp. — common
Squatina sp. div.
Raja sp. div. — dominant
Dasyastis sp.
Rhinoptera sp.

Miothunnus deldenius van Deinse, 1953

The number of species seems to be somewhat larger than in the Zenderen Member, but more material has been collected. Notable differences have, however, been found in the quantitative composition of the fauna. The number of *Isurus hastalis* decreases strongly. *Isurus escheri* becomes a rare species and the number of *Lamna* sp., on the contrary, increases. An increase is also found in the number of specimens of *Cetorhinus,* of which in the Delden Member, besides gill-rakers (funiculi), many teeth have been found. Furthermore many species appear, as in the Zenderen Member, that can be regarded characteristic for a shallow sandy sea bottom, e.g. *Scyliorhinus, Galeorhinus, Squalus, Squatina, Raja* and *Rhinoptera.* These genera demonstrate clearly the regressive character of the Delden Member. The climate will not have been very different from that of the Zenderen Member. However, there seems to be an increase in the number of southern species.

An Elasmobranchii fauna collected from the Sylt Stufe of the Morsum Kliff at Sylt (north-western Germany) is kept in the RGM. This fauna agrees very well with the fauna of the Delden Member, especially by the large number of Rajidae. This material, too, shows signs of transport. The teeth have been collected in a sandy clay with thin glauconite streaks.

Another fauna (RGM collection) from the building pit for a tunnel under the first harbour dock near Kallo (Belgium) at the base of the Sands of Kattendijk (Janssen, 1974) is of interest. Among many reworked teeth an autochthonous fauna occurred in which *Lamna* sp. van den Bosch (1969a) is the most frequent species. A number of other species occurs in this fauna that matches the fauna of

the Delden Member very closely. The higher part of the Sands of Kattendijk in Belgium yields other species of which the tubercles of *Raja antiqua* Leriche, 1926, non Agassiz, 1844 attract attention. Also many remains of *Cetorhinus* are found there. Finally, in this part of the Sands of Kattendijk *Carcharodon carcharias* (Linné) occurs. This fauna has not been encountered in the Gelderse Achterhoek and Twente. So, with all these arguments in mind, it can be concluded that the Delden Member correlates more or less with the lower part of the Sands of Kattendijk near Antwerp in Belgium and with the "Sylt Stufe" in north-western Germany.

Correlations with areas outside the North Sea Basin have not been possible. At many places deposits from this period are missing because of geological events.

FAUNA OF THE LIEVELDE MEMBER

Not a single boring or exposure in the Lievelde Member has yielded the slightest indication of faunal elements. Nevertheless it can be supposed that the Lievelde Member belongs to the Pliocene because of its superposition on top of the Delden Member.

Stratigraphical correlations

General remarks — A tentative correlation of the Tertiary deposits of the Gelderse Achterhoek and Twente with deposits of other parts of the North Sea Basin is represented here in enclosure 2. Many of the correlations suggested in this table have already been discussed in the palaeontological parts of this paper.

The stratigraphical denominations used in this chapter have been adopted from Denizot (1957), Sorgenfrei (1957), and Hinsch (1958), or — in the case of units described after publication of those papers — from the original publication.

The correlations are based on our personal observations and on information taken from several issues of the Lexique Stratigraphique International (Denizot, 1957; Sorgenfrei, 1957; Hinsch, 1958). Finally, a large number of papers — not all of them mentioned here — has been used for further information. We have endeavoured to obtain the most probable chronological correlation in this table by a careful comparison of the lithological and palaeontological characteristics of the different deposits. In this way some subjectivity can hardly be avoided.

We did not aim at a correlation with a chronological subdivision that can be used all over western Europe. Much attention has already been paid to this subject in the literature. Recently, Hinsch & Ortlam (1974) published their opinion on this matter, to which paper the reader is referred.

At the left side of the table a rough chronological subdivision is given. With regard to the Pliocene and the Oligocene this subdivision agrees fairly well with the opinion of most recent authors. Berggren (1971, p. 732, table 52.20), however, indicates the whole Oligocene with the stage-name Rupelian. We expect, on the contrary, obvious advantages from the maintenance of a threefold subdivision in Lattorfian, Rupelian and Chattian.

A subdivision of the Miocene according to the German "Stufen" (in a chronological sense) or according to the Belgian classification is, in our opinion, not satisfying. Therefore, we re-introduce the classic subdivision in Early, Middle and Late Miocene, previously in general indicated as Lower, Middle and Upper Miocene.

Many boundaries will in reality cut the time-levels. Therefore this correlation can at the most represent an approximation of the real situation. Nevertheless, it seems useful to us as a base for discussion. Composing a correlation table like this one resembles a jigsaw puzzle, consisting of an unknown number of pieces that continuously change their shape, while moreover an unknown number of pieces is missing.

A special difficulty is that many stratigraphical units have been poorly defined. Only very rarely, especially in the somewhat older literature, has been indicated whether a unit is introduced in a lithological, biostratigraphical or chronological sense. Also it seems to be common usage that units emphatically introduced in e.g. a lithological sense are later interpreted by others or even by the same author in a biostratigraphical or chronological sense. Moreover many lithological denominations have been distinguished on the base of palaeontological characters. The recently designed rules of the International Subcommission on Stratigraphic Classification (1972) are of great importance in this respect. The need, however, of a code — comparable to the one of the International Commission of Zoological Nomenclature — containing further rules for subsequent treatment of stratigraphical names is urgently felt. We have tried to interprete the lithological units in their original sense as much as possible, but any consistency turned out to be impossible. Some examples of the existing disorder are given here.

The "Gram Formation" was introduced by Rasmussen (1956). The section of the clay-pit of the brick-works at Gram (Denmark) was designated as the stratotype, however without a description of the lower and upper boundaries and without a detailed lithological description. The same author used in 1966, the denomination "Gram Formation" in a much wider sense, because at that time also the sections of the clay-pits at Maade and other localities were correlated with the "Gram Formation". Hinsch (1972) subsequently correlated the "Gram Formation" with (parts of) the German "Sylter Stufe", "Gramer Stufe" and "Langenfelder Stufe", which in their turn have been insufficiently defined too.

The Belgian "*Nucula*-clay", occurring in Oligocene deposits of the Tongeren region, is indicated as "Argile sableuse à *Nucula comta*" by de Heinzelin & Glibert (in Denizot, 1957). These authors state that Bosquet (1851) (incorrect date, the real year of appearance is 1852) should be regarded as the author of this lithological denomination. Bosquet, however, gave only a short description of the sediments in which he found his *Nucula lyelliana*. Most certainly it has not been his purpose to introduce a lithological denomination, neither is the denomination "Argile sableuse à *Nucula comta*" used by him.

Hinsch (1955) divided the German "Hemmoor Stufe" into "Unteres Hemmoor" (Lower Hemmoor) and "Oberes Hemmoor" (Upper Hemmoor). Hinsch (1972) states that Dittmer (1959) denominates the same subdivision as "Behrendorf" and "Oxlund" respectively. However, the paper of Dittmer does not contain the slightest indication in this respect. De topographical names Behrendorf and Oxlund are only used to indicate boring localities. So, the denominations "Behrendorf" and "Oxlund" are in reality introduced by Hinsch and they are synonymous with his former names "Unteres Hemmoor" and "Oberes Hemmoor".

North-western Belgium (Antwerp area) — The "Sables de Merxem" and the "Horizon du Kruisschans" (together representing the Merxemian) have been regarded as Pliocene after van Voorthuysen, Toering & Zagwijn (1972).

The highly important exposures of mainly Miocene sediments, that could be studied recently during the construction of the E 3 highway around Antwerp, will be described in detail by de Meuter, Wouters & Ringelé (in prep.). Pending their paper we based our correlations mainly on the provisional subdivision of Janssen & van der Mark (1968).

It has already been observed by van den Bosch (1967) that in the Mio-Pliocene of the Antwerp region a more extensive number of hiatusses occurs than has been supposed by most authors. The "Laag 1 Borgerhout" (provisional denomination, van den Bosch, 1967) is in our table intercalated between the "Sables du Kattendijk" and the "Sables de Deurne". Each of these three deposits contains a basal gravel. The fauna of this "Laag 1 Borgerhout" contains so many faunal elements not known from the Miocene that we regard this deposit as Pliocene in age. The basal gravel of this deposit is the well-known "Horizon à Hétérocètes". In the descriptions of mollusc material this deposit was indicated as "Sables de Deurne", see also Janssen & van der Mark (1969).

The upper part of the "Sables noirs d'Anvers" agrees undoubtedly with the *Astarte radiata* Acme Zone of the Gelderse Achterhoek. Its lower part, as well as the "Sables de Houthalen" can be correlated with the *Hiatella arctica* Acme Zone by the occurrence of the gastropod *Haustator eryna*. So, equivalents of the two upper biozones of the Aalten Member seem to be absent in the Miocene deposits of Belgium. However, it is possible that the upper part of the "Sables noirs d'Anvers" is younger than the sediments of the *Astarte radiata* Acme Zone, because this faunal association seems to be connected to a shallow water environment that may have existed for a longer period in the Antwerp region.

The "Kiel Sands" have been provisionally introduced by Hooyberghs & de Meuter (1972). They will be described in extenso by de Meuter, Wouters & Ringelé (in prep.). We have been able to correlate this deposit because we know it from personal observations and because from a figure in Hooyberghs & de Meuter it can be estimated what deposit is meant exactly. From this deposit a small mollusc collection — preserved in concretions with a calcite matrix — is kept in the RGM. This fauna contains the gastropod *Haustator eryna* and is therefore correlated with the lower part of the Aalten Member.

The "Sables à *Panopea menardi* d'Edegem" have been transferred by Hooyberghs & de Meuter (1972) from the Miocene to the late Oligocene, on the basis of an absolute dating of glauconite and on the evidence of planctonic foraminifera. In our opinion the molluscs as well as the shark-teeth indicate an Early Miocene age for these sands.

The upper part of the "Argile de Boom" in its type area has been removed by erosion preceding the Miocene sedimentation. From this area only the *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone is known. More to the north (Antwerp area) also the *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone is present. As a result of later erosion the "Sables du Kattendijk" can locally occur directly on top of the "Argile de Boom". In the basal gravel of these sands, however, distinct Miocene elements are found (Janssen, 1974), indicating that Miocene sediments have at some time been present at these places.

The sands, provisionally indicated here as "Sands of Ruisbroek and St. Niklaas", have already been described by Vincent (1895), van Ertborn (1901) and

Boekschoten (1967). These sands are not yet known in sufficient detail. The denominations used in the literature are "Assise inférieure de l'Oligocène Rupelien" or "Sables à *Pycnodonte callifera*". At Ruisbroek, where these sands are exposed at this moment, a mollusc fauna is encountered that contains Lattorfian faunal elements, as well as species that are more or less typical for Rupelian faunas. For these reasons we have placed this deposit on the boundary Lattorf/Rupel. From data given by van den Bosch (1964) it can be concluded that the upper part of the "Sables d'Assche" can be correlated with the "Sables de Grimmertingen". The deposits of the "Sables d'Assche", however, yield few fossils, so a definite correlation can not be made. Because no hiatus is found between the sands of Ruisbroek and the 'Sables d'Assche" a Lattorfian age seems acceptable for the uppermost part of the "Sables d'Assche".

North-eastern Belgium (Tongeren - Houthalen area) — The "Zanden van Lichtaart" have been described by Geets (1963, p. 150). The correlation with the "Horizon du Kruisschans" has been made by the same author at the base of the mollusc fauna. Tavernier & de Heinzelin (1962, p. 20) have indicated this deposit as "Sables et grès ferrugineux de Poederlee".

We do not know the deposits mentioned by de Heinzelin (1956) as "Argile de la Campine" and "Sables de Mol", so we do not give an opinion about their age.

Because only a very small mollusc fauna is known from the "Sables de Diest" it has not been possible to obtain a reliable correlation. Therefore it might very well be that these sands represent a much shorter time interval within the Late Miocene than is indicated in our table. Extensive information about this deposit and its correlation with the "Sables de Deurne" can be found in Glibert & de Heinzelin (1955), Glibert (1957-1960, 1963), Tavernier & de Heinzelin (1962).

At the base of the "Sables de Diest" a reworked mollusc fauna is locally found, that has formerly been indicated as "Boldérien". Among this material distinct "Hemmoor" species are present (e.g. abundant *Oliva dufresnei* Basterot, 1825). This fauna can be compared more or less with the "Oxlund"-deposits in north-western Germany. The stratigraphical origin of this material is indicated in the table. This fauna contains also *Haustator eryna* (Glibert, 1952; de Heinzelin, 1956; Tavernier & de Heinzelin, 1962).

The "Sables de Voort" yield in their basal part still some typical Rupelian mollusc species (de Heinzelin & Glibert, in Denizot, 1957) Therefore we have correlated the basal part of this deposit with the upper part of the Rupelian.

We have not maintained the chronostratigraphical denomination Tongrian. On the one side we regard the deposits of the younger part of the Tongrian ("Assise supérieure", de Heinzelin & Glibert, in Denizot, 1957, p. 189) as lateral equivalents of the "Argile de Boom" (as follows from the table). The older part of the Tongrian, on the other side, can easily be indicated with the German denomination Lattorfian, at least those parts that contain a well preserved mollusc fauna ("Sables de Grimmertingen"). These "Sables de Grimmertingen" overlie discordantly Paleocene or Mesozoic deposits. This hiatus is in outline indicated in the table. Van den Bosch (1964) has studied and compared shark-teeth and ray faunas from these sands. The correlation of the "Sables de Neerrepen", that did yield no faunas, remains questionable.

Western Germany, Lower Rhine area — The deposits of Pliocene and younger

Miocene age of this region are insufficiently known. Marine deposits of Early Pliocene age near Nütterden have been mentioned in the literature. These can not yet be correlated with certainty.

The indication "Langenfeld-Stufe" has been used by Anderson (1958, p. 292) for Late Miocene deposits in this region. With "Clays of Bocholt" (provisional indication) the clays, exposed for example in the clay-pit B. Leub (Werk 3) on the road from Bocholt to Dingden, are meant. This clay is a clear lateral equivalent of the Eibergen Member.

The denomination of the deposits known from the classic locality Dingden (Königsmühle) has been changed in this paper. As the lithostratigraphical terminology has become very confused at Dingden we give here (Table 10) a synopsis of the different subdivisions. It may be clear from this diagram that for Dingden (and adjacent areas) the German classification can be used as well as the Dutch one.

The deposits in the Lower Rhine area — described by Anderson (1958, p. 290) — from which a "Hemmoor" fauna has been collected (e.g. Hoerstgen) have not yet received a local lithological denomination. We have indicated these deposits provisionally as "Hemmoor of Hoerstgen etc.".

The "Lintforter Schichten" have been correlated with the Winterswijk Member on the basis of lithological characters mainly. From this deposit the bivalve *Nuculana deshayesiana* is also known (see Wölk, 1941).

As only very little is known about the fauna of the "Ratinger Ton", we can not decide whether this clay contains equivalents of the two assemblage zones that are present in the Brinkheurne Member. The bivalve *Nuculana deshayesiana* is known from this deposit (Hinsch, 1958, p. 48).

In the "Walsumer Meeressand" locally a distinct transgressive gravel occurs near the top of the deposit (see also Wölk, 1941). This gravel might indicate the rapid extension of the transgressive Rupelian sea.

The barren "Hamborner Schichten", locally found underlying the "Walsumer Meeressand", have been correlated with the Lattorfian after Anderson (1962).

North-western Germany, Schleswig-Holstein and Niedersachsen — Hinsch (1958, p. 40) has placed the "Morsumer Stufe" into the Pliocene, more precisely in the "Piacentin/Asti". Hinsch & Ortlam (1974, p. 14), however, correlate the "Morsumer Stufe" with the Tabianiano. In our opinion the fauna of this deposit can not easily be correlated with Pliocene faunas within the North Sea Basin. Also, this fauna should necessarily be restudied.

In Germany the "Sylter Stufe" is usually regarded to represent the youngest Miocene deposit. There appears to be, however, a distinct resemblance with the fauna of the Delden Member in the Netherlands and with the lower part of the "Sables du Kattendijk" in Belgium. For this reason we will not exclude the possibility that the "Sylter Stufe" is partly of Pliocene age.

The stratigraphy of the other Miocene deposits in this area has mainly been adopted from Hinsch & Ortlam (1974). As stated before the "Hemmoor Stufe" and the "Reinbek Stufe" of north-western Germany can be correlated with the Aalten Member in the Gelderse Achterhoek. In Germany, however, the "Hemmoor Stufe" shows a regressive character. Nowadays, the "Hemmoor Stufe" is usually subdivided in the "Behrendorf" and "Oxlund" ("Unterstufen"), see Hinsch (1969). The fauna of the "Behrendorf" has much in common with the *Hiatella arctica* Acme Zone. The shallower facies of the "Oxlund" are not known from the Gelderse Achterhoek or Twente. The reworked fauna of the "Boldérien" in Belgium

resembles the "Oxlund"-fauna very closely. In Germany the deposits of the "Reinbek Stufe" are of a transgressive character. The fauna has a fair agreement to that of the *Astarte radiata* Acme Zone. In north-western Germany faunas resembling those of the two upper biozones of the Aalten Member are only found in the "Twistringer Schichten". The lower part of these deposits contains a fauna in which "Hemmoor" influences can distinctly be observed. The higher part yields

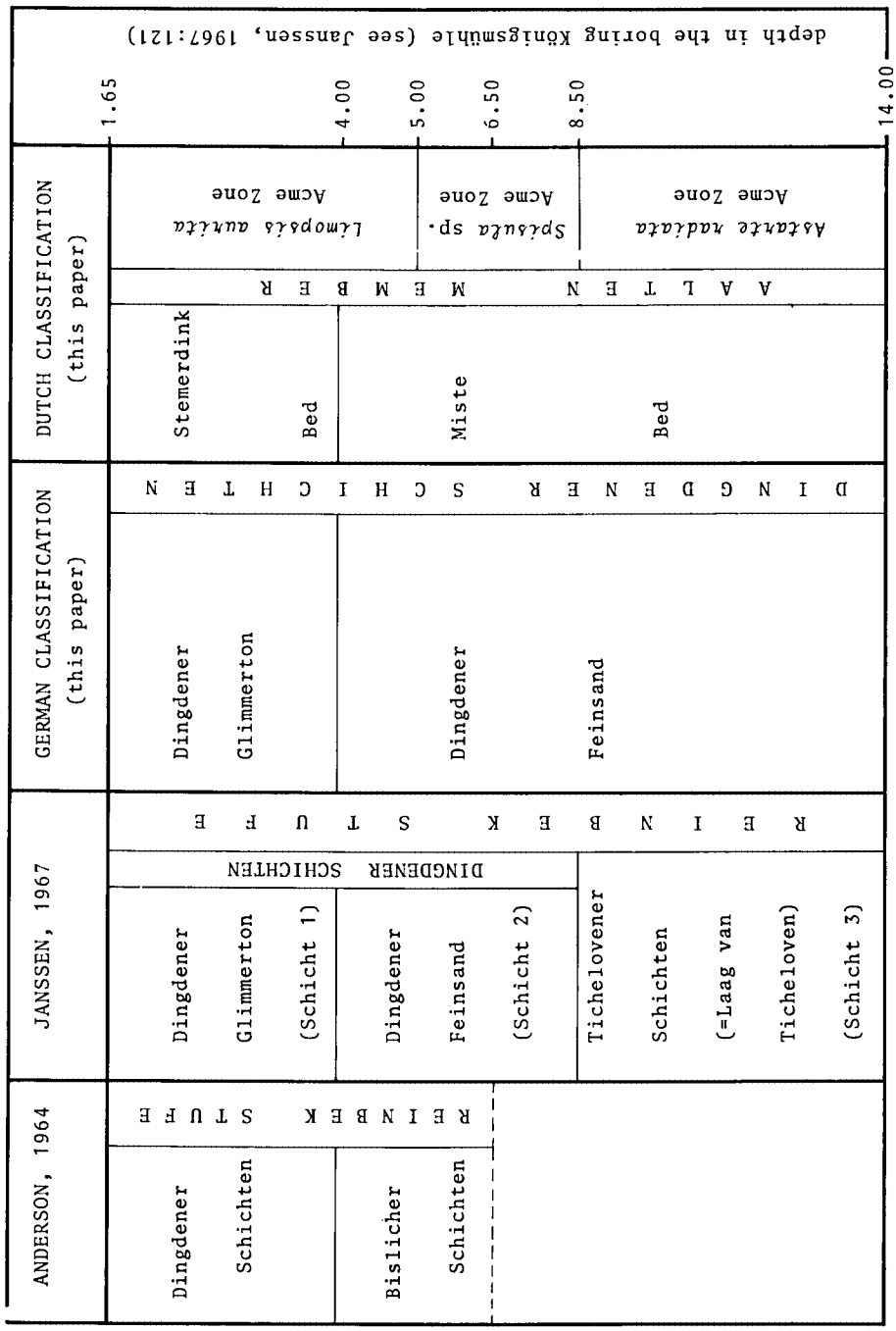

Table 10. A tabular review of the stratigraphical units for the Miocene deposits near the Königsmühle at Dingden, western Germany, according to different authors.

a fauna strongly resembling that of the *Limopsis aurita* Acme Zone in the Gelderse Achterhoek. The opinions mentioned here have been discussed in more detail in the palaeontological chapter.

The classification of the Oligocene has mainly been adopted from Hinsch & Ortlam (1974).

Denmark — The "Pliocene Clay Ironstone" is correlated here, in accordance with Rasmussen (1966, p. 321), with the "Morsumer Stufe" ("Limonitsandstein" of Sylt). Details about the classification of the Danish Late Miocene have been mentioned in the general remarks of this chapter.

The "Hodde Formation" and the „Arnum Formation" can in general be compared with the "Reinbek Stufe" and the 'Hemmoor Stufe" of north-western Germany. The gastropod *Streptochetus abruptus* (Beyrich, 1856), known from the "Twistringer Schichten", the "Reinbeker Schichten", and also found in the "Hodde Formation" (Rasmussen, 1968), seems to have had a limited horizontal distribution rather than a restricted vertical range. The mollusc fauna of the "Arnum Formation" is extensively described by Sorgenfrei (1958).

The correlation of the "Klintinghoved Mica Clay" with the "Vierland Stufe" is based on papers by Sorgenfrei (1940, 1957). For the Danish Oligocene we use the classical subdivision in "Branden Clay" and "Cilleborg Clay". The recently introduced subdivision of Christensen & Ulleberg (1973) has also been incorporated.

Samenvatting

Aan de hand van een grote hoeveelheid gegevens die door boringen en ander veldwerk gedurende de laatste 15 jaar in de streek rond Winterswijk en in Twente zijn verkregen, wordt een nieuwe stratigrafische indeling van tertiaire afzettingen (Oligoceen tot en met Plioceen) van de betreffende streek geïntroduceerd.

Nieuw ingevoerde lithologische eenheden zijn de Afzetting van Ratum, de Afzetting van Brinkheurne, de Afzetting van Winterswijk, de Afzetting van Aalten, de Afzetting van Eibergen, de Afzetting van Zenderen en de Afzetting van Lievelde. In de Afzetting van Aalten wordt een lithologische onderverdeling ingevoerd in Laag van Miste en Laag van Stemerdink. De Afzetting van Delden, die voorkomt tussen de Afzettingen van Zenderen en van Lievelde werd al eerder beschreven. Deze afzetting wordt hier nieuw gedefinieerd.

Voor elke lithostratigrafische eenheid wordt een stratotype aangewezen, alsmede enkele parastratotypen. De stratotypen zijn meestal in boringen gekozen, bij de parastratotypen bevinden zich ook natuurlijke ontsluitingen of groeven. Door middel van kaarten is steeds de locatie van de type-secties aangegeven, terwijl in een aantal gevallen het verband met de plaatselijke stratigrafie door middel van dwarsprofielen wordt aangegeven. Lithologische en granulometrische overzichten van de stratotypen zijn in beeld gebracht op bijlage 1. Zoveel mogelijk is ook de globale dagzoom van een afzetting vermeld. Bij de beschrijvingen van de lithologische eenheden wordt een correlatie met de aangrenzende gebieden besproken.

In het tweede gedeelte van deze publicatie wordt ingegaan op de paleontologie van de besproken afzettingen. Eerst wordt een overzicht gegeven van alle fos-

sielgroepen, die uit het onderzoekgebied bekend zijn (Tabel 1). Tevens worden nog niet gepubliceerde gegevens vermeld betreffende een collectie ostracoden uit de Afzetting van Aalten (Tabel 2 t/m 5).

Doordat de mollusken en de Elasmobranchii veruit het best bekend zijn worden deze diergroepen per lithostratigrafische eenheid uitgebreider behandeld. Bovendien wordt voor de Afzetting van Eibergen een lijst gegeven van de daaruit bekende walvisachtigen en andere mariene zoogdieren.

In de Afzettingen van Brinkheurne en van Aalten zijn de geconstateerde verschillen in de mollusken-associaties aanleiding tot het invoeren van een biostratigrafische onderverdeling van deze afzettingen.

In de Afzetting van Brinkheurne worden twee biozones onderscheiden, n.l. de *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone in het onderste deel van de afzetting, en de *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone in het bovenste deel. Tussen beide zones ligt een steriel gedeelte van de Afzetting van Brinkheurne.

In de Afzetting van Aalten worden met behulp van kwantitatief onderzoek van de molluskenfauna een viertal biozones onderscheiden, n.l. van onder naar boven de *Hiatella arctica* Acme Zone, de *Astarte radiata* Acme Zone, de *Spisula* sp. Acme Zone en de *Limopsis aurita* Acme Zone. Deze biozones worden steeds gedefinieerd met behulp van de beschikbare paleontologische gegevens. Tevens wordt steeds een typische referentie sectie vastgelegd. Een interessant feit is, dat de biozones van de Afzetting van Aalten niet parallel verlopen aan de lithologisch indeling. De grenzen tussen de biozones blijken een hoek te maken met de lithologische grenzen.

De biozones worden zo veel mogelijk gecorreleerd met andere fauna's van het Noordzee Bekken. Ook wordt ingegaan op de meest waarschijnlijke chronologische correlatie.

Speciale aandacht wordt nog besteed aan enkele omgewerkte fauna's welke aan de basis van de Afzetting van Winterswijk en de Afzetting van Aalten worden aangetroffen. Uit laatstgenoemde fauna blijkt, dat afzettingen met een jong-oligocene of oud-miocene ouderdom aanwezig geweest moeten zijn.

Aan de hand van de lithologische en paleontologische gegevens wordt tenslotte een overzicht gegeven van de mogelijke correlaties binnen het Noordzee Bekken. De afzettingen van het Nederlandse Peelgebied zijn hierbij met opzet buiten beschouwing gelaten, omdat te weinig hierover bekend is. Bij deze correlaties, die samengevat zijn in bijlage 2, werden grote moeilijkheden ondervonden door de gewoonlijk zeer onvolledige beschrijvingen van de stratigrafische eenheden in de literatuur en van een slordig gebruik van de namen door latere auteurs.

Zusammenfassung

In den letzten 15 Jahren sind viele Bohrungen in der Gegend von Winterswijk und in Twente (Niederlande, Provinzen Gelderland und Overijssel) niedergebracht worden. Zusammen mit in Ziegeleigruben und natürlichen Aufschlüssen gesammelten Daten liegen sie eine neue stratigraphische Unterteilung der Tertiärablagerungen (Oligocän bis Pliocän) in diesem Gebiet zugrunde.

Folgende lithologischen Bezeichnungen werden hier neu aufgestellt: Afzet-

ting van Ratum, Afzetting van Brinkheurne, Afzetting van Winterswijk, Afzetting van Aalten, Afzetting van Eibergen, Afzetting van Zenderen, Afzetting van Lievelde. Die Afzetting van Aalten ist noch aufgegliedert worden in Laag van Miste und Laag van Stemerdink. Die Afzetting van Delden (mit der Afzetting van Zenderen im Liegenden und der Afzetting van Lievelde im Hangenden) ist schon früher beschrieben worden. Diese Ablagerung ist hier neu gefasst worden.

Für jede lithostratigraphische Einheit ist ein Lithostratotypus festgelegt worden, wie auch einige Parastratotypen. Die Stratotypen sind meistens Bohrungen, die Parastratotypen sind vielfach auch natürliche Aufschlüsse oder Ziegeleigruben. Die genaue Lage der Typusprofile ist mittels Karten im Text festgelegt worden. Lithologische und granulometrische Einzelheiten sind dargestellt in der Beilage 1. Regionale Querprofile erläutern öfters die Lokalstratigraphie. Auch der ungefähre Ausstrich ist so viel wie möglich erwähnt. Eine Korrelation mit Ablagerungen der benachbarten Gebieten ist der lithologischen Beschreibung beigegeben.

Der paläontologische Charakter der Ablagerungen wird im zweiten Teile dieser Arbeit behandelt. Zuerst ist eine Übersicht gegeben aller Tiergruppen die in den untersuchten Ablagerungen festgestellt werden konnten (Tabelle 1). Noch unveröffentliche Daten einer Sammlung Ostracoden aus der Afzetting van Aalten sind in den Tabellen 2 bis 5 beigelegt.

Weil die Mollusken und Selachier am besten bekannt sind, wird für diese Tiergruppen pro lithostratigraphische Einheit eine etwas ausführlichere Erörterung gegeben. Weiterhin wird für die Afzetting van Eibergen eine Liste beigelegt der bekannten Walreste und anderen marinen Säugetiere.

Die beobachteten Unterschiede in den Molluskenvergesellschaftungen gestatten eine biostratigraphische Gliederung der Afzetting van Brinkheurne und der Afzetting van Aalten.

In der Afzetting van Brinkheurne sind zwei Biozonen unterschieden worden, nämlich die *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone und der *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone. Zwischen beiden Zonen liegt ein fossilleerer Teil der Afzetting van Brinkheurne.

Mittels quantitativer Untersuchung der Molluskenfauna ist die Afzetting van Aalten in vier Biozonen untergliedert worden. Von unten nach oben: *Hiatella arctica* Acme Zone, *Astarte radiata* Acme Zone, *Spisula* sp. Acme Zone und *Limopsis aurita* Acme Zone. Diese Zonen sind mittels der paläontologischen Daten festgelegt worden. Stets wird ein typischer Referenzprofil festgelegt. Eine interessante Tatsache ist, dass die Biozonierung der Afzetting van Aalten der lithologischen Unterteilung nicht parallel ist. Die biostratigraphischen Grenzen schneiden die lithologischen.

Die Biozonen sind so viel möglich mit anderen Faunen des Nordseebeckens verglichen worden. Die meist wahrscheinliche chronologische Einstufung wird diskutiert.

Einiger umgelagerten Faunen die an der Basis der Afzetting van Winterswijk und der Afzetting van Aalten gefunden sind, wird spezielle Andacht gewidmet. Aus den letztgenannten Faunen ergibt sich, dass Ablagerungen von spät-oligocänem oder früh-miocänem Alter durch Erosion völlig abgetragen worden sind.

Mittels lithologischer und biostratigraphischer Daten wird schliesslich noch eine Übersicht gegeben (Beilage 2) der möglichen Korrelationen innerhalb des Nordseebeckens. Ablagerungen des niederländischen Peelgebietes sind dabei absichtlich ausser Betracht gelassen, weil zu wenig Einzelheiten dieser Ablagerungen vorliegen. Bei diesem Korrelationsversuch wurden grosse Schwierigkeiten erlebt

wegen der gewöhnlicherweise sehr unvollständigen Beschreibungen der stratigraphischen Einheiten in der Literatur und wegen nachlässiger Interpretation der Namen von späteren Autoren.

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Review of boring sections used in this paper

The comprehensive descriptions of the boring sections are scattered throughout the text. To enable a quick location of any desired description a summary of the boring sections — arranged in numerical order — is given here. Stratotypes and reference sections are indicated. Outcrops and other exposures are not mentioned here, unless a detailed lithological description has been given in the text.

Boring 28G.3-1 at the Twickel estate, on the Twickelse Vaart, municipality of Delden. General information see p. 45.

0.00 - 1.40 m Quaternary.
1.40 - 7.50 m Delden Member, stratotype section, see p. 45.
7.50 - 13.00 m Zenderen Member, reference section, see p. 41.
13.00 - 16.00 m Eibergen Member, see p. 43.
16.00 - 21.65 m Aalten Member, reference section, see p. 30.
16.00 - 21.00 m Stemerdink Bed, reference section, see p. 30.
21.00 - 21.65 m Miste Bed, reference section, see p. 30.
21.65 - 35.00 m Brinkheurne Member, reference section, see p. 13.

Boring 28G.158 near Tusveld, municipality of Zenderen. General information see p. 41.

0.00 - 3.10 m Quaternary.
3.10 - 15.95 m Delden Member, reference section, see p. 47.
15.95 - 23.90 m Zenderen Member, reference section, see p. 41.
23.90 - 24.05 m Eibergen Member, see p. 41.

Boring 28G.172 near the "Retraitehuis', municipality of Zenderen. General information see p. 39.

0.00 - 6.00 m Quaternary.
6.00 - 16.50 m Delden Member, reference section, see p. 46.
16.50 - 23.46 m Zenderen Member, stratotype section, see p. 39.
23.46 - 23.71 m Eibergen Member, see p. 39.

Boring 34B.3-1 near the Gelselaars bridge, municipality of Neede. General information see p. 43.

0.00 - 27.50 m Quaternary.
27.50 - 32.50 m ? Lievelde Member, see p. 56.
32.50 - 49.50 m Delden Member, reference section, see p. 47.
49.50 - 68.50 m Zenderen Member, reference section, see p. 43.
68.50 - 72.50 m Eibergen Member, see p. 43.

Boring 34D.4-4 west of Groenlo, municipality of Groenlo. General information see p. 48.

0.00 - 3.40 m Quaternary.
3.40 - 10.90 m Lievelde Member, reference section, see p. 53.
10.90 - 15.30 m Delden Member, reference section, see p. 48.
15.30 - 17.00 m Zenderen Member, see p. 49.
17.00 - 17.20 m Eibergen Member, see p. 49.

Boring 34G.1-24 at "Ticheloven", municipality of Eibergen. General information see p. 28.

0.00 - 0.80 m Quaternary.
0.80 - 4.15 m Aalten Member, reference section, see p. 29.
0.80 - 3.50 m Stemerdink Bed, reference section, see p. 29.
3.50 - 4.15 m Miste Bed, reference section, see p. 29.
4.15 - 4.35 m Brinkheurne Member.
The part from 3.50 - 4.15 m of this section is also the typical reference section of the *Astarte radiata* Acme Zone, see p. 85.

Boring 34G.3-1 at the F.O.W. clay-pit, municipality of Eibergen. General information see p. 27.

0.30 - 4.80 m Eibergen Member, reference section, see p. 27.
4.80 - 15.55 m Aalten Member, reference section, see p. 27.
4.80 - 12.25 m Stemerdink Bed, reference section, see p. 27.
12.25 - 15.55 m Miste Bed, reference section, see p. 27.
15.55 - 15.60 m Winterswijk Member.

Boring 34G.3-13 at the F.O.W. clay-pit, municipality of Eibergen. General information see p. 33.

0.00 - 8.50 m Eibergen Member, stratotype section, see p. 33.
8.50 - 9.50 m Aalten Member, Stemerdink Bed, see p. 34.

Boring 41B.2-6 at Lievelde, municipality of Lichtenvoorde. General information see p. 52.

0.00 - 0.15 m Quaternary.
0.15 - 9.00 m Lievelde Member, stratotype section, see p. 52.
9.00 - 15.70 m Delden Member, reference section, see p. 49.
15.70 - 40.00 m Eibergen Member, reference section, see p. 37.

Boring 41D.2-7 south-east of Aalten, municipality of Aalten. General information see p. 26.

0.00 - 7.35 m Quaternary.
7.35 - 34.50 m Eibergen Member, reference section, see p. 35.
34.50 - 53.00 m Aalten Member, reference section, see p. 26.
34.50 - 45.00 m Stemerdink Bed, reference section, see p. 26.
45.00 - 53.00 m Miste Bed, reference section, see p. 26.
53.00 - 58.50 m ? Late Oligocene sediments, see p. 27.
58.50 - 60.00 m Winterswijk Member, see p. 27.

Boring 41E.3-39 at "'t Klooster", municipality of Aalten. General information see p. 36.

0.00 - 3.35 m Quaternary.
3.35 - 5.35 m Delden Member, reference section, see p. 49.
5.35 - 15.00 m Eibergen Member, reference section, see p. 36.

Boring 41E.3-67 at "Borninkhof", Haart, municipality of Aalten. General information see p. 19.

0.00 - 1.70 m Quaternary.
1.70 - 8.00 m Eibergen Member, reference section, see p. 20.
8.00 - 20.80 m Aalten Member, stratotype section, see p. 20.
8.00 - 16.00 m Stemerdink Bed, reference section, see p. 20.
16.00 - 20.80 m Miste Bed, reference section, see p. 21.
20.80 - 22.00 m Winterswijk Member, see p. 21.
The part from 16.00 - 18.00 m of this boring is also the typical reference section of the *Spisula* sp. Acme Zone, see p. 90.

Boring 41E.3-75 at Miste, municipality of Winterswijk. General information see p. 22.

0.00 - 1.25 m Quaternary.
1.25 - 4.10 m Aalten Member, reference section, Miste Bed, stratotype section, see p. 22.
4.10 - 4.30 m Winterswijk Member.
The part from 3.25 to 4.10 m of this boring is also the typical reference section of the *Hiatella arctica* Acme Zone, see p. 83.

Boring 41E.3-143 at "De Vlijt", municipality of Winterswijk. General information see p. 15.

0.00 - 0.25 m Quaternary.
0.25 - 2.55 m Winterswijk Member, stratotype section, see p. 15.
2.55 - 7.55 m Brinkheurne Member, reference section, see p. 15.

Boring 41E.4-177 at "Stemerdink", Brinkheurne, municipality of Winterswijk. General information see p. 16-17.

0.00 - 1.50 m Quaternary.
1.50 - 16.30 m Aalten Member.
16.30 - c. 40.00 m Winterswijk Member, reference section.
c. 40.00 - 48.42 m Brinkheurne Member.
For a description in detail of this boring see van den Bosch (1969, p. 35-38).

Boring 41E.4-387 at "Stemerdink", Brinkheurne, municipality of Winterswijk. General information see p. 25.

0.00 - 1.50 m Quaternary.
1.50 - 18.90 m Aalten Member, reference section, see p. 25.
1.50 - 12.00 m Stemerdink Bed, reference section, see p. 25.
12.00 - 18.90 m Miste Bed, reference section, see p. 25.
18.90 - 19.00 m Winterswijk Member, see p. 25.
The part from 6.00 to 11.00 m of this boring is also the typical reference section of the *Limopsis aurita* Acme Zone, see p. 93.

Boring 41E.4-446 at "Wassink", Brinkheurne, municipality of Winterswijk. General information see p. 10.

0.00 - 1.00 m Quaternary.
1.00 - 26.50 m Brinkheurne Member, stratotype section, see p. 11.
26.50 - 34.90 m Ratum Member, reference section, see p. 8.
34.90 - 37.35 m Liassic sediments.

Boring 41E.4-517 at "Stemerdink", Brinkheurne, municipality of Winterswijk. General information see p. 17.

0.00 - 3.50 m Quaternary.
3.50 - 19.50 m Aalten Member.
19.50 - 42.42 m Winterswijk Member, reference section, see p. 17.
42.42 - 54.72 m Brinkheurne Member, see p. 18.
54.72 - 55.30 m Ratum Member, see p. 18.
55.30 - 77.10 m Pre-Tertiary rocks.

Boring 41E.4-566 at "Stemerdink", Brinkheurne, municipality of Winterswijk. General information see p. 23.

0.00 - 2.30 m Quaternary.
2.30 - 17.25 m Aalten Member, reference section, see p. 23.
2.30 - 8.50 m Stemerdink Bed, stratotype section, see p. 23.
8.50 - 17.25 m Miste Bed, reference section, see p. 24.
17.25 - 17.50 m Winterswijk Member.

Boring 41F.3-65 at Ratum, municipality of Winterswijk. General information see p. 7.

0.00 - 1.00 m Quaternary.
1.00 - 1.50 m Brinkheurne Member, see p. 7.
1.50 - 19.00 m Ratum Member, stratotype section, see p. 7.
19.00 - 19.20 m Liassic clay

Manuscript received 15 December 1974.

Plate 1

COMMON MOLLUSCAN SPECIES FROM THE *Serpula septaria* - *Ancistrosyrinx volgeri* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

All specimens from the clay-pit complex of the brick-works "de Vlijt" and "te Siepe", Winterswijk.

Fig. 1. *Nuculana* (s. lat.) *deshayesiana* (Nyst, 1835). RGM 184 677. Height 16.0 mm.

Fig. 2. *Nuculana* (s. lat.) *deshayesiana* (Nyst, 1835). RGM 184 678. Height 17.7 mm.

Fig. 3. ? *Portlandia* (s. lat.) *sphaerica* (von Koenen, 1868). Collection M. C. Cadée. Height 3.2 mm.

Fig. 4. ? *Portlandia* (s. lat.) *sphaerica* (von Koenen, 1868). Collection M. C. Cadée. Height 3.5 mm.

Fig. 5. *Bathyarca saxonica* (von Koenen, 1893). Collection M. C. Cadée. Height 2.5 mm.

Fig. 6. *Thyasira nysti* (Philippi, 1846). RGM 184 679. Height 10.6 mm.

Fig. 7. *Thyasira nysti* (Philippi, 1846). Collection M. C. Cadée. Height 10.9 mm.

Plate 1

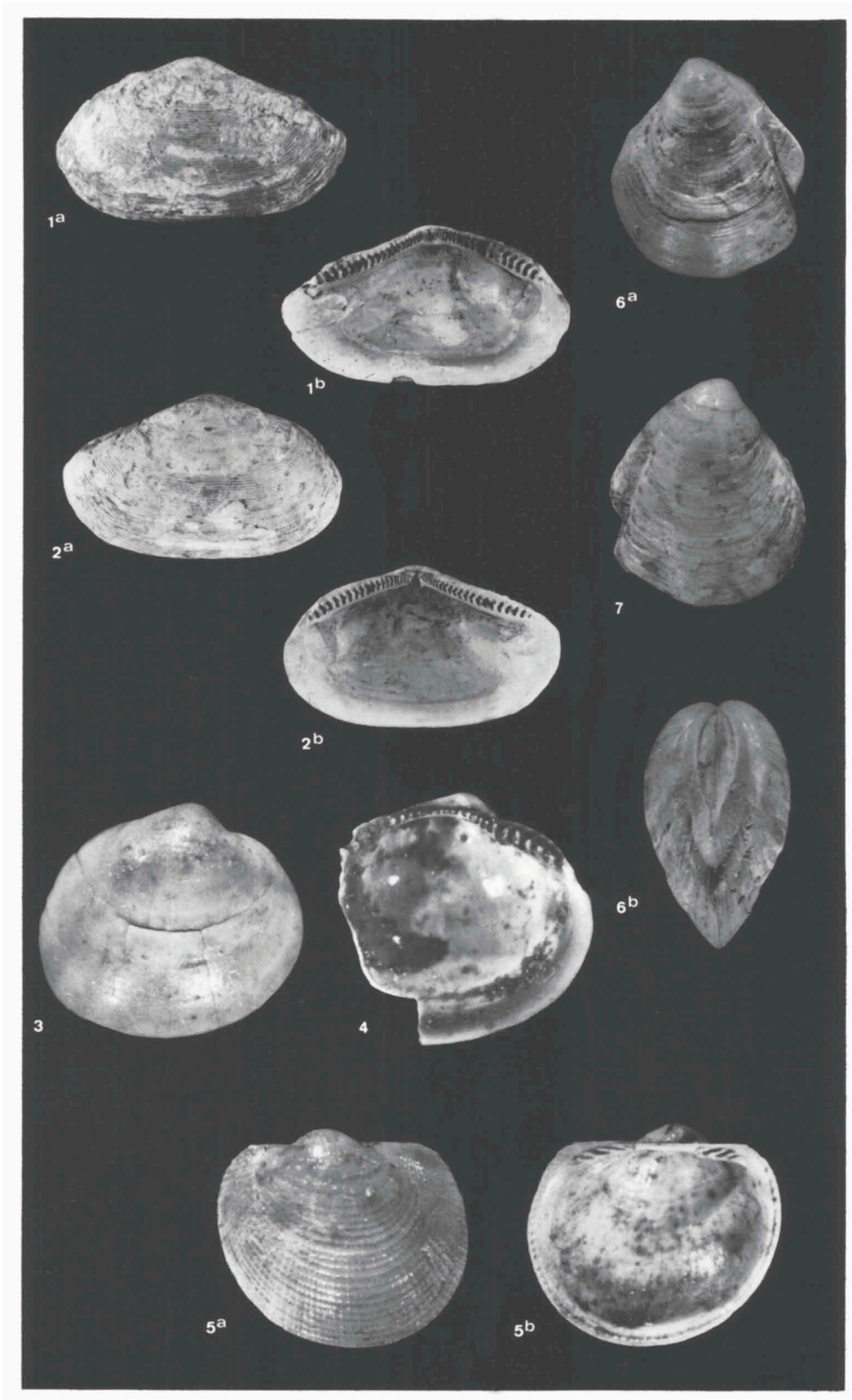


Plate 2

COMMON MOLLUSCAN SPECIES FROM THE *Cyclocardia kickxi - Astarte kickxi* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

All specimens from clay-pits at Niel, Belgium (Rupel area).

Fig. 1. *Nucula (Lamellinucula) duchasteli* Nyst, 1835. RGM 184 680. Height 13.8 mm.

Figs. 2-4. *Corbula (Varicorbula) gibba gibba* (Olivi, 1792). RGM 184 683-184 685. Height resp. 3.3 mm, 3.4 mm and 3.6 mm.

Fig. 5. *Aporrhais speciosa* (Schlotheim, 1820). Collection M. C. Cadée. Height 41.9 mm.

Fig. 6. *Dentalium* (s.s.) *kickxi* Nyst, 1845. Collection M. C. Cadée. Height 31.5 mm.

Fig. 7. *Charonia (Sassia) flandrica* (de Koninck, 1838). RGM 184 681. Height 38.0 mm.

Fig. 8. *Euspira helicina* (Brocchi, 1814). RGM 184 682. Height 20.7 mm.

Plate 2

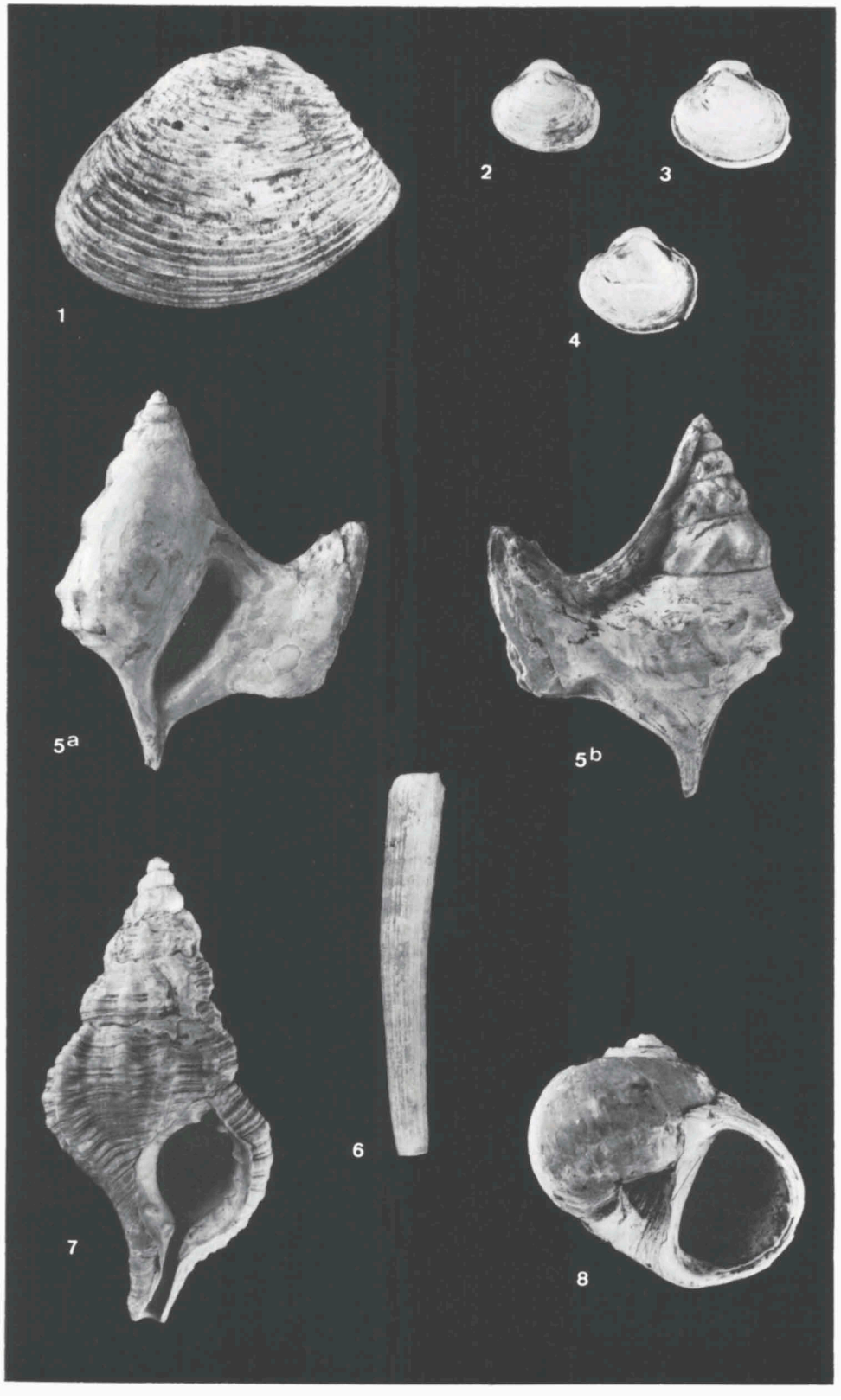


Plate 3

COMMON MOLLUSCAN SPECIES FROM THE *Serpula septaria* - *Ancistrosyrinx volgeri* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

All specimens from the clay-pit complex of the brick-works "de Vlijt" and "te Siepe", Winterswijk.

Fig. 1. *Solariella speyeri* (von Koenen, 1867). Collection M. C. Cadée. Height 2.0 mm.

Fig. 2. *Phalium (Semicassis) rondeleti* (Basterot, 1853). RGM 184 686. Height 30.7 mm.

Fig. 3. *Euspira* sp. Collection M. C. Cadée. Height 8.4 mm.

Fig. 4. *Hexaplex (Paziella) pauwelsi* (de Koninck, 1837). Collection M. C. Cadée. Height 13.5 mm.

Fig. 5. *Mathilda crispula* (Sandberger, 1863). Collection M. C. Cadée. Height 6.8 mm.

Fig. 6. *Aquilofusus waeli* (Nyst, 1852). Collection M. C. Cadée. Height 21.7 mm.

Fig. 7. *Aquilofusus waeli* (Nyst, 1852). RGM 127 045. Height 22.5 mm.

Fig. 8. *Typhis (Lyrotyphis) fistulosus schlotheimi* (Beyrich, 1854). Collection M. C. Cadée. Height 9.4 mm.

Fig. 9. *Typhis (Lyrotyphis) fistulosus schlotheimi* (Beyrich, 1854). Collection M. C. Cadée. Height 6.7 mm.

Fig. 10. *Aquilofusus multisulcatus* (Nyst, 1845). Collection M. C. Cadée. Height 26.0 mm.

Fig. 11. *Aquilofusus rotatus* (Beyrich, 1856). Collection M. C. Cadée, Height 15.9 mm.

Fig. 12. *Aquilofusus rotatus* (Beyrich, 1856). RGM 85 488. Height 18.0 mm.

Plate 3

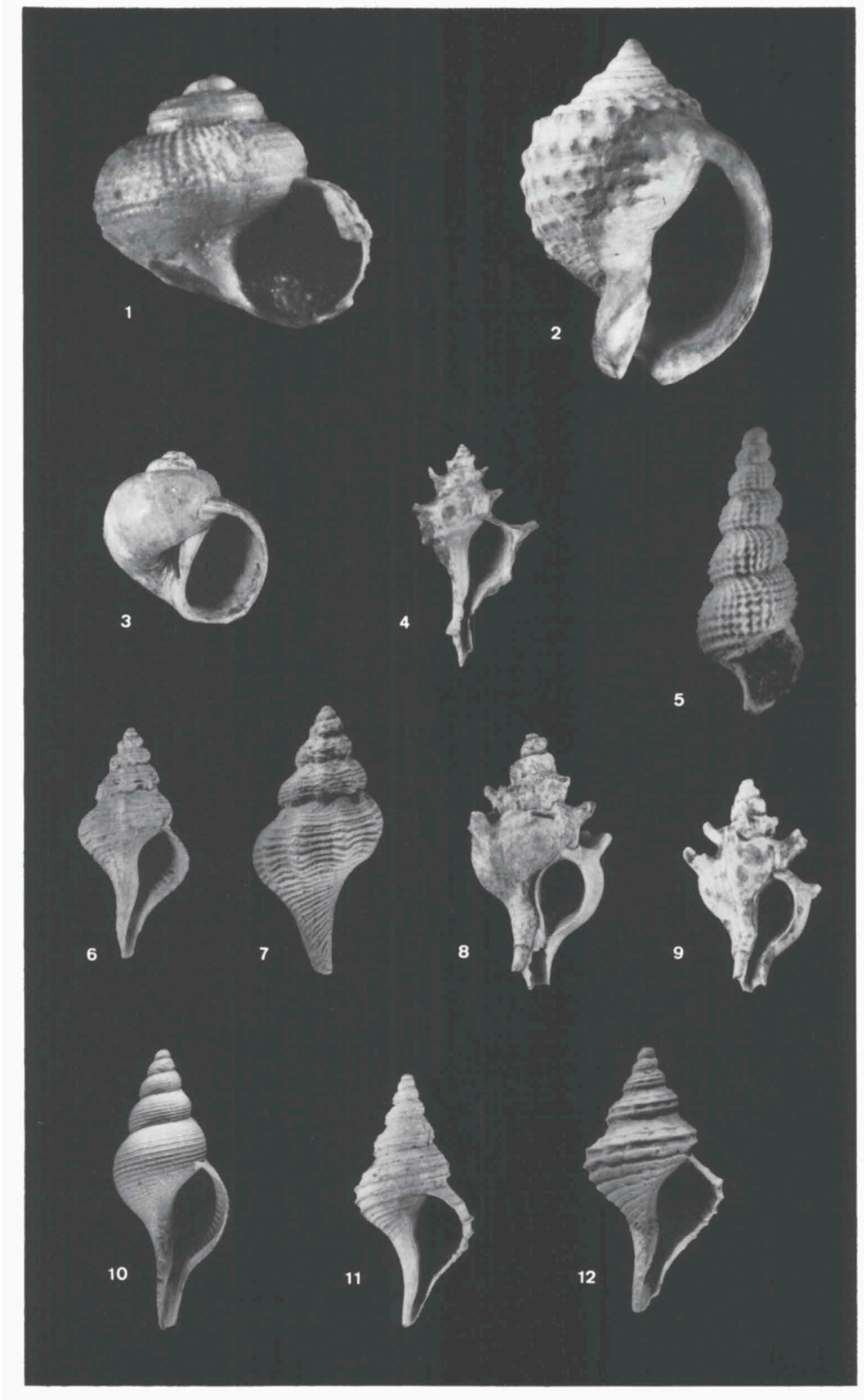


Plate 4

COMMON MOLLUSCAN SPECIES FROM THE *Serpula septaria - Ancistrosyrinx volgeri* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

All specimens from the clay-pit complex of the brick-works "de Vlijt" and "te Siepe", Winterswijk.

Fig. 1. *Streptochetus (Streptodyction) cheruscus elongatus* (Nyst, 1845). RGM 127 048. Height 12.6 mm.

Fig. 2. *Fusinus elatior* (Beyrich, 1856). RGM 127 040. Height 15.4 mm.

Fig. 3. *Fusinus elatior* (Beyrich, 1856). Collection M. C. Cadée. Height 13.8 mm.

Fig. 4. *Epalxis (Bathytoma) crenata* (Nyst, 1845). Collection M. C. Cadée. Height 23.0 mm.

Fig. 5. *Epalxis (Bathytoma) crenata* (Nyst, 1845). Collection M. C. Cadée. Height 25.0 mm.

Fig. 6. *Turricula (Surcula) regularis* (de Koninck, 1838). Collection M. C. Cadée. Height 50.5 mm.

Fig. 7. *Brachytoma behmi* (von Koenen, 1867). Collection M. C. Cadée. Height 7.2 mm.

Fig. 8. *Brachytoma behmi* (von Koenen, 1867). Collection M. C. Cadée. Height 5.9 mm.

Fig. 9. *Turris (Fusiturris) duchasteli* (Nyst, 1838) s.s. Collection M. C. Cadée. Height 11.7 mm.

Fig. 10. *Spiratella umbilicata* (Bornemann, 1855). RGM 184 687. Height 1.8 mm.

Plate 4

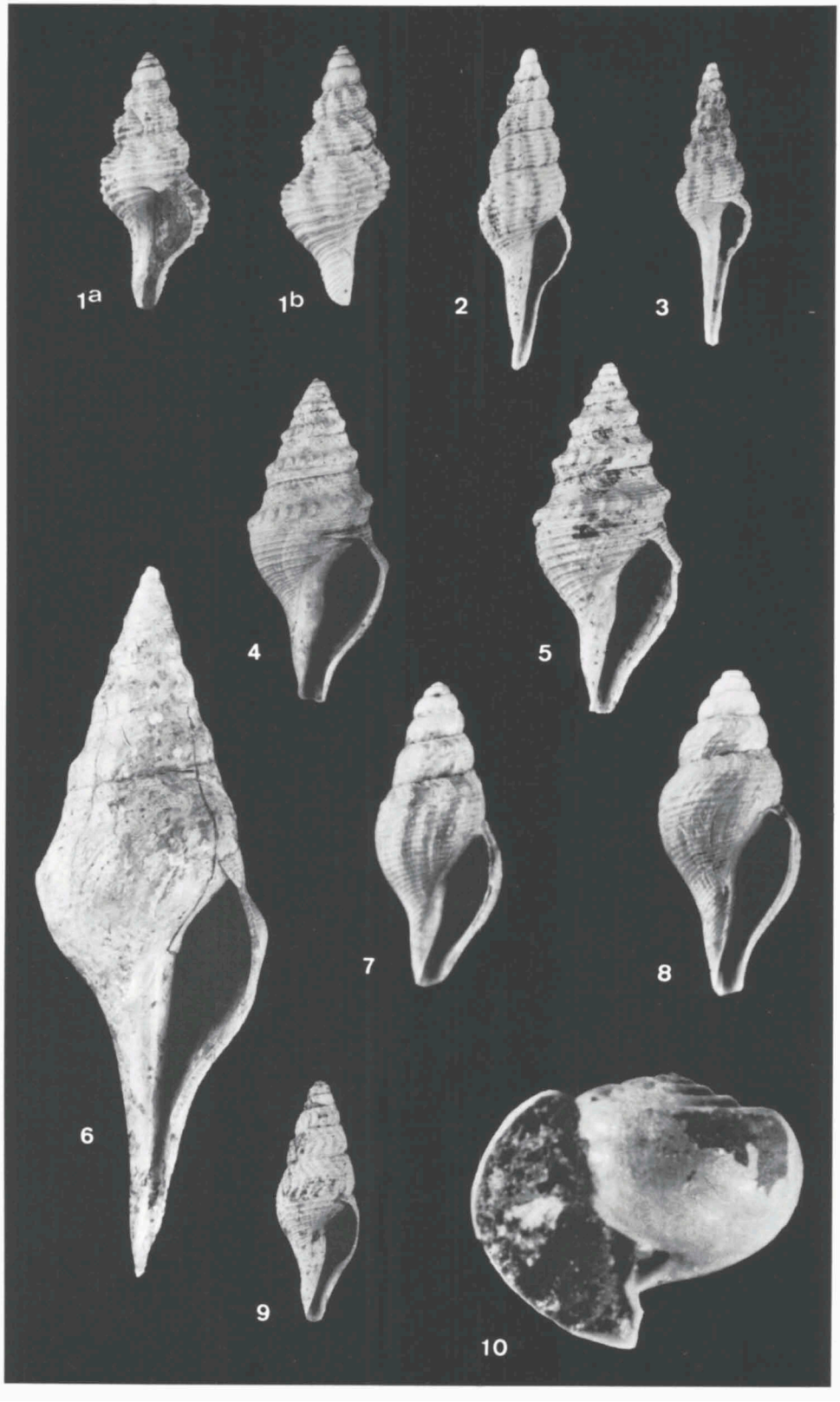


Plate 5

COMMON MOLLUSCAN SPECIES FROM THE *Cyclocardia kickxi* - *Astarte kickxi* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

All specimens from clay-pits at Niel, Belgium (Rupel area).

Fig. 1. *Aquilofusus multisulcatus* (Nyst, 1845). Collection M. C. Cadée. Height 36.6 mm.

Fig. 2. *Streptochetus (Streptodyction) cheruscus elongatus* (Nyst, 1845). RGM 184 688. Height 28.1 mm.

Fig. 3. *Epalxis (Bathytoma) crenata* (Nyst, 1845). RGM 184 689. Height 29.4 mm.

Figs. 4-6. *Turis (Fusiturris) selysi* (de Koninck, 1838). RGM 184 690-184 692. Height resp. 25.0 mm, 32.4 mm and 34.4 mm.

Figs. 7-8. *Turricula (Surcula) regularis* (de Koninck, 1838). RGM 184 693-184 694. Height resp. 34.4 mm and 21.4 mm.

Plate 5

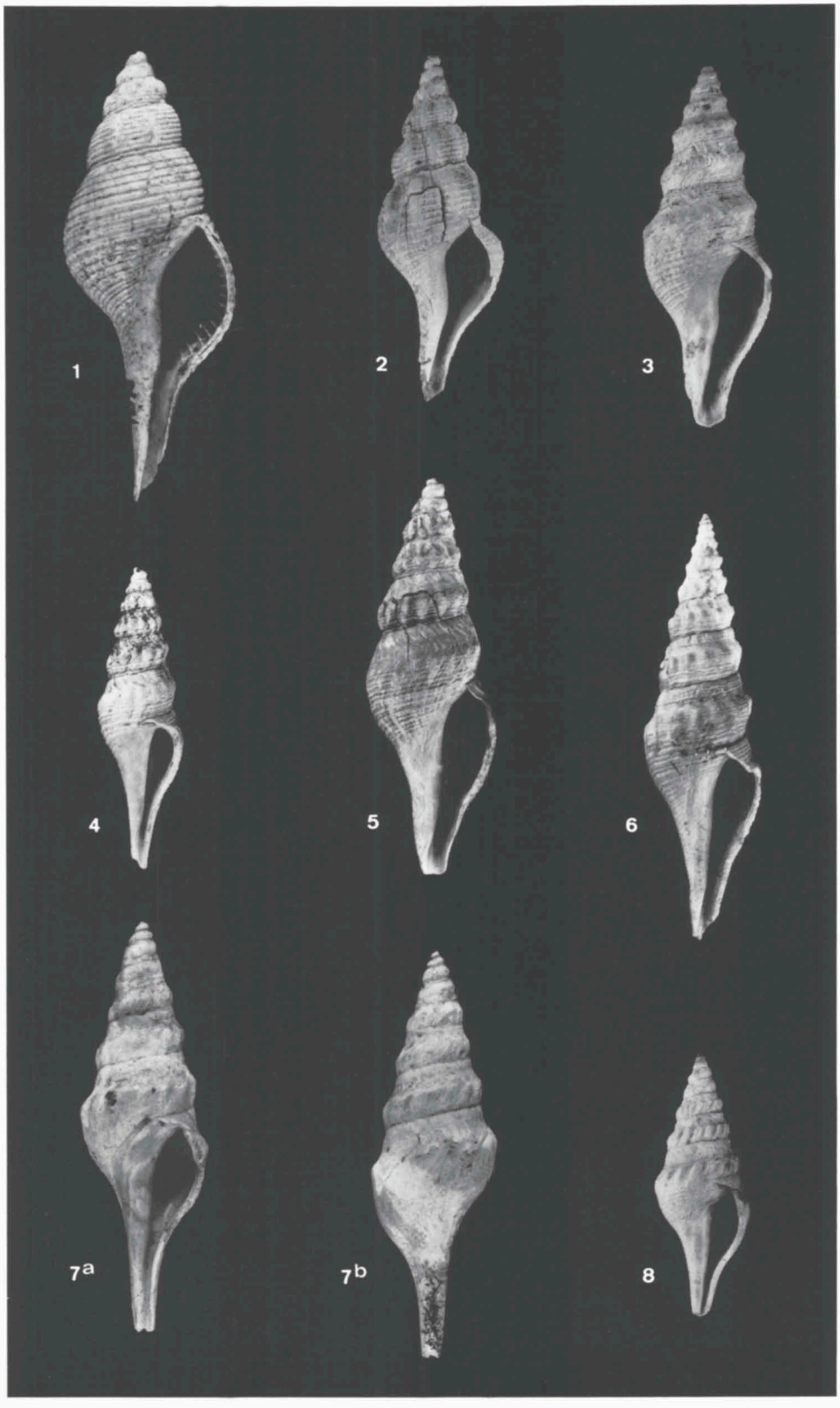


Plate 6

LESS COMMON MOLLUSCAN SPECIES, PROBABLY RESTRICTED TO THE *Cyclocardia kickxi - Astarte kickxi* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

Figs. 1-3 from clay-pits at Niel, Belgium (Rupel area); fig. 4 from the clay-pit of the Scholten brick-works at the Kuiperberg near Ootmarsum.

Fig. 1. *Galeodea depressa* (von Buch, 1831). RGM 184 695. Height 41.7 mm.

Fig. 2. *Neptunea erratica* (de Koninck, 1838). Collection M. C. Cadée. Height 43.6 mm.

Fig. 3. *Spaniorhinus striatulus* (Nyst, 1845). RGM 184 696. Height 6.0 mm.

Fig. 4. *Pycnodonte paradoxa* (Nyst, 1835). RGM 76 038. Height 12.3 mm.

Plate 6

Plate 7

COMMON MOLLUSCAN SPECIES FROM THE *Cyclocardia kickxi* - *Astarte kickxi* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER, KNOWN FROM THE RUPEL AREA ONLY

All specimens from clay-pits at Niel, Belgium (Rupel area).

Fig. 1. *Hilberia hoeninghausi* (Defrance, 1825). RGM 184 697. Height 44.1 mm.

Fig. 2. *Hilberia hoeninghausi* (Defrance, 1825). RGM 184 698. Height 37.4 mm.

Fig. 3. *Cancellaria (Merica) evulsa* (Solander, 1766). RGM 184 699. Height 11.7 mm.

Fig. 4. *Cancellaria (Merica) evulsa* (Solander, 1766). RGM 184 700. Height. 15.7 mm.

Fig. 5. *Gemmula (Oxytropa) koninckí* (Nyst, 1845). RGM 184 701. Height 25.8 mm.

Fig. 6. *Gemmula (Oxytropa) koninckí* (Nyst, 1845). RGM 184 702. Height 43.6 mm.

Fig. 7. *Tornatellaea simulata* (Solander, 1766). Collection M. C. Cadeé. Height 14.2 mm.

Plate 7

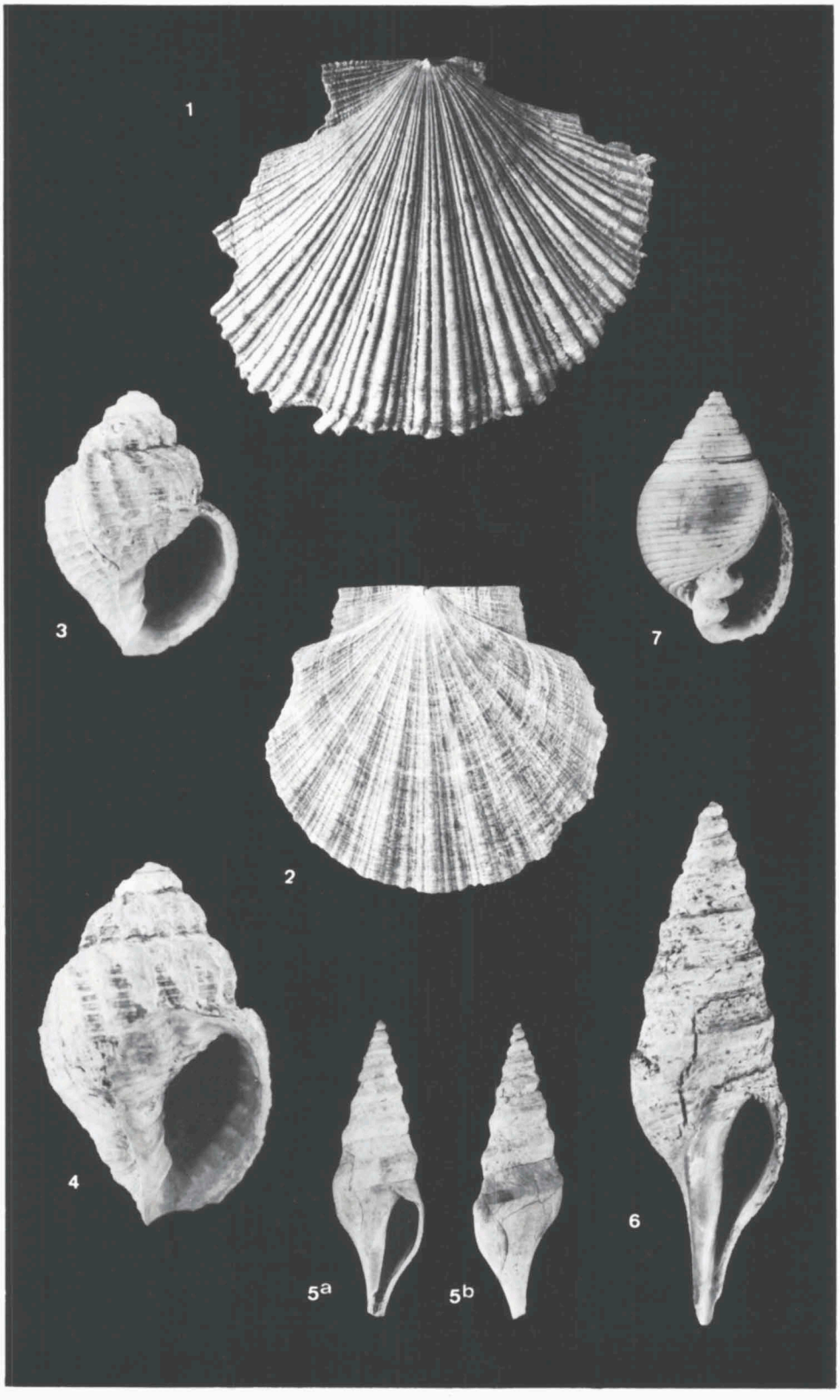


Plate 8

MOLLUSCAN SPECIES RESTRICTED TO THE WINTERSWIJK MEMBER

Figs. 1-4 from the stratotype of the Winterswijk Member in the south-eastern part of the clay-pit complex of the brick-works "de Vlijt" and "te Siepe" at Winterswijk.

Fig. 1. *Limopsis (Pectunculina) retifera* Semper, 1861. Collection M. C. Cadeé. Height 2.7 mm.

Fig. 2. Nuculidae sp. Collection M. C. Cadeé. Height 10.5 mm.

Fig. 3. *Solemya obovata* von Koenen, 1868. Collection J. Boscheinen. Height 3.4 mm.

Fig. 4. *Euspira fissurata* (von Koenen, 1891). RGM 117 061. Height 8.3 mm. (Also figured by Janssen, 1972c, fig. 3a-d).

RARE MOLLUSCAN SPECIES RESTRICTED TO THE *Serpula septaria* - *Ancistrosyrinx volgeri* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

Figs. 5-6 from the construction-pit for the E 3 tunnel at the right bank of the river Scheldt at Antwerp, Belgium; figs. 7-11 from the clay-pit complex of the brick-works "de Vlijt" and "te Siepe" at Winterswijk.

Fig. 5. *Thyasira obtusa* (Beyrich, 1848). RGM 184 703. Height 12.0 mm.

Fig. 6. *Aquilofusus biformis* (Beyrich, 1856). RGM 184 704. Height 34.1 mm.

Fig. 7. *Alvania* (? *Arsenia*) *rupeliensis* Tembrock, 1964. Collection M. C. Cadée. Height 2.6 mm.

Fig. 8. *Alvania* (?*Arsenia*) *rupeliensis* Tembrock, 1964. Collection M. C. Cadée. Height 2.4 mm.

Fig. 9. *Turriscala rudis* (Philippi, 1843). RGM 184 705. Height 8.2 mm.

Fig. 10. *Babylonella fusiformis* (Cantraine, 1836). Collection M. C. Cadée. Height 5.0 mm.

Fig. 11. *Crenilabium elatior* (von Koenen, 1868). Collection M. C. Cadée. Height 6.0 mm.

Plate 8

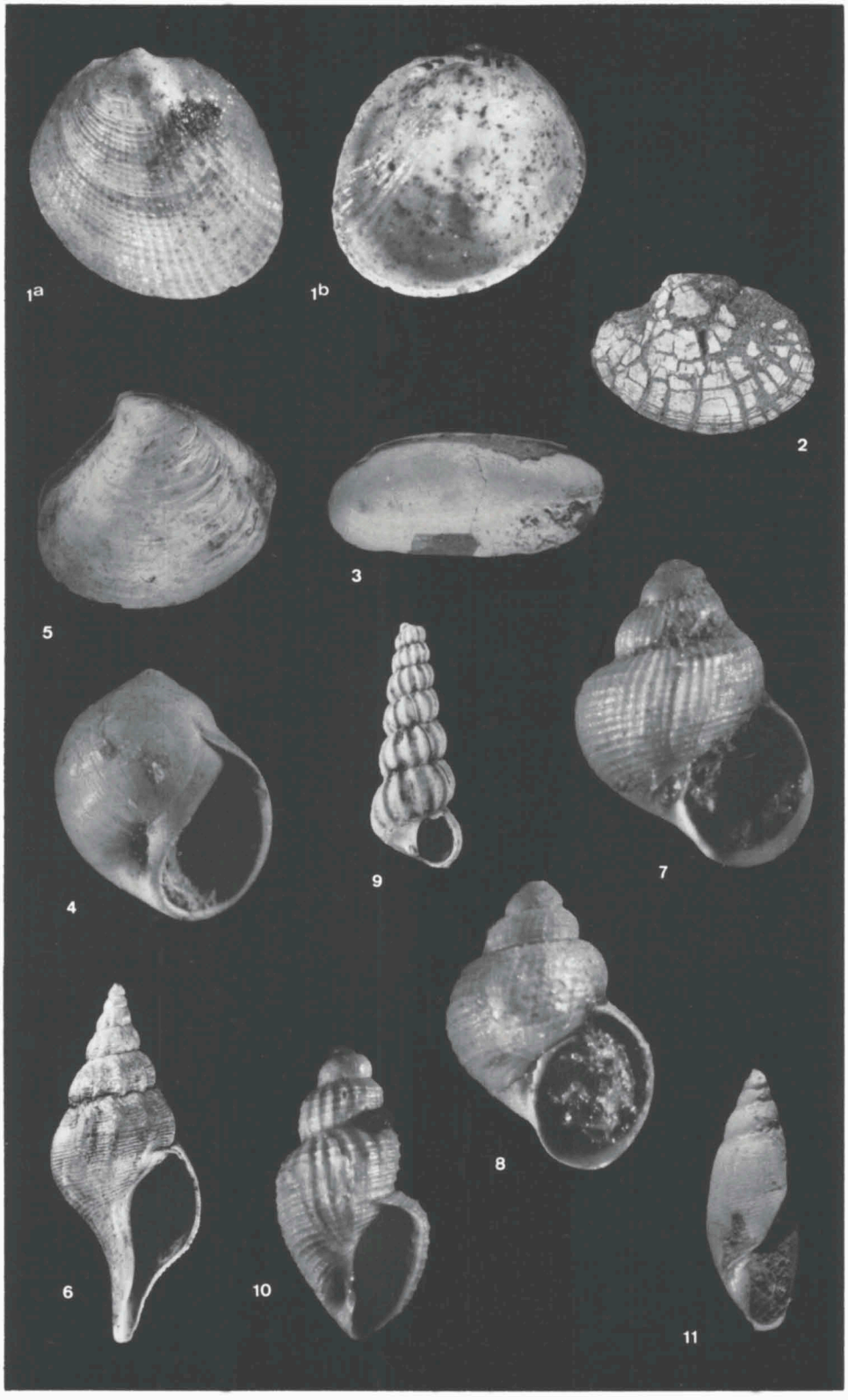


Plate 9

RARE MOLLUSCAN SPECIES RESTRICTED TO THE *Serpula septaria* - *Ancistrosyrinx volgeri* ASSEMBLAGE ZONE OF THE BRINKHEURNE MEMBER

Both specimens from the construction-pit for the E 3 tunnel at the right bank of the river Scheldt at Antwerp, Belgium.

Fig. 1. *Aturia* sp. RGM 184 706. Height c. 105 mm.

Fig. 2. *Aturia* sp. RGM 184 809. Height c. 115 mm.

Plate 9

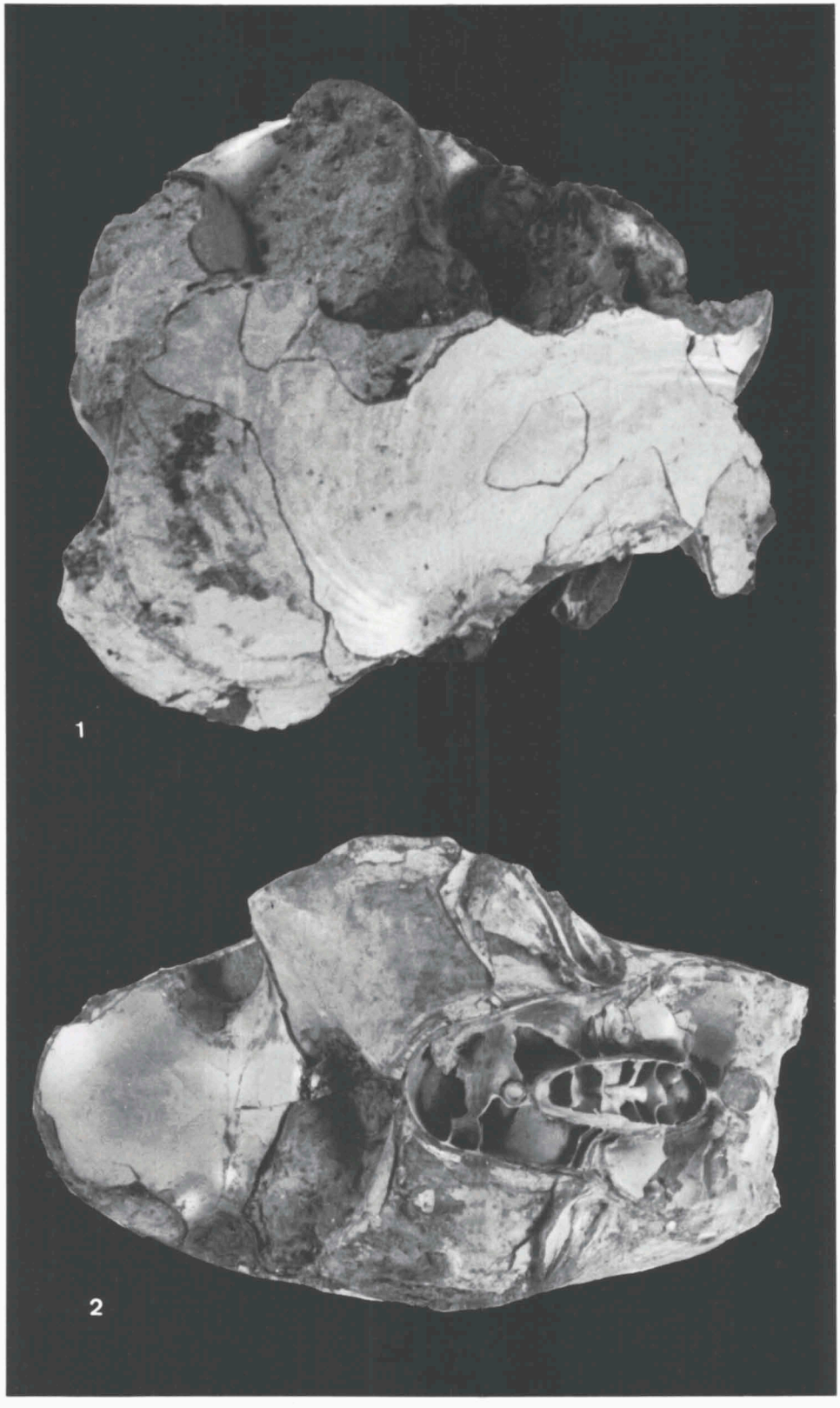


Plate 10

NOT DECALCIFIED REWORKED FAUNA FROM THE AALTEN MEMBER (MISTE BED) OF WINTERSWIJK-MISTE, TEMPORARY EXCAVATION NEAR THE STRATOTYPE OF THE MISTE BED. FIGS. 1-9 REPRESENT THE MOLLUSCAN SPECIES THAT DO NOT OCCUR IN THE AUTOCHTHONOUS FAUNA OF THE *Hiatella arctica* ACME ZONE

Fig. 1. *Pecten (Pecten) brummeli* Nyst, 1864. RGM 184 707. Height 44.7 mm.

Fig. 2. *Pycnodonte* (s. s.) *navicularis* (Brocchi, 1814). RGM 184 708. Height 39.3 mm.

Fig. 3. *Arctica islandica* (Linné, 1767). RGM 184 709. Height c. 19 mm.

Figs. 4-6. *Dentalium* (s. s.) aff. *seminudum* auct. non Deshayes, 1860. RGM 184 710-184 712. Height resp. 14.0 mm, 11.0 mm and 11.6 mm.

Fig. 7. *Ecphora wiechmanni* (von Koenen, 1860). RGM 184 713. Height 17.6 mm.

Figs. 8-9. *Haustator goettentrupensis* (Cossmann, 1899). RGM 184 714-184 715. Height 25.2 mm and 24.0 mm, respectively.

Fig. 10. Reworked phosphorite concretion containing not decalcified fossils, with a phosphorite concretion in situ, containing fossils from the autochthonous fauna of the Miste Bed, attached to it. RGM 184 716. Height c. 49 mm.

Plate 10

Plate 11

MOLLUSCAN SPECIES FROM REWORKED DECALCIFIED PHOSPHORITE CONCRETIONS FROM THE BASE OF THE AALTEN MEMBER (MISTE BED)

All specimens from temporary excavations at Winterswijk-Miste near the stratotype of the Miste Bed.

Fig. 1. *Glycymeris* (s. s.) *lunulata baldii* Glibert & van de Poel, 1965. Internal mould. RGM 184 781. Height c. 50 mm.

Fig. 2. *Glycymeris* (s. s.) *lunulata baldii* Glibert & van de Poel, 1965. External mould. RGM 184 782. Height of concretion c. 35 mm.

Fig. 3. *Mytilus* (s. s.) aff. *acutirostris* Sandberger, 1863. Internal mould. RGM 184 783. Height 53 mm. 3a: lateral view, 3b: dorsal view.

Fig. 4. Phosphorite concretion with external mould of Pectinidae sp. RGM 184 784. Height of concretion c. 51 mm.

Fig. 5. Phosphorite concretion with external mould of Pectinidae sp. RGM 184 785. Height of concretion 31 mm.

Fig. 6. Phosphorite concretion with external mould of *Callista beyrichi* (Semper, 1861). RGM 184 786. Height of concretion c. 32 mm.

Fig. 7. Phosphorite concretion with external mould of *Laevicardium (Habecardium) tenuisulcatum* (Nyst, 1836). RGM 184 787. Height of concretion c. 22 mm.

Fig. 8. *Pelecyora (Cordiopsis)* sp. Internal mould. RGM 184 788. Height 43.8 mm.

Fig. 9. *Laevicardium (Habecardium) tenuisulcatum* (Nyst, 1836). Wax-cast of external mould (see fig. 7). RGM 184 787.

Fig. 10. *Laevicardium (Habecardium) tenuisulcatum* (Nyst, 1836). Wax-cast of external mould. RGM 184 789. Height of shell 12.5 mm.

Fig. 11. *Callista beyrichi* (Semper, 1861). Wax-cast of external mould. RGM 184 790. Height of shell fragment c. 13.5 mm.

Fig. 12. *Haustator goettentrupensis* (Cossmann, 1899). Wax-cast of external mould. RGM 184 791. Height of shell fragment c. 14 mm.

Fig. 13. *Cominella bolli* (Beyrich, 1854). Wax-cast of external mould. RGM 184 792. Height of shell fragment c. 10 mm.

Plate 11

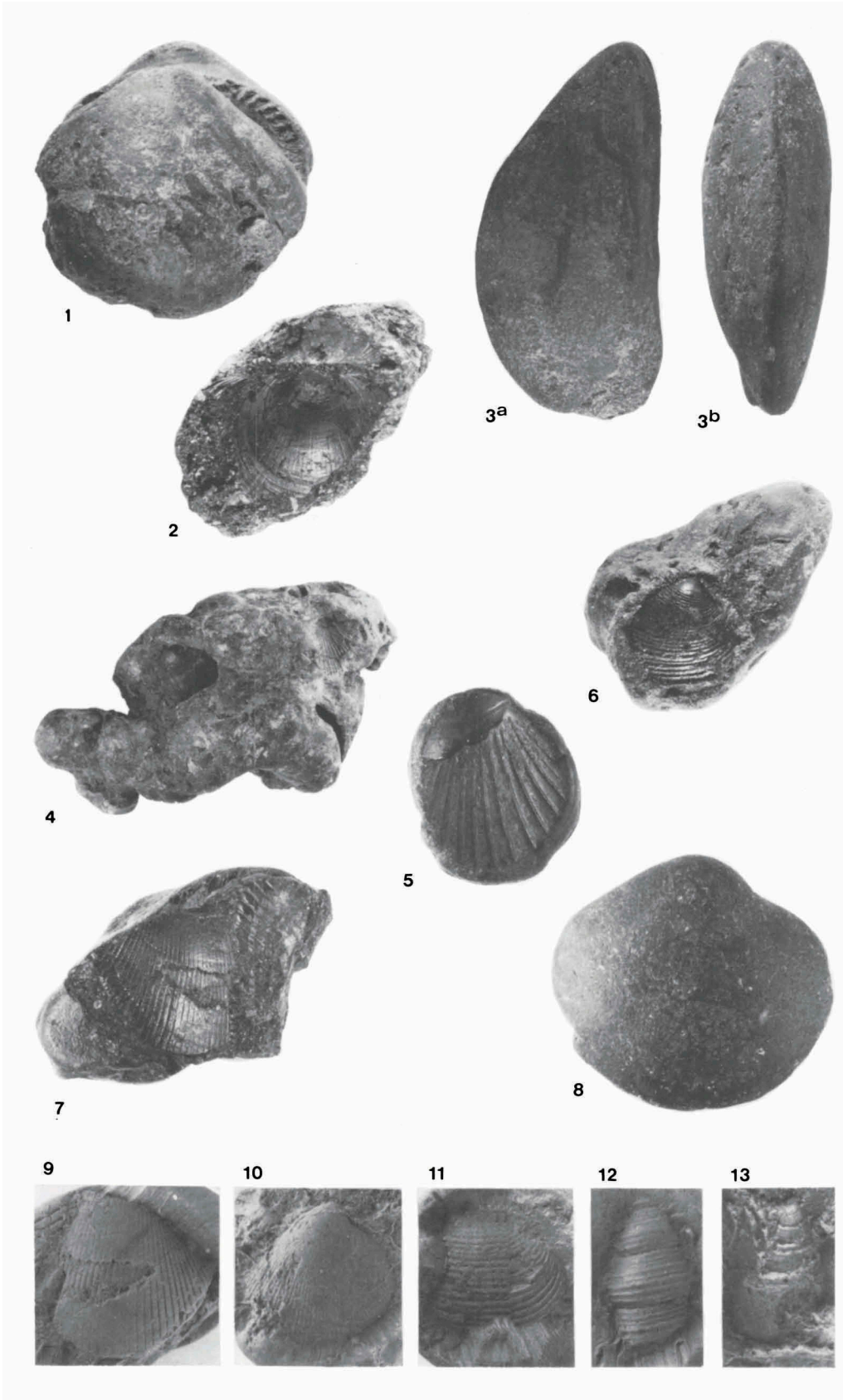


Plate 12

MOLLUSCAN SPECIES RESTRICTED TO THE *Hiatella arctica* ACME ZONE OF THE AALTEN MEMBER

All specimens from Winterswijk-Miste, temporary excavation near the stratotype of the Miste Bed.

Fig. 1. *Lembulus emarginatus* (Lamarck, 1819). RGM 184 717. Height 5.0 mm.

Fig. 2. *Bucardium* sp. RGM 184 718. Height c. 37 mm.

Fig. 3. *Ancillarina* sp. RGM 184 719. Height 24.2 mm.

Fig. 4. *Morum* sp. RGM 184 720. Height 24.3 mm.

Fig. 5. *Trigonostoma planispira* (Nyst, 1845). RGM 184 721. Height 18.0 mm.

Fig. 6. *Trigonostoma* sp. RGM 184 722. Height 27.2 mm.

Fig. 7. Fasciolariidae sp. RGM 116 921. Height 67.6 mm (also figured by Janssen, 1972a, pl. 7, fig. 2).

Fig. 8. Terebridae sp. RGM 184 723. Height 96.7 mm.

Plate 12

Plate 13

MOLLUSCAN SPECIES THAT ARE MUCH MORE COMMON IN THE *Hiatella arctica* ACME ZONE THAN IN THE OTHER BIOZONES OF THE AALTEN MEMBER

All specimens from Winterswijk-Miste, temporary excavation near the stratotype of the Miste Bed.

Fig. 1. *Lutraria* cf. *latissima* Deshayes, 1830. RGM 184 724. Height c. 46 mm.

Fig. 2. *Bursa (Lampasopsis) austriaca* (Hoernes & Auinger, 1884). RGM 184 725. Height 38.0 mm.

Fig. 3. *Chicoreus aquitanicus* (Grateloup, 1833). RGM 184 726. Height 92.6 mm.

Fig. 4. *Kelletia (Boreokelletia) hosiusi* (Beyrich, 1856). RGM 184 727. Height 90.3 mm.

Fig. 5. *Clavatula* (s. s.) *boreointerrupta* Kautsky, 1925. RGM 184 728. Height 49.5 mm.

Plate 13

Plate 14

MOLLUSCAN SPECIES THAT ARE MUCH MORE COMMON IN THE *Hiatella arctica* ACME ZONE THAN IN THE OTHER BIOZONES OF THE AALTEN MEMBER

All specimens from Winterswijk-Miste, temporary excavation near the stratotype of the Miste Bed.

Fig. 1. *Cyrtodaria angusta* (Nyst & Westendorp, 1839). RGM 184 729. Height 8.6 mm.

Fig. 2. *Dentalium (Antalis) dumasi* Cossmann & Peyrot, 1916. RGM 184 730. Height 35.6 mm.

Fig. 3. *Architectonica* (s. s.) *carocollata* (Lamarck, 1822). RGM 184 731. Height 15.7 mm.

Fig. 4. *Haustator eryna* (d'Orbigny, 1852). RGM 184 732. Height 32.1 mm.

Figs. 5-6. *Crepidula (Janacus) crepidula* (Linné, 1766). RGM 184 733-184 734. Height resp. 24.7 mm and 31.8 mm.

Fig. 7. *Euspira gottschei* (Kautsky, 1925). RGM 184 735. Height 25.0 mm.

Fig. 8. *Neverita josephinia olla* (des Serres, 1829). RGM 184 736. Height 17.8 mm.

Fig. 9. *Hadriania coelata* (Dujardin, 1837). RGM 184 737. Height 25.1 mm.

Fig. 10. *Pterynotus (Pterochelus) angustifolius* (Kautsky, 1925). RGM 184 738. Height 22.3 mm.

Fig. 11. *Hinia* (s. s.) *schroederi* (Kautsky, 1925). RGM 184 739. Height 7.5 mm.

Fig. 12. *Trigonostoma behmi* (Beyrich, 1856). RGM 184 740. Height 29.6 mm.

Fig. 13. *Trigonostoma ornatissima* (Zilch, 1935). RGM 184 741. Height 17.0 mm.

Fig. 14. *Vaginella depressa* Daudin, 1800. RGM 184 742. Height 7.0 mm.

Plate 14

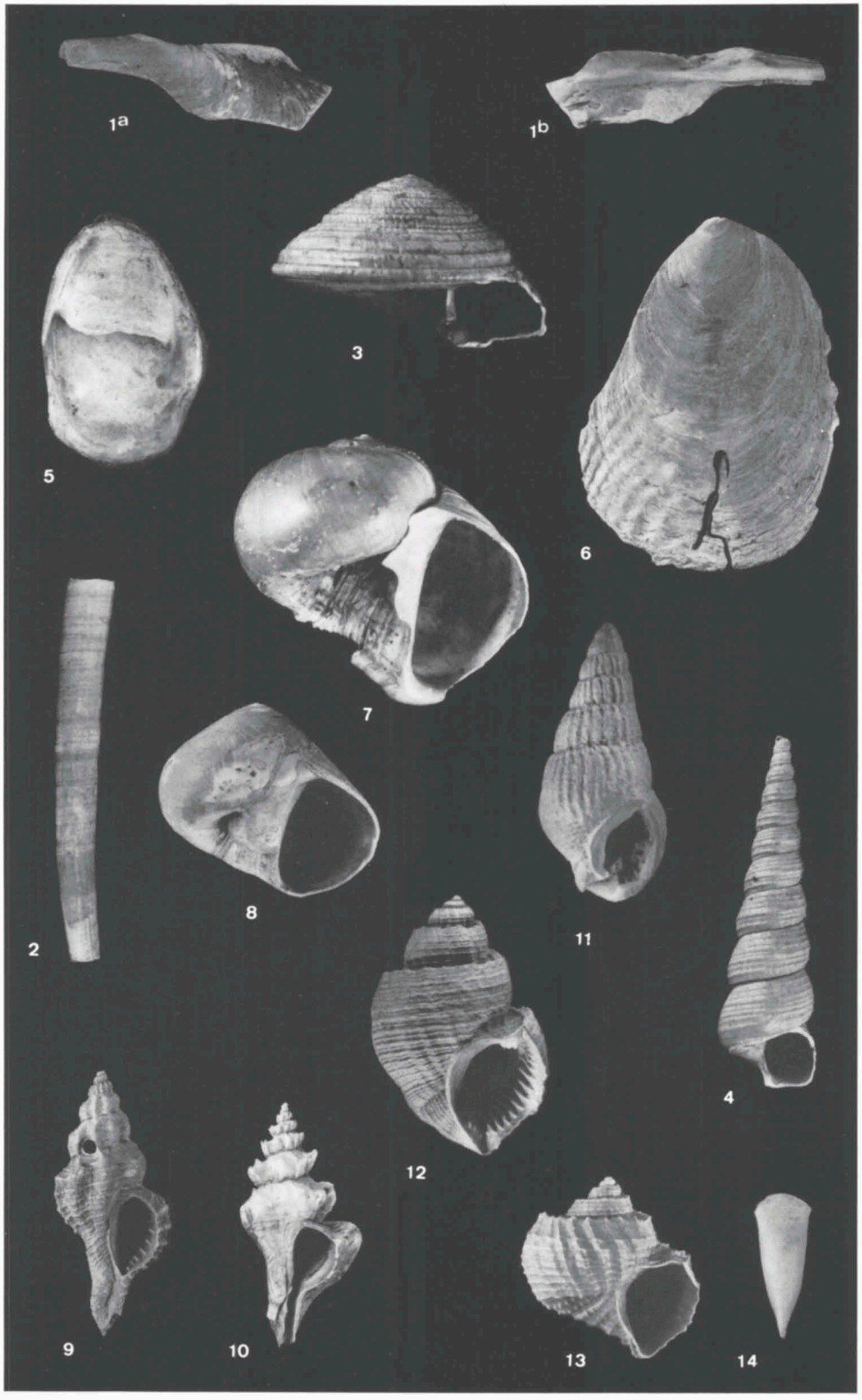


Plate 15

INVERTEBRATE SPECIES THAT ARE MUCH MORE COMMON IN THE *Astarte radiata* ACME ZONE THAN IN THE OTHER BIOZONES OF THE AALTEN MEMBER

Figs. 1-2 from temporary excavations north-east of the Ticheloven farm at Eibergen-Loo, near boring 34G.1-24. Figs. 3-9 from Winterswijk-Miste, temporary excavation near the stratotype of the Miste Bed.

Fig. 1. *Glycymeris* (s. s.) *lunulata baldii* Glibert & van de Poel, 1965. RGM 184 743. Height 48.7 mm.

Fig. 2. *Arctica islandica* (Linné, 1767). RGM 184 744. Height 65.0 mm.

Fig. 3. *Venericardia (Glans) aculeata ronchetti* Glibert & van de Poel, 1970. RGM 184 745. Height 27.7 mm.

Fig. 4. *Astarte (? Astarte) waeli* Glibert, 1945. RGM 184 746. Height 2.5 mm.

Fig. 5. *Clausinella scalaris* (Bronn, 1831). RGM 184 747. Height 22.0 mm.

Fig. 6. *Pelecyora (Cordiopsis) polytropa nysti* (d'Orbigny, 1852). RGM 184 748. Height 56.3 mm.

Fig. 7. *Lepetella compressiuscula* (Karsten, 1849). RGM collection. Height c. 2.4 mm (specimen lost).

Fig. 8. *Ringicula (Ringiculina) ventricosa* (Sowerby, 1824). RGM 184 749. Height 6.7 mm.

Fig. 9. *Sphenotrochus intermedius* (Goldfuss). RGM 184 750. Height 5.5 mm.

Plate 15

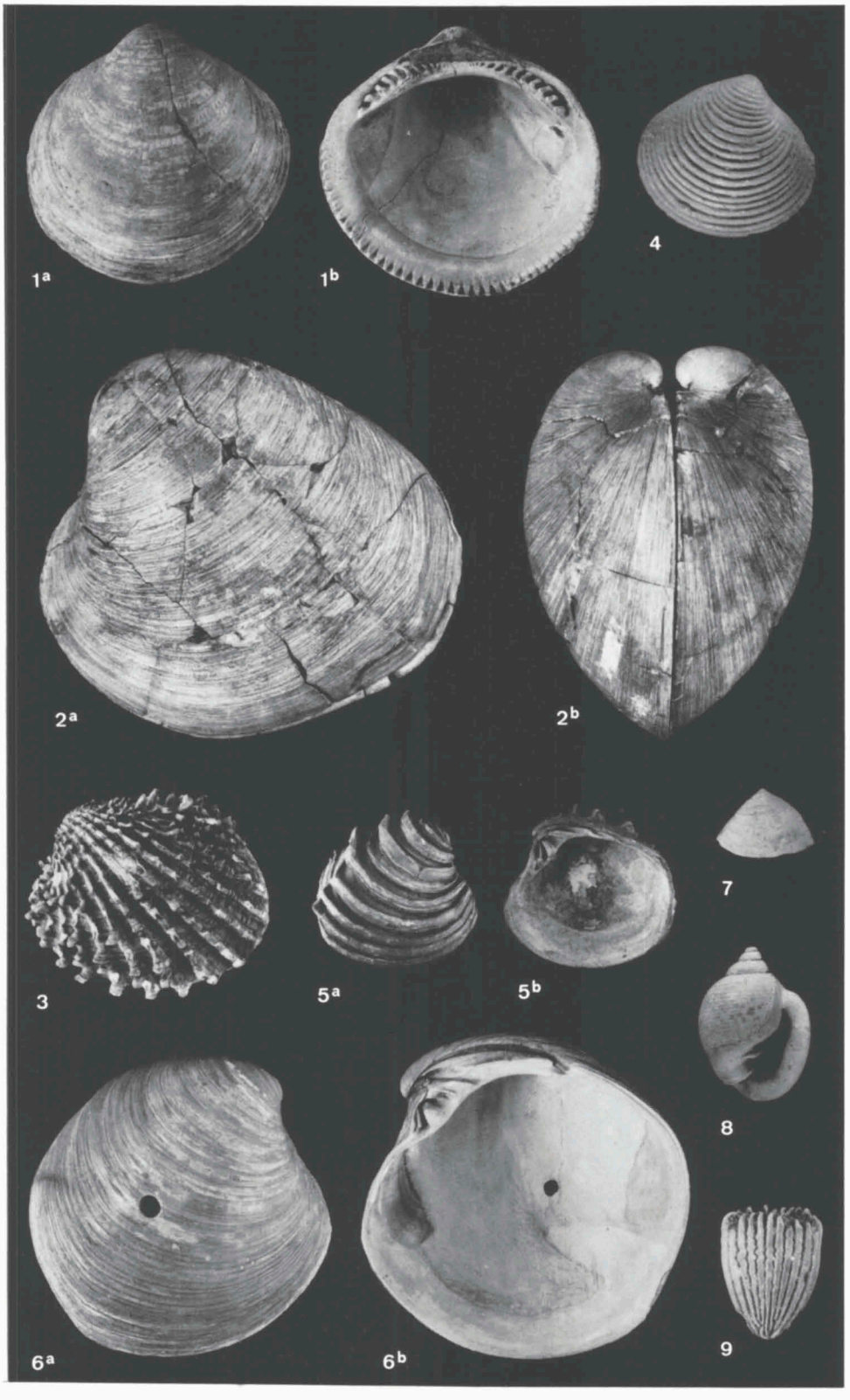


Plate 16

MOLLUSCAN SPECIES KNOWN FROM THE *Hiatella arctica* ACME ZONE AND THE *Astarte radiata* ACME ZONE OF THE AALTEN MEMBER THAT DO ALSO OCCUR IN THE REINBEKER SCHICHTEN OF NORTHERN GERMANY

Figs. 1-3 from Winterswijk-Miste, temporary excavation near stratotype of the Miste Bed.

Fig. 1. *Meiocardia harpa* (Goldfuss, 1840). RGM 184 751. Height 45.6 mm.

Fig. 2. *Ficus simplex* (Beyrich, 1854). RGM 184 752. Height 13.2 mm.

Fig. 3. *Amyclina facki* (von Koenen, 1872). RGM 184 753. Height 16.9 mm.

MOLLUSCAN SPECIES KNOWN FROM THE *Spisula* SP. ACME ZONE AND THE *Limopsis aurita* ACME ZONE OF THE AALTEN MEMBER THAT ARE HARDLY OR NOT KNOWN FROM THE *Hiatella arctica* ACME ZONE AND THE *Astarte radiata* ACME ZONE OF THE AALTEN MEMBER

Figs. 4-12 from temporary excavations near the Königsmühle at Dingden, western Germany. Figs. 4, 7 and 8 from the "Dingdener Glimmerton" (= Aalten Member, Stemerdink Bed), figs. 5, 6 and 9-12 from the "Dingdener Feinsand" (= Aalten Member, Miste Bed, upper part).

Fig. 4. *Portlandia (Yoldiella) curvirostris* (Lehmann, 1885). RGM 184 754. Height 2.6 mm.

Fig. 5. *Abra lehmanni* Anderson, 1964. RGM 184 755. Height 9.0 mm.

Fig. 6. *Trivia westfalica* Schilder, 1929. RGM 184 756. Height 7.6 mm.

Fig. 7. *Eudolium dingdense* Anderson, 1964. RGM 184 757. Height 28.0 mm.

Fig. 8. *Aquilofusus festivus* (Beyrich, 1856). RGM 184 758. Height 25.8 mm.

Fig. 9. *Haedropleura maitreja* (von Koenen, 1872) RGM 184 759. Height 9.9 mm.

Fig. 10. *Magnella andersoni* Dittmer, 1960. RGM 184 760. Height 7.5 mm.

Fig. 11. *Thatcheria circumfossa* (von Koenen, 1872). RGM 184 761. Height 14.3 mm.

Fig. 12. *Tornatina bellardii* (von Koenen, 1882). RGM 184 762. Height 6.0 mm.

Plate 16

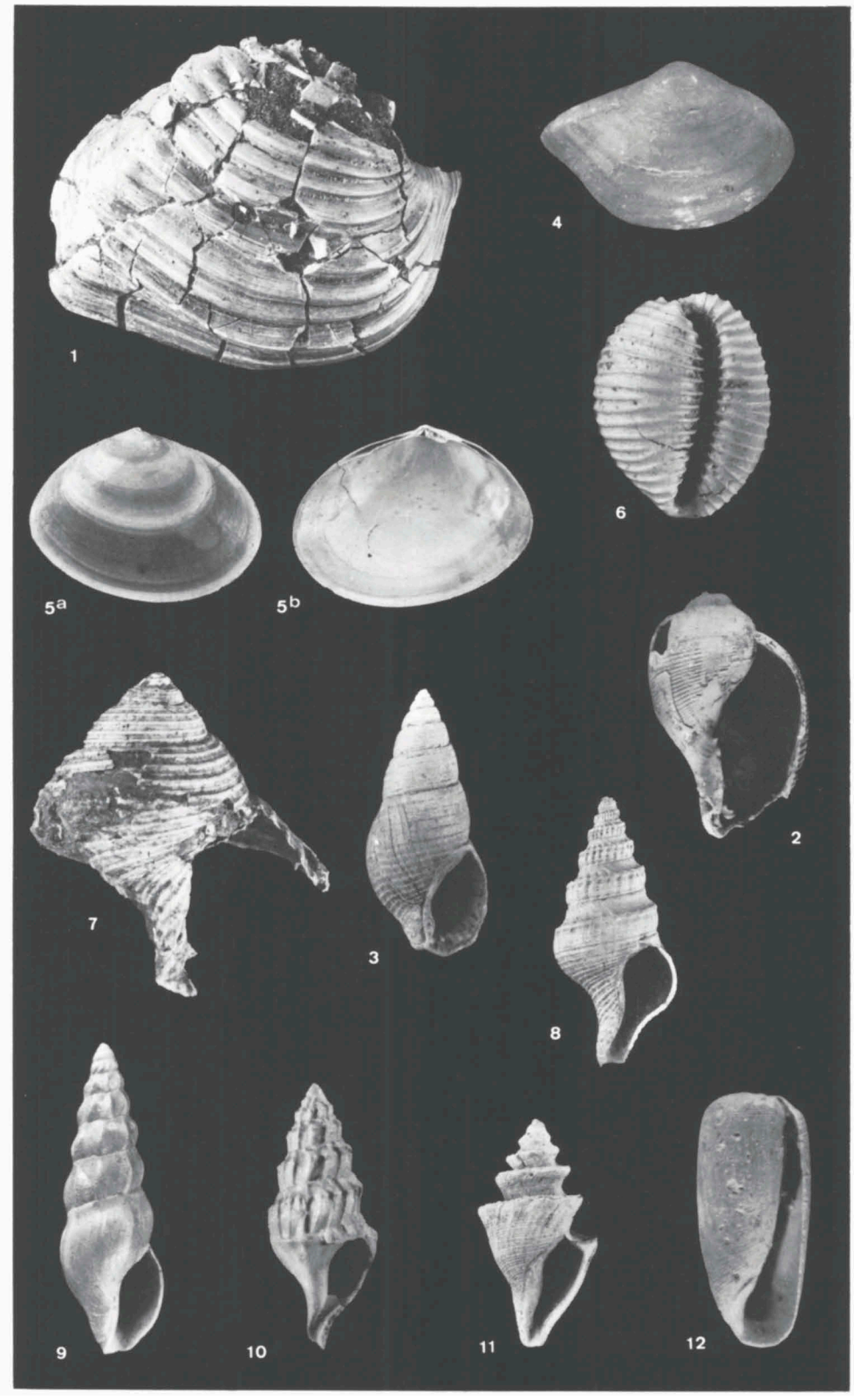


Plate 17

MOLLUSCAN SPECIES ONLY KNOWN FROM THE *Spisula* SP. ACME ZONE OF THE AALTEN MEMBER

All specimens from temporary excavations near the Königsmühle at Dingden, western Germany, "Dingdener Feinsand" (= Aalten Member, Miste Bed, upper part).

Fig. 1. *Yoldia* (s. s.) *longa* Bellardi, 1875. RGM 184 763. Height 6.4 mm.

Fig. 2. *Propeamussium (Parvamussium) squamosoreticulatum* (Anderson, 1964). RGM 184 764. Height 5.1 mm.

Fig. 3. *Hilberia duwelzi* (Nyst, 1861). RGM 184 765. Height 19.8 mm.

Fig. 4. *Congeria basteroti* (Deshayes, 1836). RGM 184 766. Height 5.4 mm.

Fig. 5. *Angulus (Oudardia)* aff. *donacillus* (Wood, 1857). RGM 184 767. Height 10.8 mm.

Fig. 6. *Xylophaga* sp. RGM 184 768. Height 6.7 mm.

Fig. 7. *Pecchiola argentea* (Mariti, 1797). RGM 184 769. Height 38.6 mm.

Plate 17

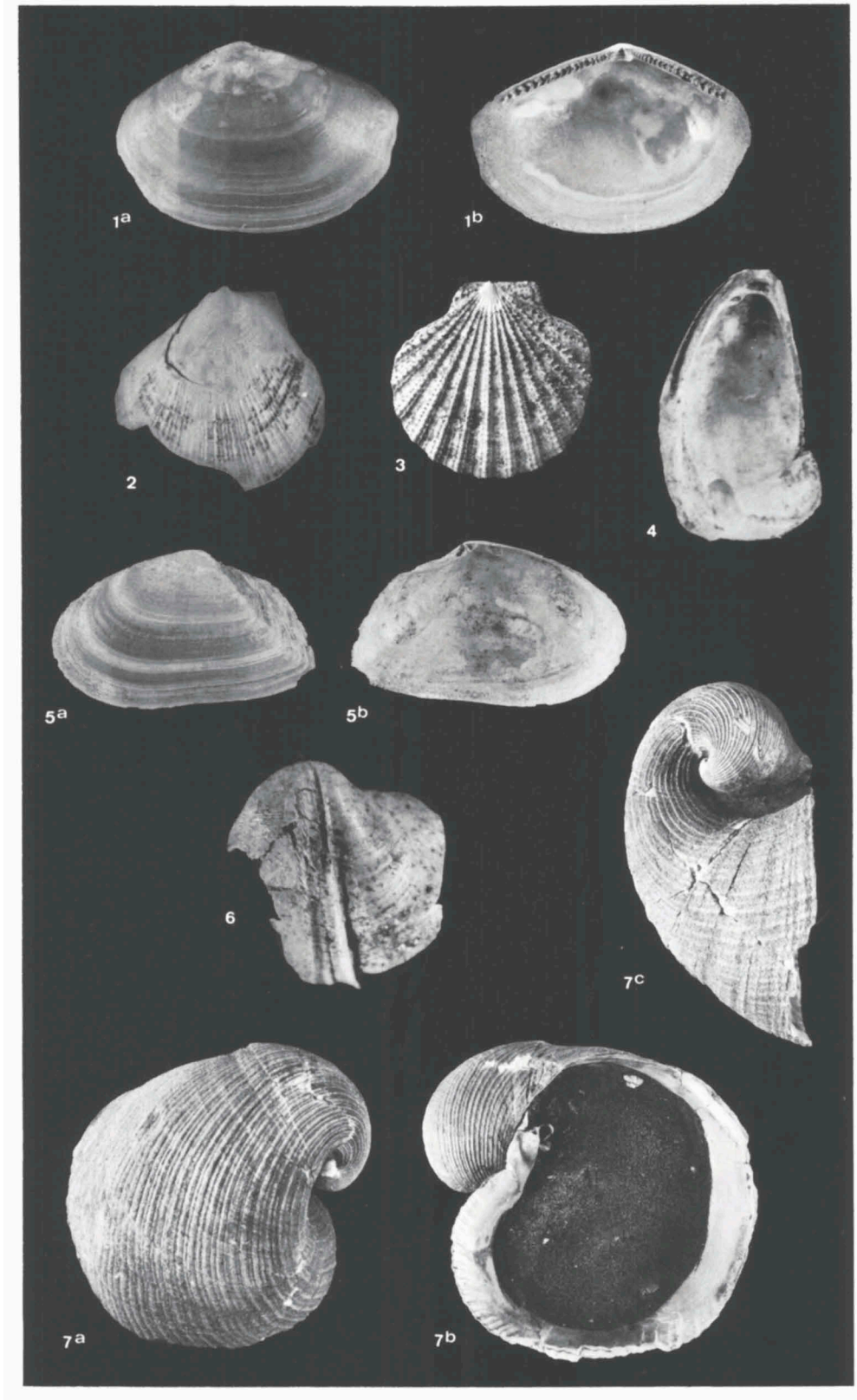


Plate 18

MOLLUSCAN SPECIES ONLY KNOWN FROM THE *Spisula* SP. ACME ZONE OF THE AALTEN MEMBER

All specimens from temporary excavations near the Königsmühle at Dingden, western Germany, "Dingdener Feinsand" (= Aalten Member, Miste Bed, upper part).

Fig. 1. *Solariella formosa* Janssen, 1967. RGM 184 770. Height 5.0 mm.

Fig. 2. *Cirsotrema (Elegantiscala) kimacowiczi* (Zilch, 1934). RGM 184 771. Height 25.2 mm.

Fig. 3. *Coralliophila (Pseudomurex) bracteata* (Brocchi, 1814). RGM 184 772. Height 9.2 mm.

Fig. 4. *Coralliophila (Aldrichia) granifera* (Michelotti, 1847). RGM 184 773. Height 18.8 mm.

Fig. 5. *Murex (Tubicauda) spinicosta* Bronn, 1831. RGM 184 774. Height 45.0 mm.

Fig. 6. *Amyclina badensis* (Hoernes, 1852). RGM 184 776. Height 13.4 mm.

Fig. 7. *Amyclina banatica* (Zilch, 1934) sensu Anderson, 1964. RGM 184 777. Height 5.9 mm.

Fig. 8. *Mitroborsonia debilis* (Beyrich, 1856). RGM 184 775. Height 33.0 mm.

Fig. 9. *Gemmula* (s. s.) *coronata* (von Münster, 1844). RGM 184 778. Height 28.2 mm.

Fig. 10. *Genota acuticostata* (Kautsky, 1925). RGM 184 779. Height 19.8 mm.

Plate 18

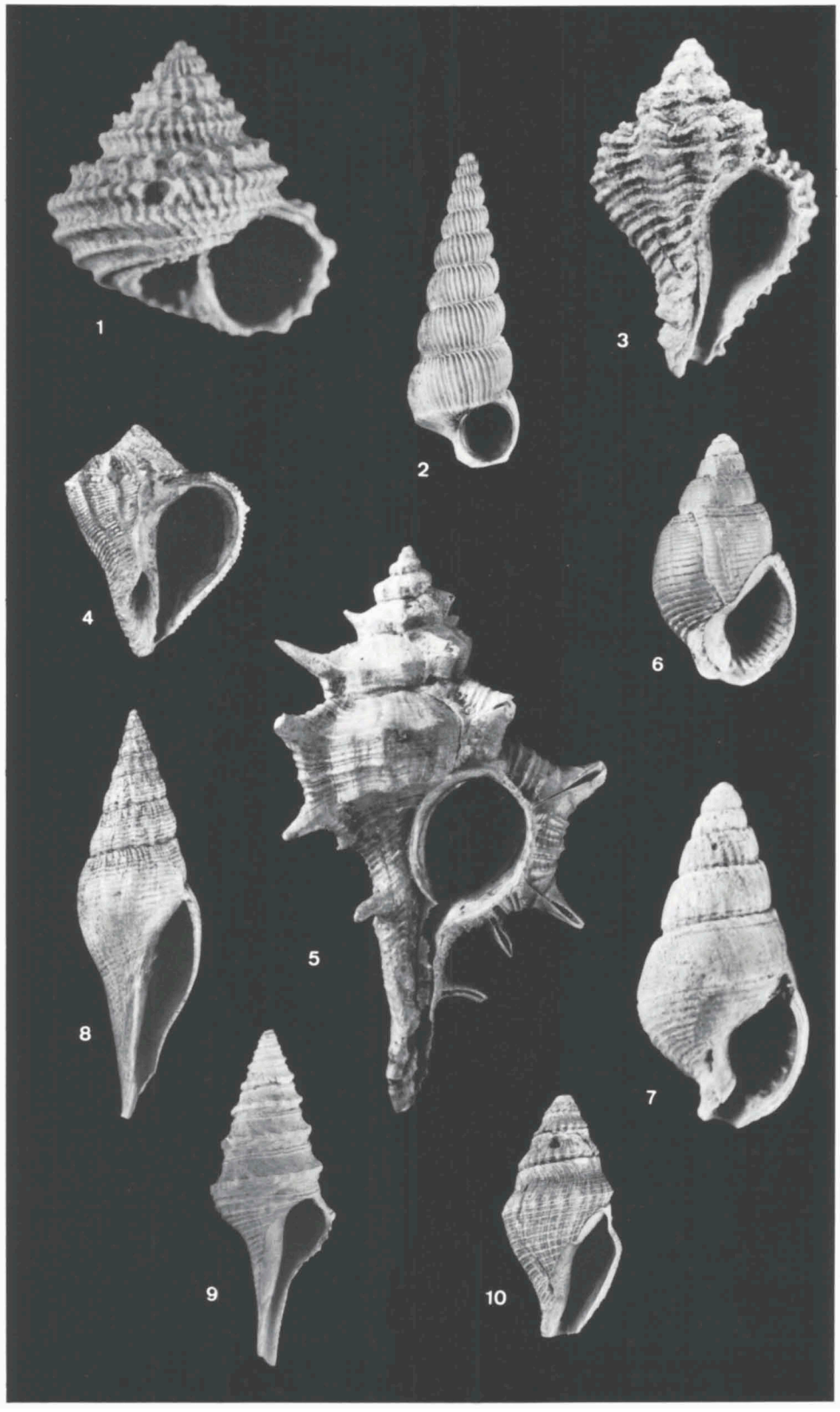


Plate 19

INVERTEBRATE SPECIES FROM THE DELDEN MEMBER

Figs. 1 and 3 from the outcrop in the Twickelse Vaart at the Twickel estate, north of Delden. Figs. 2, 4 and 6 from the Twente-kanaal near Delden. Fig. 5 from boring 28G.3-1 at Delden, 4.50 - 5.00 m below surface. Figs. 1-4 represent internal moulds.

Fig. 1. *Arctica islandica* (Linné, 1767). RGM 113 199. Height c. 57 mm.

Fig. 2. *Pygocardia rustica* (Sowerby, 1818). RGM 114 362. Height c. 43 mm.

Fig. 3. *Panopea* sp. RGM 107 949. Height c. 40 mm.

Fig. 4. *Scaphella* sp. RGM 75 844. Height 24.4 mm.

Fig. 5. *Lingula* sp. RGM 184 780. Height 12.7 mm.

Fig. 6. *Lingula* sp. on phosphorite concretion. RGM 61 803. Height of concretion c. 56 mm.

Plate 19

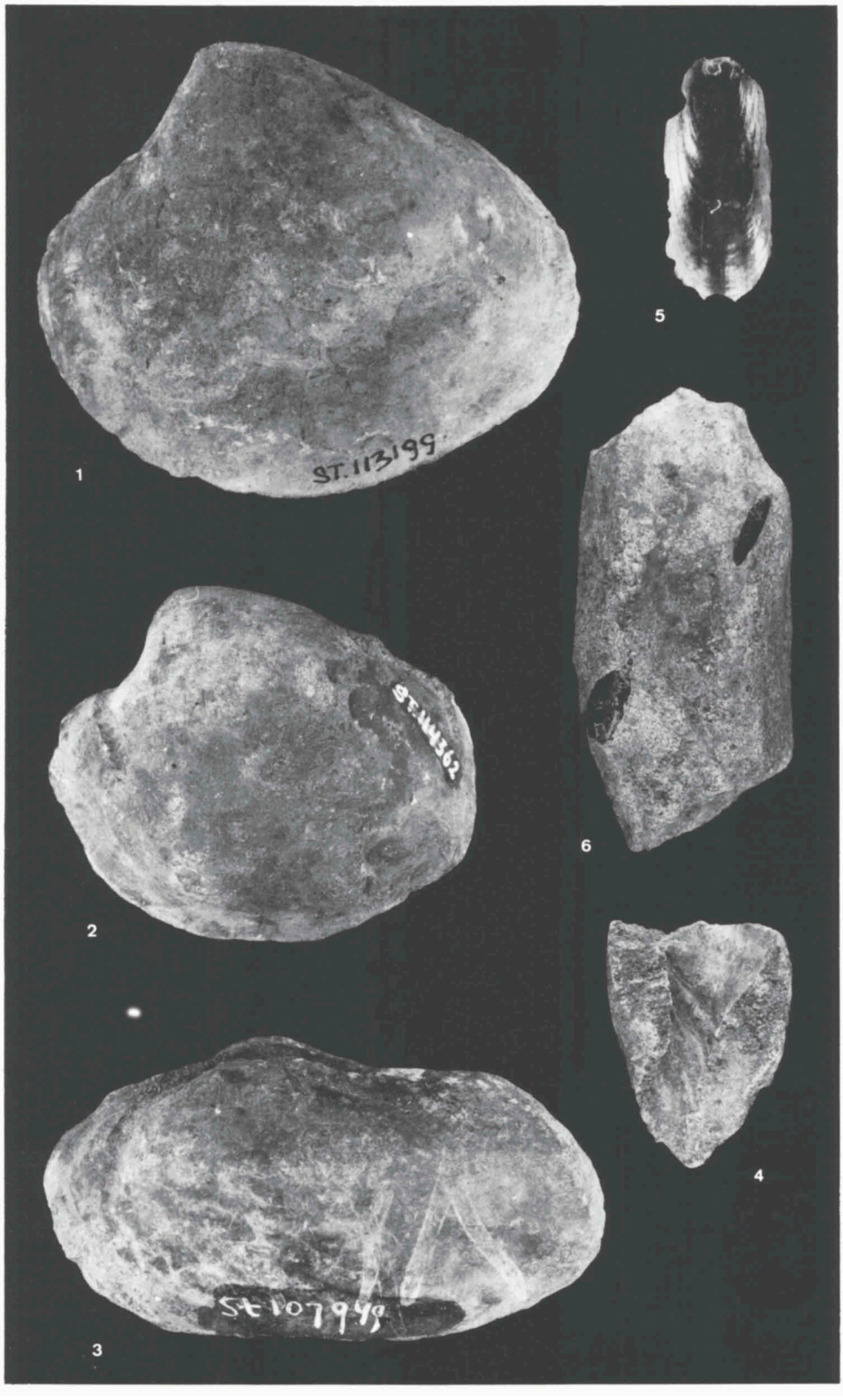


Plate 20

ELASMOBRANCHII FROM THE BRINKHEURNE MEMBER

Fig. 1. *Odontaspis acutissima* Agassiz, 1843. Right upper anterior tooth, RGM 155 612, 1½ ×. Winterswijk, clay-pit complex of the brick-works "de Vlijt" and "te Siepe"; *Serpula septaria - Ancistrosyrinx volgeri* Assemblage Zone.

Fig. 2. *Lamna rupeliensis* (le Hon, 1871). Right upper lateral tooth, RGM 107 779, 1 ×.Ootmarsum, clay-pit of the Scholten brick-works; *Cyclocardia kickxi - Astarte kickxi* Assemblage Zone.

Fig. 3. *Lamna rupeliensis* (le Hon, 1871). Left lower lateral tooth, RGM 107 779, 1 ×. Locality as above.

Fig. 4. *Lamna rupeliensis* (le Hon, 1871). Right upper posterior lateral tooth, RGM 127 063, 1½ ×. Locality as in fig. 1.

Fig. 5. *Isurus gracilis* (le Hon, 1871). Right lower anterior tooth, RGM 107 781, 1 ×. Locality as in fig. 2.

Fig. 6. *Isurus gracilis* (le Hon, 1871). Left lower anterior tooth, RGM 175 781, 1×. Boring 41E.4-516 at Slotboom, Winterswijk (Kotten), depth 2.60 m below surface.

Fig. 7. *Isurus gracilis* (le Hon, 1871). Left upper anterior tooth, RGM 107 781, 1 ×. Locality as in fig. 2.

Fig. 8. *Isurus gracilis* (le Hon, 1871). Right upper anterior tooth, RGM 61 772, 1 ×. Locality as in fig. 1.

ELASMOBRANCHII FROM THE BASE OF THE WINTERSWIJK MEMBER

Fig. 9. *Squalus alsaticus* Andrea, 1892. Anterior tooth, RGM 175 782, 6½ ×. Section 41E.3-143 in the clay-pit complex of the brick-works "de Vlijt" and "te Siepe", Winterswijk, depth 2.30 - 2.55 m.

Fig. 10. *Squalus alsaticus* Andrea, 1892. Posterior lateral tooth, RGM 175 783, 6 ×. Locality as above.

ELASMOBRANCHII FROM THE BASE OF THE AALTEN MEMBER; REWORKED FAUNA BELONGING TO THE FAUNA IN THE DECALCIFIED REWORKED PHOSPHORITE CONCRETIONS

Fig. 11. *Isurus desori* (Agassiz, 1844). Right upper anterior tooth, RGM 175 786, 1 ×. Temporary exposure at Winterswijk-Miste near the stratotype of the Miste Bed.

Fig. 12. *Isurus desori* (Agassiz, 1844). Right upper anterior tooth, RGM 175 785, 1 ×. Locality as above.

Fig. 13. *Isurus desori* (Agassiz, 1844). Right upper anterior tooth, RGM 175 784, 1 ×. Locality as above.

Fig. 14. *Isurus desori* (Agassiz, 1844). Right upper lateral tooth, RGM 25 889, 1 ×. Dieters at Rekken, Eibergen (Staring collection nr. 8871).

Fig. 15. *Isurus desori* (Agassiz, 1844). Right upper lateral tooth, RGM 175 440, 1 ×. Locality as in fig. 11.

Fig. 16. *Isurus hastalis* (Agassiz, 1843), narrow type. Right upper anterior tooth, RGM 175 787, 1 ×. Locality as in fig. 11.

ELASMOBRANCHII FROM THE BASE OF THE AALTEN MEMBER; REWORKED FAUNA BELONGING TO THE REWORKED NOT DECALCIFIED FAUNA

Fig. 17. *Isurus retroflexus* (Agassiz, 1843). Right upper lateral tooth, RGM 175 456, 1 ×. Locality as in fig. 11. 17a: external view, 17b: internal view.

Fig. 18. *Isurus retroflexus* (Agassiz, 1843). Right lower anterior tooth, RGM 175 455, 1 ×. Locality as in fig. 11.

Plate 20

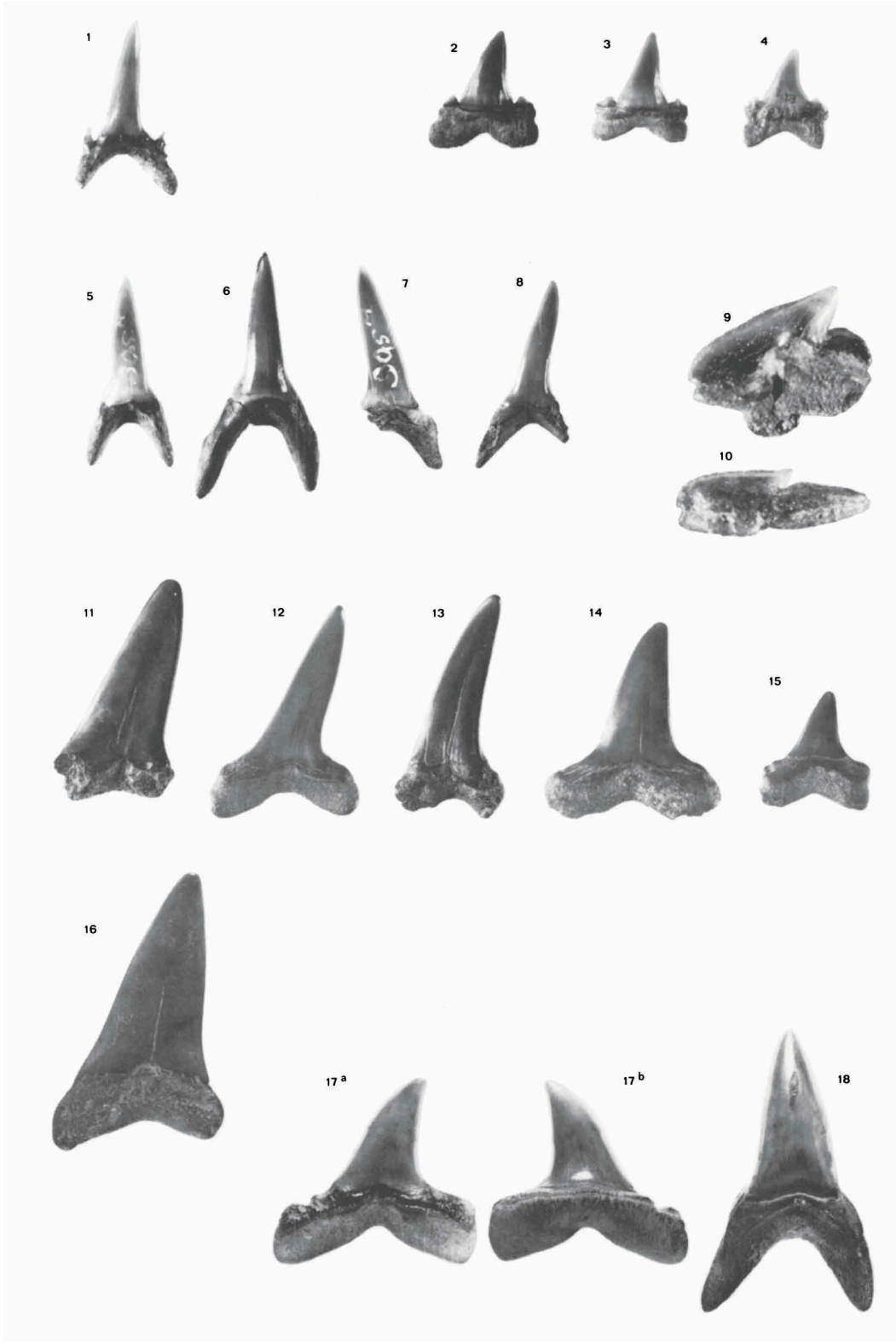


Plate 21

ELASMOBRANCHII FROM THE AALTEN MEMBER (MISTE BED)

All specimens (unless otherwise stated) from temporary exposure at Winterswijk-Miste near the stratotype of the Miste Bed.

Fig. 1. *Hexanchus primigenius* (Agassiz, 1843). Left upper anterior tooth, RGM 175 458, 1 ×.

Fig. 2. *Hexanchus primigenius* (Agassiz, 1843). Right lower lateral tooth, RGM 155 481, 1 ×.

Fig. 3. *Hexanchus primigenius* (Agassiz, 1843). Right lower anterior tooth, RGM 155 481, 1 ×.

Fig. 4. *Odontaspis vorax* le Hon, 1871. Left upper lateral tooth, RGM 155 503, 1 ×.

Fig. 5. *Odontaspis vorax* le Hon, 1871. Right lower anterior tooth, RGM 155 506, 1 ×.

Fig. 6. *Odontaspis molassica* Joleaud, 1912. Right upper lateral tooth, RGM 175 793, 1½ ×. Temporary excavation 34G.1-1 north-east of the Ticheloven farm at Eibergen-Loo.

Fig. 7. *Odontaspis molassica* Joleaud, 1912. Right upper lateral tooth, RGM 175 449, 1½ ×.

Fig. 8. *Odontaspis molassica* Joleaud, 1912. Left lower anterior tooth, RGM 175 448, 1½ ×.

Fig. 9. *Odontaspis molassica* Joleaud, 1912. Left lower lateral tooth, RGM 175 792, 1½ ×.

Fig. 10. *Lamna cattica* (Philippi, 1846). Right upper anterior tooth ?, RGM 175 794, 1½ ×.

Fig. 11. *Lamna cattica* (Philippi, 1846). Right upper lateral tooth, RGM 175 450, 1½ ×.

Fig. 12. *Lamna cattica* (Philippi, 1846). Right upper lateral tooth, RGM 175 795, 1½ ×.

Fig. 13. *Lamna cattica* (Philippi, 1846). Right lower lateral tooth, RGM 175 796, 1½ ×.

Fig. 14. *Isurus hastalis* (Agassiz, 1843), narrow type. Left upper posterior tooth, RGM 155 442, 1 ×.

Fig. 15. *Isurus hastalis* (Agassiz, 1843), narrow type. Left upper lateral tooth, RGM 175 788, 1 ×.

Fig. 16. *Isurus hastalis* (Agassiz, 1843), narrow type. Left upper lateral tooth, RGM 155 443, 1 ×.

Fig. 17. *Isurus hastalis* (Agassiz, 1843), narrow type. Left upper lateral tooth, RGM 155 446, 1 ×.

Fig. 18. *Isurus hastalis* (Agassiz, 1843), narrow type. Second left upper anterior tooth, RGM 155 447, 1 ×.

Fig. 19. *Isurus hastalis* (Agassiz, 1843), narrow type. First left upper anterior tooth, RGM 155 448, 1 ×.

Fig. 20. *Isurus hastalis* (Agassiz, 1843), narrow type. Right lower anterior tooth, RGM 155 459, 1 ×.

Fig. 21. *Isurus hastalis* (Agassiz, 1843), narrow type. Left lower anterior tooth, RGM 175 789, 1 ×.

Fig. 22. *Isurus hastalis* (Agassiz, 1843), narrow type. Left lower lateral tooth, RGM 175 790, 1 ×.

Fig. 23. *Isurus hastalis* (Agassiz, 1843), narrow type. Left lower lateral tooth, RGM 175 791, 1 ×.

Fig. 24. *Isurus hastalis* (Agassiz, 1843), narrow type. Left lower lateral tooth, RGM 175 791, 1 ×.

Fig. 25. *Isurus benedeni* Menesini, 1969. Right upper lateral tooth, RGM 175 457, 1 ×. 25a: external view, 25b: internal view.

Fig. 26. *Galeocerdo aduncus* Agassiz, 1843. Lateral tooth, RGM 175 450, 1 ×.

Fig. 27. *Galeocerdo aduncus* Agassiz, 1843. Posterior lateral tooth, RGM 175 451, 1 ×.

Plate 21

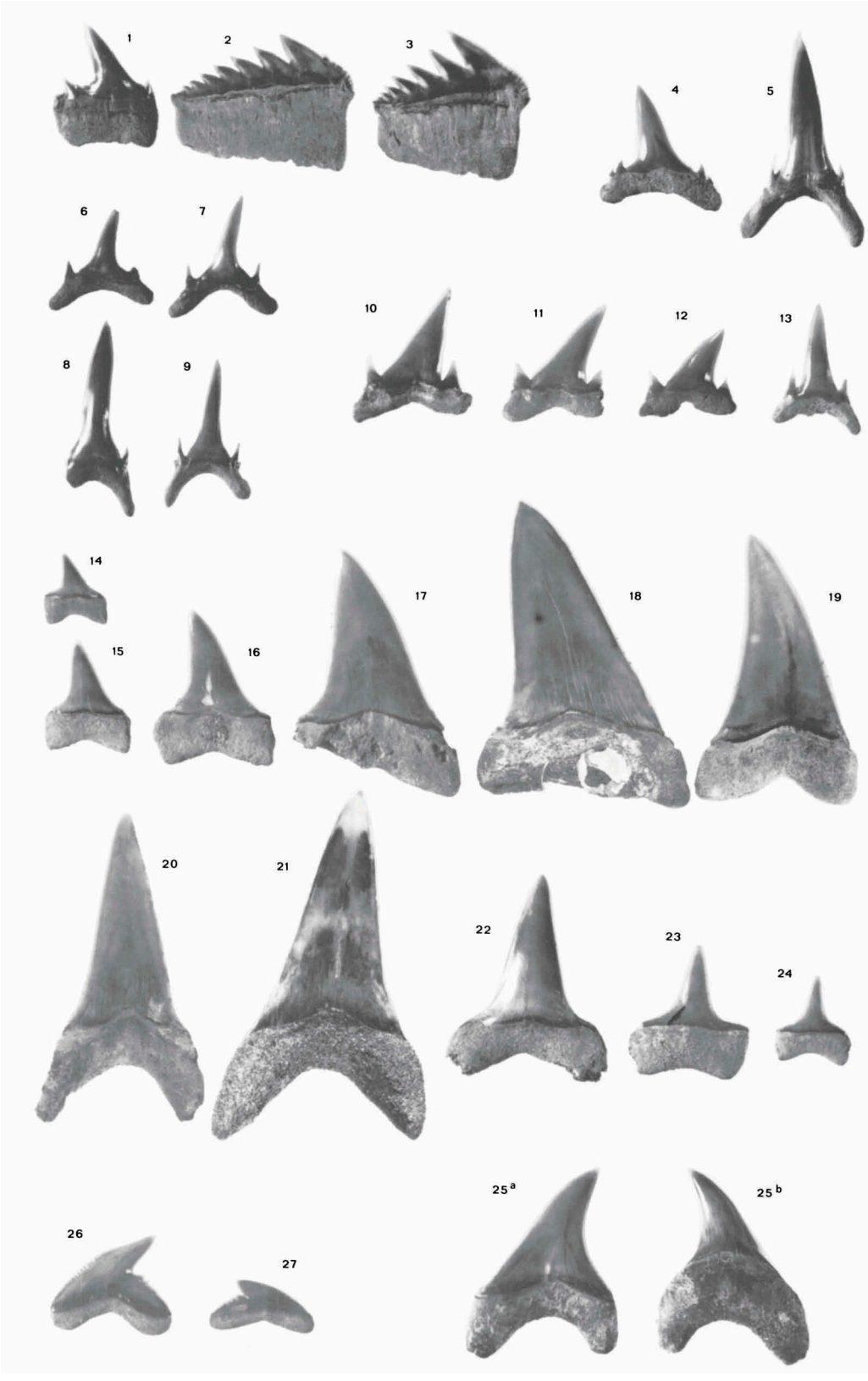


Plate 22

ELASMOBRANCHII FROM THE AALTEN MEMBER (STEMERDINK BED)

Fig. 1. *Dasyatis targionii* (Lawley, 1876). Dermal tubercle, RGM 86 869, 1 ×. Clay-pit of the F. O. W. brick-works at Eibergen (Zwilbroek), 34G.3-1, Stemerdink Bed or lower part of the Eibergen Member. 1a: external view, 1b: internal view, 1c: lateral view.

Fig. 2. *Procarcharodon megalodon* (Agassiz, 1843). Internal view of right lower lateral tooth, RGM 14 323 (Staring collection nr. 4737), ½ ×. Probably from "De Giffel" at Winterswijk (Meddo).

Fig. 3. *Sphyrna* aff. *laevissima* (Cope, 1867). Right upper lateral tooth. RGM 175 797, 1½ ×. Temporary exposure near the Königsmühle at Dingden, western Germany, Dingdener Glimmerton (= Stemerdink Bed).

ELASMOBRANCHII FROM THE EIBERGEN MEMBER

Figs. 4-9 from the clay-pit of the F. O. W. brick-works at Eibergen (Zwilbroek), 34G.3-13.

Fig. 4. *Isurus hastalis* (Agassiz, 1843). Second right upper anterior tooth, RGM 175 799, 1 ×.

Fig. 5. *Isurus hastalis* (Agassiz, 1843). Right upper lateral tooth, RGM 175 035, 1 ×.

Fig. 6. *Isurus hastalis* (Agassiz, 1843). Right upper lateral tooth, RGM 175 037, 1 ×.

Fig. 7. *Isurus hastalis* (Agassiz, 1843). Left upper lateral tooth, RGM 156 387, 1 ×.

Fig. 8. *Isurus hastalis* (Agassiz, 1843). Right lower anterior tooth, RGM 156 548, 1 ×.

Fig. 9. *Isurus hastalis* (Agassiz, 1843). Left lower lateral tooth, RGM 175 063, 1 ×.

Plate 22

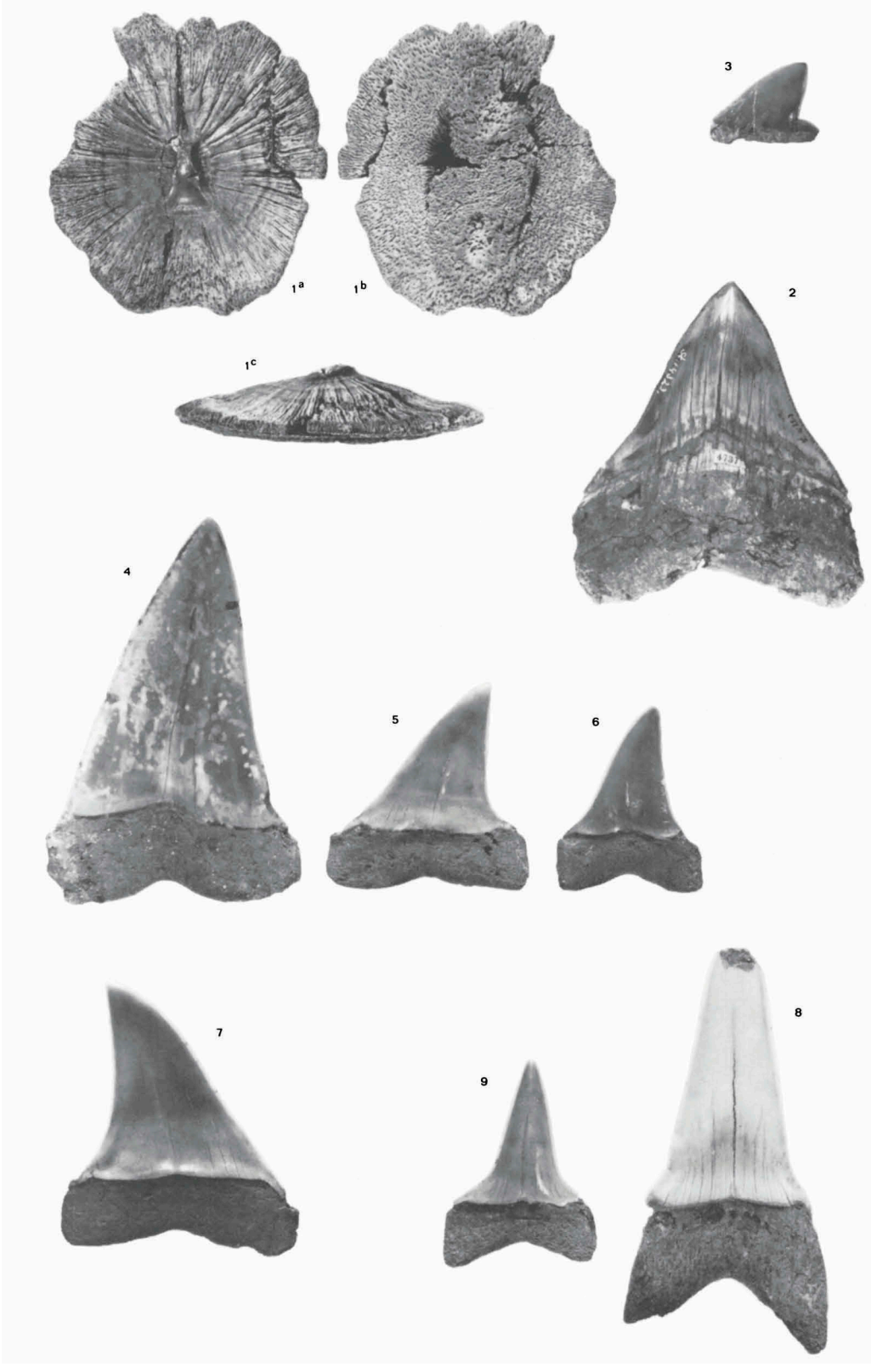


Plate 23

ELASMOBRANCHII FROM THE ZENDEREN MEMBER

Figs. 1-9 from the Twente-kanaal near Delden.

Fig. 1. *Isurus hastalis* (Agassiz, 1843), less narrow type. Left upper lateral tooth, RGM 155 323, 1 ×.

Fig. 2. *Isurus hastalis* (Agassiz, 1843), less narrow type. First left upper lateral tooth, RGM 155 307, 1 ×.

Fig. 3. *Isurus hastalis* (Agassiz, 1843), less narrow type. Right upper lateral tooth, RGM 155 332, 1 ×.

Fig. 4. *Isurus hastalis* (Agassiz, 1843), less narrow type. Right upper lateral tooth, RGM 155 329, 1 ×.

Fig. 5. *Isurus escheri* (Agassiz, 1844). Left upper lateral tooth, RGM 155 377, 1 ×.

Fig. 6. *Isurus escheri* (Agassiz, 1844). First left upper anterior tooth, RGM 155 338, 1 ×.

Fig. 7. *Isurus escheri* (Agassiz, 1844). Right upper lateral tooth, RGM 155 335, 1 ×.

Fig. 8. *Isurus escheri* (Agassiz, 1844). Left lower anterior tooth, RGM 155 350, 1 ×.

Fig. 9. *Isurus escheri* (Agassiz, 1844). Right lower lateral tooth, RGM 155 351, 1 ×.

ELASMOBRANCHII FROM THE DELDEN MEMBER

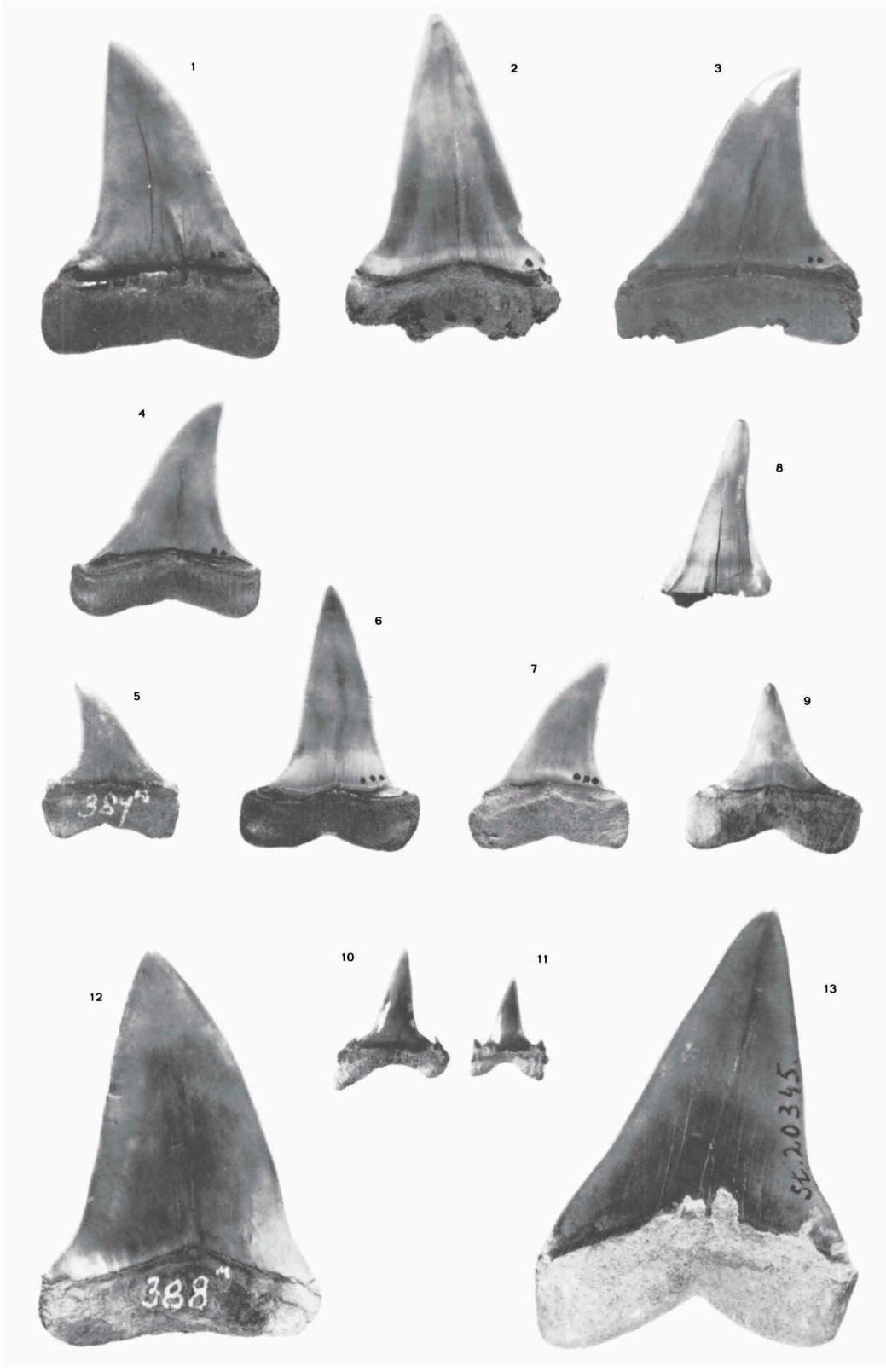
Fig. 10. *Lamna* sp. van den Bosch, 1969. Right upper lateral tooth, 1½ ×. Collection M. C. Cadée. Aalten, exposure in the wood " 't Klooster".

Fig. 11. *Lamna* sp. van den Bosch, 1969. Left lower lateral tooth, 1½ ×. Collection M. C. Cadée. Locality as above.

Fig. 12. *Isurus hastalis* (Agassiz, 1843), less narrow type. Left upper anterior tooth, RGM 155 402, 1 ×. Twente-kanaal near Delden.

Fig. 13. *Isurus hastalis* (Agassiz, 1843), less narrow type. Right upper anterior tooth. RGM 155 386, 1 ×. Twente-kanaal near Delden.

Plate 23



Enclosure I. v. d. Bosch et al., Tertiary stratigraphy of the Winterswijk area, Scripta Geol. 29 (1975)

Lithological section of the most important borings.

Fig. 1
41F.3-65 Willinkbeek

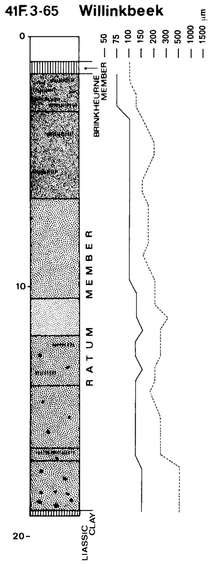


Fig. 2
41E.4-446 Wassink

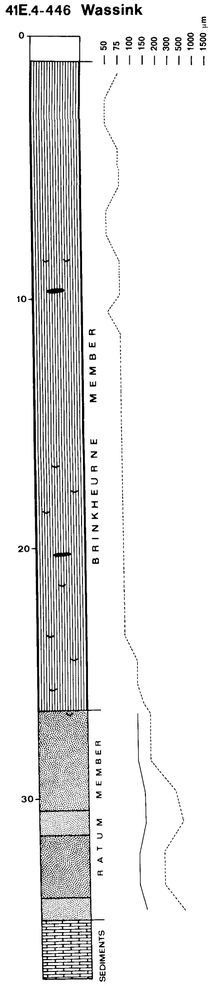


Fig. 3
41E.4-517 Stemerdink

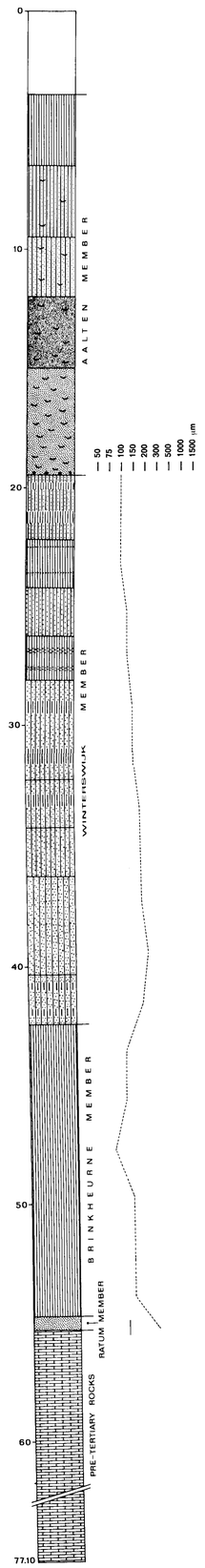


Fig. 4
41E.3-143 De Vlijt

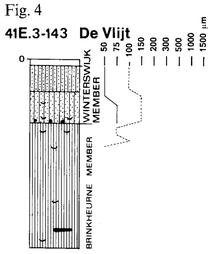


Fig. 5
41D.2-7+8 Aalten

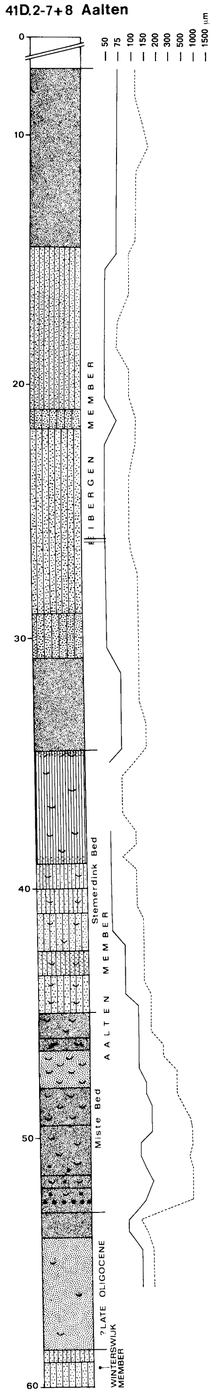


Fig. 6
41E.3-67 Borninkhof

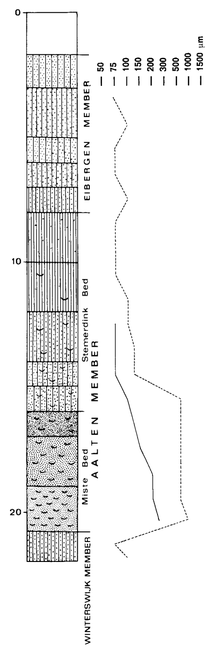


Fig. 7
41E.3-75 Miste

Fig. 8
41E.4-566 Stemerdink

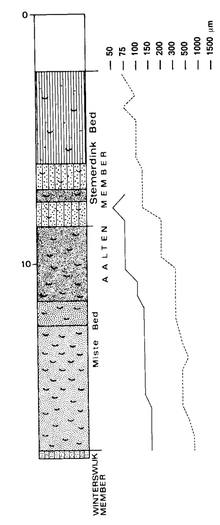


Fig. 9
34G.1-24 Ticheloven

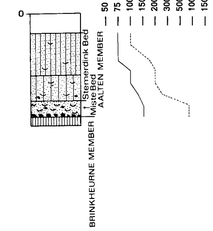


Fig. 10
34G.3-13 F.O.W.

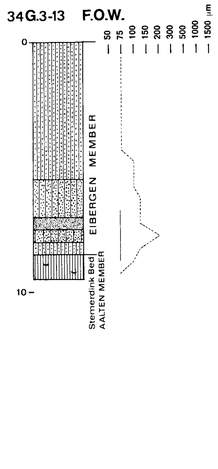


Fig. 11
28G.172 Zenderen

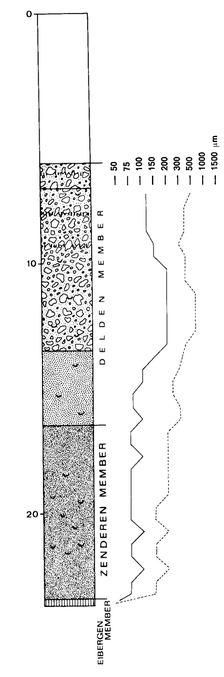


Fig. 12
34B.3-1 Gelselaarsbrug

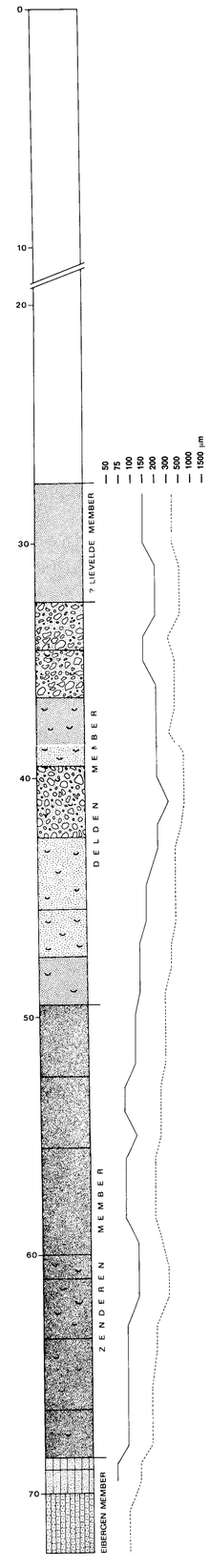


Fig. 13
28G.3-1 Twickel

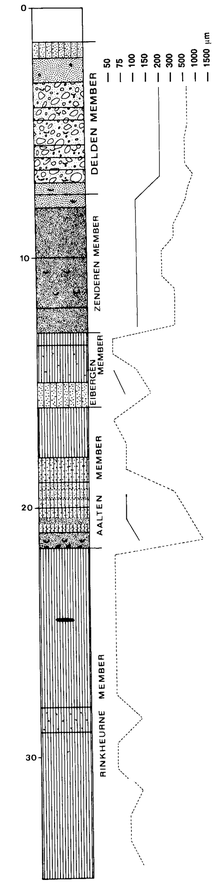


Fig. 14
34D.4-4 Groenlo

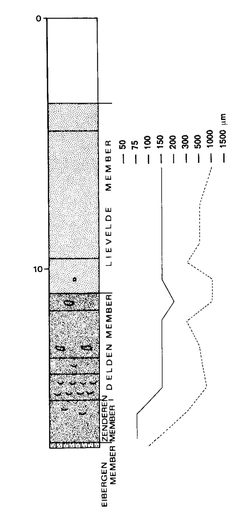
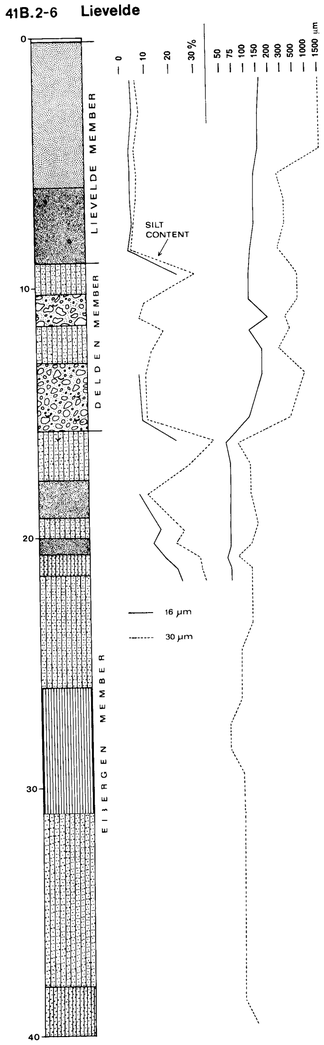


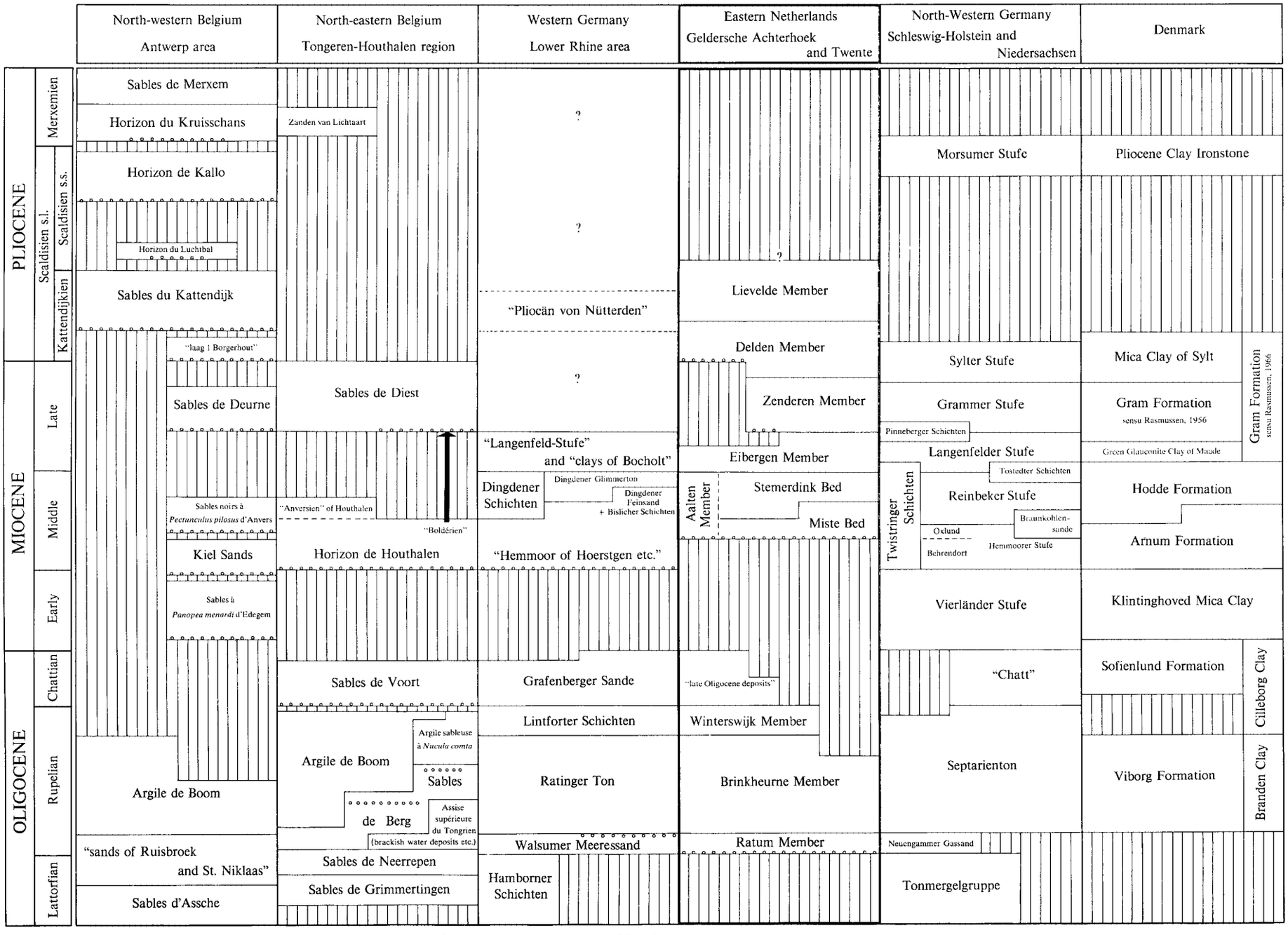
Fig. 15
41B.2-6 Lievelde



LEGEND:

- HEAVY CLAY
- LITTLE SANDY CLAY
- RATHER SANDY CLAY
- VERY SANDY CLAY
- EXTREMELY SANDY CLAY
- FINE – RATHER FINE SAND VERY – EXTREMELY SILTY
- FINE – RATHER FINE SAND RATHER SILTY
- FINE – RATHER FINE SAND, LITTLE SILTY
- RATHER FINE – RATHER COARSE SAND
- RATHER FINE – RATHER COARSE SAND WITH PHOSPHORITE CONCRETIONS IN SITU
- CONSOLIDATED ROCKS
- QUATERNARY DEPOSITS
- REWORKED PHOSPHORITE CONCRETIONS
- FINE GRAVEL
- CALCAREOUS SEPTARIA
- SHELLS
- ESTIMATED AVERAGE GRAIN SIZE OF THE SAND FRACTION
- ESTIMATED MAXIMUM GRAIN SIZE OF THE SAND FRACTION

Enclosure 2. v. d. Bosch et al., Tertiary stratigraphy of the Winterswijk area, Scripta Geol. 29 (1975)



Correlation of the lithological units described in this paper with other deposits in the North Sea basin.