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THE VIJLEN CHALK (EARLY EARLY TO EARLY LATE MAASTRICHTIAN) IN ITS TYPE AREA AROUND VIJLEN AND MAMELIS (SOUTHERN LIMBURG, THE NETHERLANDS)[1]

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(20 figures)

ABSTRACT.- The Vijlen Chalk in its type area around Vijlen (Southern Limburg, The Netherlands) is characterized by major changes in the lateral and vertical composition of its bioclast and microfossil contents. Echinoderm clasts predominate in the south of this area where sedimentation took place in a low-energy environment below storm wave base. The predominance of mollusc clasts and the repeated occurrence of glauconite-rich, pebble-bearing beds with abundant belemnite clasts in the north presumably reflects high-energy conditions in a shallow subtidal (above storm wave base) to occasionally intertidal environment. The rhythmic succession of belemnite-poor and belemnite-rich intervals in the Mamelis reference sections presumably reflects rhythmic variations in relative sea level. These variations may have been responsible for the regional appearance or disappearance of various microfossil taxa or for (sometimes repeated) changes in their relative frequency or abundance.

KEY-WORDS.- Vijlen Chalk, Maastrichtian, Southern Limburg, The Netherlands, Bioclast assemblages, Depositional environment.

RESUME.- La Craie de Vijlen (Maastrichtien très ancien à début du récent) dans sa région-type autour de Vijlen et Mamelis (Sud-Limbourg, Pays-Bas). La Craie de Vijlen dans sa région-type autour de Vijlen (Sud-Limbourg, Pays-Bas) est caractérisée par des changements majeurs dans la composition latérale et verticale de son contenu en bioclastes et en microfossiles. Les clastes d'Echinodermes prédominent dans le Sud de cette région où la sédimentation prend place dans un environnement de bas niveau énergétique, en dessous de la base des vagues de tempêtes. La prédominance des clastes de mollusques et l'apparition répétée de lits contenant des galets, riches en glauconites avec de nombreux clastes de Belemnites dans le Nord reflètent probablement des conditions de haut niveau énergétique, dans un environnement "subtidal" peu profond (au dessus de la base des vagues de tempêtes) à, occasionnellement "intertidal". La succession rythmique d'intervalles pauvres et riches en Belemnites dans les coupes de référence de Mamelis reflète sans doute des variations rythmiques du niveau relatif de la mer. Ces variations ont pu être responsables de l'apparition ou de la disparition régionale de divers taxa de microfossiles ainsi que des changements (parfois répétés) dans leurs fréquences relatives ou leur abondance.

MOTS-CLES.- Craie de Vijlen, Maastrichtien, Sud-Limbourg, Pays-Bas, associations de bioclastes, environnement sédimentaire.

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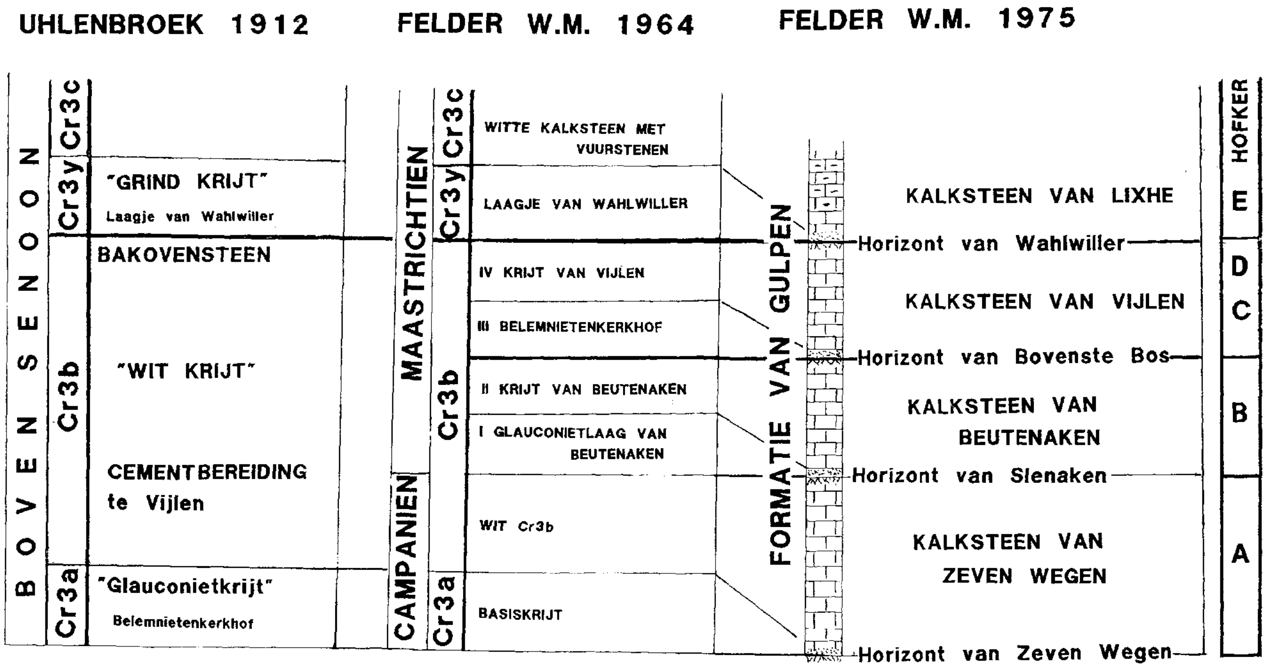


Fig.1.- Subdivision of lower portion of the «Gulpensch Krijt» (Uhlenbroek, 1912) or Gulpen Formation (W.M. Felder, 1975) after, Uhlenbroek (1912), W.M. Felder (1964) and W.M. Felder (1975).

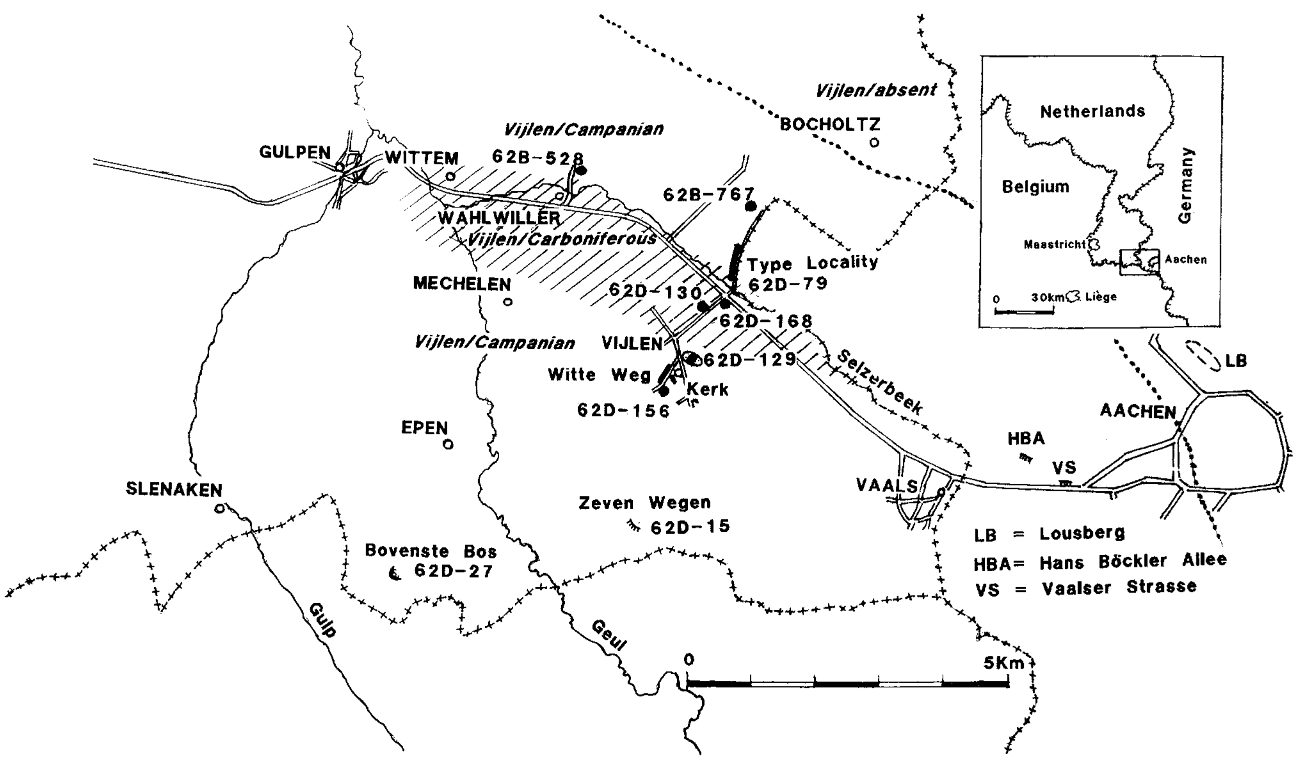


Fig. 2.- Location map for the type area of the Vijlen Chalk. Diagonal hatching indicates area in which Vijlen Chalk rests directly on top of Carboniferous basement. Further to the north and south, the Vijlen Chalk rests on Campanian deposits (Vaals greensand, Zeven Wegen Chalk or Beutenaken Chalk). The Vijlen Chalk is absent in the northeastern part of the area, where it may have been deposited only locally in the form of a beach conglomerate.

1.- INTRODUCTION

The term "Vijlen Chalk" was introduced by W.M. Felder (1975) as part of a modern lithostratigraphic subdivision of the Late Cretaceous strata in Southern Limburg (the Netherlands) and environs. This subdivision was meant to replace the partly ambiguous terminology of Uhlenbroek (1912) that had been used for more than 50 years. The succinct description of the Cretaceous in Southern Limburg by Uhlenbroek (1912) had been made as an explanation of the geological map of that area. He assigned the lower half of the "Gulpensch Krijt" to the "Cr3b" (fig.1) and stated that this lithological unit of white chalk was delimited by a glauconite-rich chalk at its base (the "Cr3a"; described as a belemnite graveyard by Jongmans, 1945) and a conglomerate at its top (the "Cr3y").

In 1952, however, a new belemnite graveyard was discovered about halfway the "Cr3b" in outcrops (for example, 62D-15b; fig.2) along a road through the Vijlenerbosch, to the south of Vijlen (W.M. Felder, 1957, 1960). This in turn led to doubts about the validity of Uhlenbroek's subdivision and therefore triggered new investigations.

Analysis of foram (Hofker, 1958) and belemnite assemblages (Schmid, 1959) showed that this new belemnite graveyard subdivided Uhlenbroek's "Cr3b" in such a way, that the strata below this bed could be assigned to the Campanian, and those above it to the Maastrichtian.

Three boreholes were drilled at Wahlwiller (62B-528), Vijlen Jongensschool (62D-129) and Mamelisserberg (62D-130) in order to obtain a better understanding of the stratigraphic succession within Uhlenbroek's "Cr3b" (fig.2). The Wahlwiller borehole yielded the evidence that the newly discovered belemnite graveyard of the Vijlenerbosch was distinctly older than Uhlenbroek's "Cr3y" ("Laagje van Wahlwiller" or "Wahlwiller bed"). The Vijlen Jongensschool and Mamelisserberg boreholes proved that the base of the "Cr3b" occurred at a greater depth than had been assumed previously. Meanwhile, Hofker (1961, 1966) recognized four foram zones in the "Cr3b": A, B, C and D, whereas W.M. Felder (1964) proposed a subdivision of the "Cr3b" into five lithological units (fig.1).

These and other investigations yielded ample proof that Uhlenbroek's simple subdivision of the Cretaceous had become obsolete. Repeated thickness changes and complete wedging of layers appeared to be common phenomena. This also led to the conclusion that the stratigraphic and tectonic interpretation of Uhlenbroek's (1912) geological map had to be revised in accordance with the newly obtained data. Therefore, Hofker (1966) completely abandoned Uhlenbroek's terminology and proposed a new subdivision of the Late Cretaceous and calcareous Early Tertiary strata consisting of seventeen foram zones (fig.3).

A new lithostratigraphic subdivision of the Cretaceous in Southern Limburg (fig.3) was published by W.M. Felder (1975). In that paper he distinguished three instead of five (cf. W.M. Felder, 1964) lithological units in the former "Cr3b" (fig.1). The boundaries between these units were named "horizons": mappable lithostratigraphic interfaces without any thickness which can be recognized because of obvious lithostratigraphic and/or biostratigraphic changes at these levels (cf. Albers *et al.*, 1978). Unfortunately, W.M. Felder (1975) only mentioned the designation of stratotype sections for the lithological units. It should be kept in mind, however, that he also established stratotypes for the horizons separating these units (cf. Albers *et al.*, 1978).

It is emphasized that the lithofacies of these units is not necessarily uniform (Albers, 1976; Albers *et al.*, 1978). It can vary to a certain degree since the units are characterized by the horizons at their base and top, rather than by their lithology. In practice, the horizons are identified by changes in lithology and fossil contents (notably foram assemblages and belemnites insofar as the members of the Gulpen Formation are concerned).

W.M. Felder (1975) introduced the term "Kalksteen van Vijlen" (Vijlen Chalk) for all the strata in between the Bovenste Bos Horizon at the base and the Wahlwiller Horizon at the top. He designated the sunken road between Mamelis and Bocholtzerheide (here further referred to as the Mamelis sunken road) at the Dutch-German border in the municipality of Vaals as stratotype (locality 62D-79).

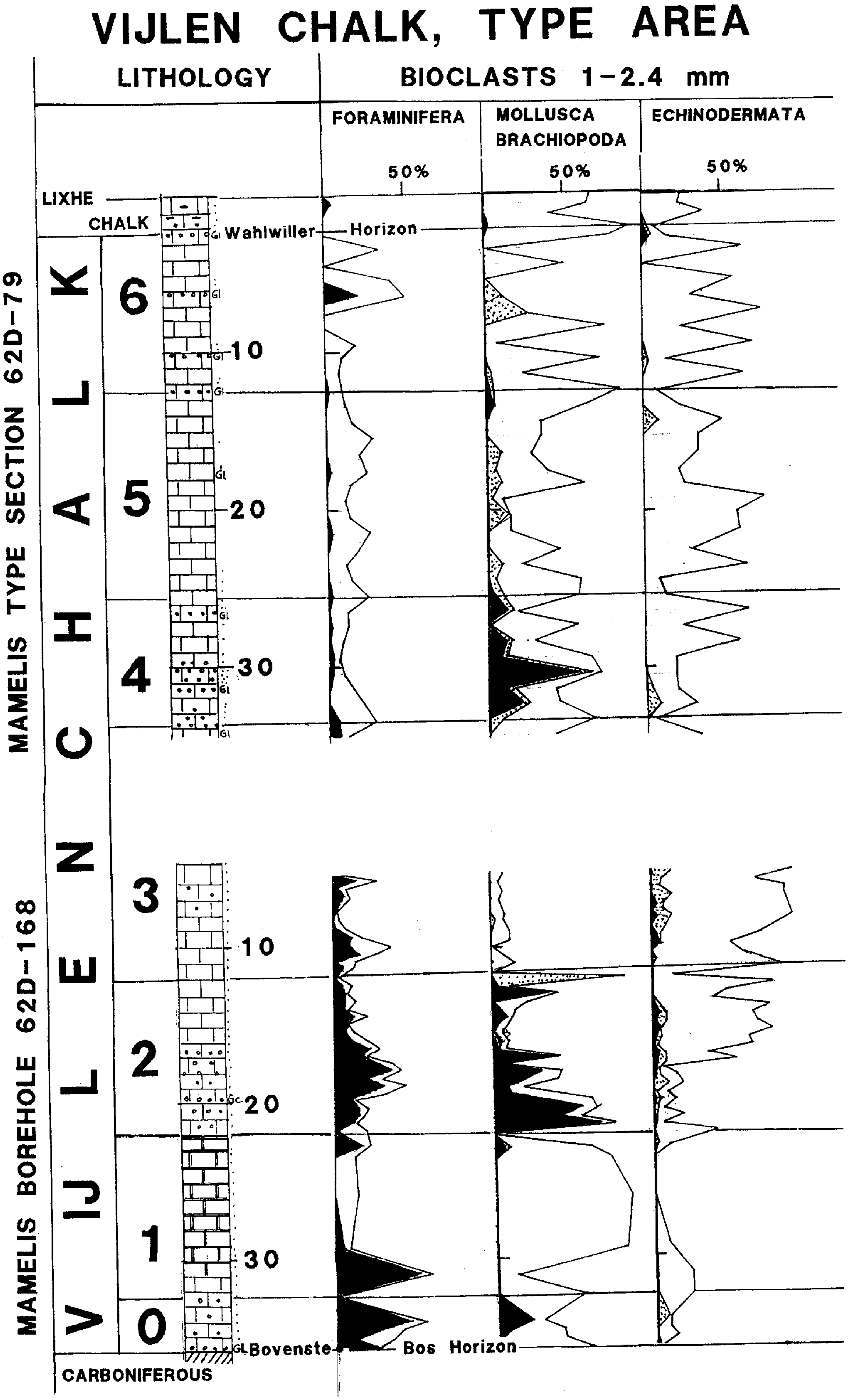
Albers & Felder (1979) described the Vijlen Chalk as a yellow-grey, glauconite-bearing fine-grained chalk with at its base and locally also higher up in the succession glauconite-rich intercalations. The Vijlen Chalk is characterized by foram assemblages of Hofker's (1966) foram zones C and D, and perhaps (locally?) the basal portion of zone E (Albers & Felder, 1979).

Detailed investigations on belemnite assemblages by Keutgen & Van der Tuuk (1990) have recently established the biostratigraphic age of the Vijlen Chalk. The glauconite-rich basal strata immediately above the Bovenste Bos Horizon have yielded belemnites of the Early Early (*obtusa* Zone) and basal Late Early (lower *sumensis* Zone) Maastrichtian in the stratotype section of the Bovenste Bos Horizon (62D-27). The stratotype section of Mamelis sunken road (62D-79) yielded belemnites of the upper Late Early (*cimbrica* Zone) and basal Early Late (basal *junior* Zone) Maastrichtian.

			Oost van de Maas	West van de Maas		Uhlenbroek (1912)	Hofker (1966)
Formatie v. Houthem		Kalksteen van Geleen	Vc		Horz. van Lutterade Horz. van Geleen	Md	R
		Kalksteen van Bunde	Vb		Horz. van Bunde		Q
		Kalksteen van Geulhem	Va	XIw	Horz. van Vroenhoven		P
Formatie v. Maastricht	Boven	Kalksteen van Meerssen	IVf	Xw	Horz. van Caster		N M L
		Kalksteen van Nekum	IVe	IXw	Horz. van Kanne Horz. van Laumont	Mc	K
	Onder	Kalksteen van Emael	IVd	VIIIw	Horz. van Lava Horz. van Romontbos	Mb	I
		Kalksteen van Schiepersberg	IVc		Horz. van Schiepersberg		H
		Kalksteen van Gronsveld	IVb		Horz. van St. Pieter		G
		Kalksteen van Valkenburg	IVa		Horz. van Lichtenberg		
Formatie v. Gulpen	Boven	Kalksteen van Lanaye	IIIg	VIIw	Horz. van Nivelle	Cr4	F
		Kalksteen van Lixhe 3	IIIf	VIw	Horz. van Boirs		E
		Kalksteen van Lixhe 2	IIIe	Vw	Horz. van Halembaye 2 Horz. van Halembaye 1	Cr3c	
		Kalksteen van Lixhe 1	IIId	IVw	Horz. van Wahlwiller	Cr3y	
	Onder	Kalksteen van Vylen	IIIc	IIIw	Horz. van Bovenste Bos	Cr3b	D C
		Kalksteen van Beutenaken	IIIb		Horz. van Slenaken		B
		Kalksteen van Zeven Wegen	IIIa	IIw	Horz. van Zeven Wegen	Cr3a	A
Formatie v. Vaals	Boven	Zand van Terstraeten	IIf	Iw	Horz. van Terstraten	Cr2	A'
		Zand van Beusdal	IIe		Horz. van Beusdal		
	Onder	Zand van Vaalsbroek	IId		Horz. van Vaalsbroek Horz. van Overgeul		
		Zand van Grenspaal 7	IIc		Horz. van Grenspaal 7		
		Zand van Cottessen	IIb		Horz. van Cottessen		
		Zand van Raren	IIa		Horz. van Raren		
Formatie v. Aken		Zand van Aken	Ib		Horz. van Schampelheide	Cr1	
		Klei van Hergenrath	Ia		Horz. van Hergenrath		

Fig. 3.- W.M. Felder's (1975) lithostratigraphic subdivision of the Late Cretaceous and Dano-Montian strata in Southern Limburg compared with Uhlenbroek's (1912) lithostratigraphic subdivision and Hofker's (1966) foram zonation (from W.M. Felder, 1975; reproduced with author's permission)

Fig. 4.- Vijlen Chalk in the Mamelis reference sections 62D-168 (Mamelis borehole) and 62D-79 (Mamelis sunken road; designated stratotype by W.M. Felder, 1975) with percentage distribution of major bioclast groups. Percentage distribution of agglutinated forams is shown by black signature in column of Foraminifera. Percentage distribution of belemnite clasts is shown by black and that of prismatic bivalve remains by stippled signature in column of Mollusca/Brachiopoda. Percentage distribution of crinoid clasts is shown by black and that of ophiuroid clasts by stippled signature in column of Echinodermata.


VIJLEN CHALK, TYPE AREA
LITHOLOGY
BIOCLASTS 1-2.4 mm
FORAMINIFERA
MOLLUSCA BRACHIOPODA
ECHINODERMATA
50%
50%
50%
LIXHE CHALK
Wahlwiller Horizon
MAMELIS TYPE SECTION 62D-79
MAMELIS BOREHOLE 62D-168
VIJLEN CHALK
6
5
4
3
2
1
0
10
20
30
10
20
30
Gl
Bovenste Bos Horizon
CARBONIFEROUS

The present paper summarizes the results of recent ecostratigraphic studies on bioclast and microfossil (forams and ostracodes) assemblages. These have been carried out in order to obtain a better insight into the lateral and vertical variations in lithofacies and thickness of the Vijlen Chalk in its type area around Vijlen. Special attention is paid to the Mamelis sections (Mamelis sunken road, 62D-79, and Mamelis borehole, 62D-168) because they complement each other. Together they form a more or less complete reference section for the Vijlen Chalk.

2.- BIOCLAST ASSEMBLAGES

Bioclast assemblages frequently yield important data on the depositional environment, even when they have been reworked to a certain extent. Moreover, changes in the relative abundance (expressed in percentages) of certain bioclast groups can serve as a means for correlation in a similar way as, e.g., borehole logs (cf. P.J. Felder *et al.*, 1985).

For practical reasons the study of bioclast assemblages is limited to the 1.0-2.4 mm sieve fraction. P.J. Felder (1981) published a detailed description of the various bioclast groups which can be distinguished in that sieve fraction. Only a few of these seem to be of importance for the present study.

Large (larger than 1 mm) forams and notably agglutinated forams (usually belonging to the genus *Orbignyna*) are common and sometimes even abundant. The bulk of the bioclasts is formed by mollusc and echinoderm fragments. Belemnites and prismatic bivalves are distinguished as special groups among the mollusc clasts, and ophiuroids and crinoids among the echinoderm clasts. They are discussed below.

Large sponge spicules and bryozoan clasts are usually rare. The same holds for arthropod fragments, serpulid clasts and fish remains. These groups are not further considered here.

2.1.- **MAMELIS** (62D-79 and 62D-168)

As already stated above, sections 62D-79 (Mamelis sunken road) and 62D-168 (Mamelis borehole; 5643 in Kimpe *et al.*, 1978, Enclosure III) are complementary without an appreciable gap or overlap (fig.4). Seven intervals (0-6) are distinguished.

Interval 0 (32.5-35.7 m in section 62D-168) is characterized by several pebble horizons in a glauconite-rich chalk, and by relatively large numbers of agglutinated forams and molluscs (among which a distinct peak of belemnite clasts at 34.0 m). Moreover a minor ophiuroid peak occurs at 34.0 m. The pebbles in these and other intervals in the Vijlen Chalk consist of poorly rounded to well-rounded, sometimes fossiliferous and glauconite-bearing, chalkstone, as well as quartzite and occasionally phosphate pebbles. The chalkstone pebbles may be reworked fragments of calcrete formed on some nearby beach by cementation of superficial shell debris because of the evaporation of calcium carbonate-rich groundwater. The quartzite pebbles may have been derived from either the Aachen basal conglomerate or the Vaals basal conglomerate. The phosphate pebbles (and fragments of phosphatized macrofossils) may have been reworked from a possibly more or less synsedimentary intertidal or supratidal littoral deposit by heavy storms or spring-tides.

Interval 1 (22.0-32.5 m in section 62D-168) consists of a glauconite-bearing chalkstone in which mollusc clasts predominate except for a major peak of agglutinated forams (slightly over 50%) at its base and an echinoderm peak at its top. There is only one minor belemnite peak (less than 10%) near the top of this interval.

Interval 2 (12.0-22.0 m in section 62D-168) consists of a soft glauconite-rich chalk with several important pebble horizons in its lower half. The lower pebble-bearing half is characterized by high percentages of belemnites and agglutinated forams. Echinoderm clasts predominate in the upper half, in which belemnites and agglutinated forams are still important. Low percentages of crinoids and ophiuroids occur throughout this interval. A major peak (more than 80%) of prismatic bivalve fragments marks the top.

Interval 3 (above 12.0 m in section 62D-168 and below 34.0 m in section 62D-79) is characterized by the near absence of belemnite clasts in a soft, glauconite-bearing chalk with only a few pebbles about halfway this interval. Echinoderm clasts (among which small numbers of crinoids and ophiuroids) predominate. Agglutinated forams are common but not abundant.

Interval 4 (25.5-34.0m in section 62D-79) consists of a soft, glauconite-rich chalk with at least three important pebble-bearing beds. There is an alternating predominance of mollusc and echinoderm clasts. Distinct belemnite peaks and small numbers of prismatic bivalve remains occur throughout the interval. Large forams are common, but agglutinated forams occur in very small numbers. A low peak of ophiuroid clasts marks the base of this interval.

Interval 5 (13.5-25.5 m in section 62D-79) consists of a soft chalk with occasionally some glauconite. Mollusc and echinoderm clasts alternately predominate. Belemnite clasts are practically absent with the exception of a very small peak at the top of the interval, but low percentages of prismatic bivalve remains are common. Agglutinated forams are rare. There is a small peak of ophiuroid clasts near the top.

Interval 6 (2.0-13.5 m in section 62D-79) is distinguished by the presence of several glauconite-bearing pebble-horizons in an otherwise soft chalk. The uppermost of these pebble beds is called the Wahlwiller Conglomerate. The bioclast assemblages are quite similar to those of interval 5. Again, belemnite clasts are practically absent with the exception of a small peak at the very top of the interval. The alternating predominance of mollusc and echinoderm clasts can also be observed in this interval.

The following summary can be made. Large agglutinated forams are common in the lower half of the succession (intervals 0-3) and become rare in the upper half. There is a rough - but not perfect! - correlation between belemnite peaks and glauconite-rich pebble-bearing beds. Moreover, there are more or less regular intercalations of some 10 m of chalk without belemnite clasts in between the belemnite-bearing intervals (2 and 4) or individual belemnite peaks (at the top of intervals 0, 1, 5 and 6). Finally, the almost exclusive predominance of mollusc clasts in the lowermost portion of the succession (intervals 0, 1 and lower half of 2) is replaced by an alternating predominance of mollusc and echinoderm clasts in the higher portions of the succession.

2.2.- OTHER SECTIONS

It has proved impossible to recognize the complete Mamelis succession of bioclast assemblages elsewhere. The Vijlen Chalk in the Nyswiller borehole (62B-767) to the north is characterized by the practically uninterrupted predominance of mollusc clasts and an almost continuous succession of belemnite peaks. Echinoderm-dominated intervals are virtually absent. Moreover, large agglutinated forams are relatively rare or absent.

The Vijlen Chalk in the sections to the south is characterized by the practical absence of belemnite clasts except for a distinct belemnite graveyard at or immediately above its base, for example in the sections 62D-27 (Bovenste Bos), 62D-15b (Zeven Wegen in the Vijlenerbosch) or 62D-156 (Panhuis Vijlen). Practically all the bioclast assemblages above that belemnite graveyard show a predominance of echinoderm clasts (mainly fragments of irregular echinoids), for example in the sections Witte Weg/Kerk Vijlen, 62D-129 (Jongensschool Vijlen) or 62D-130 (Mamelisserberg).

3.- MICROFOSSIL ASSEMBLAGES

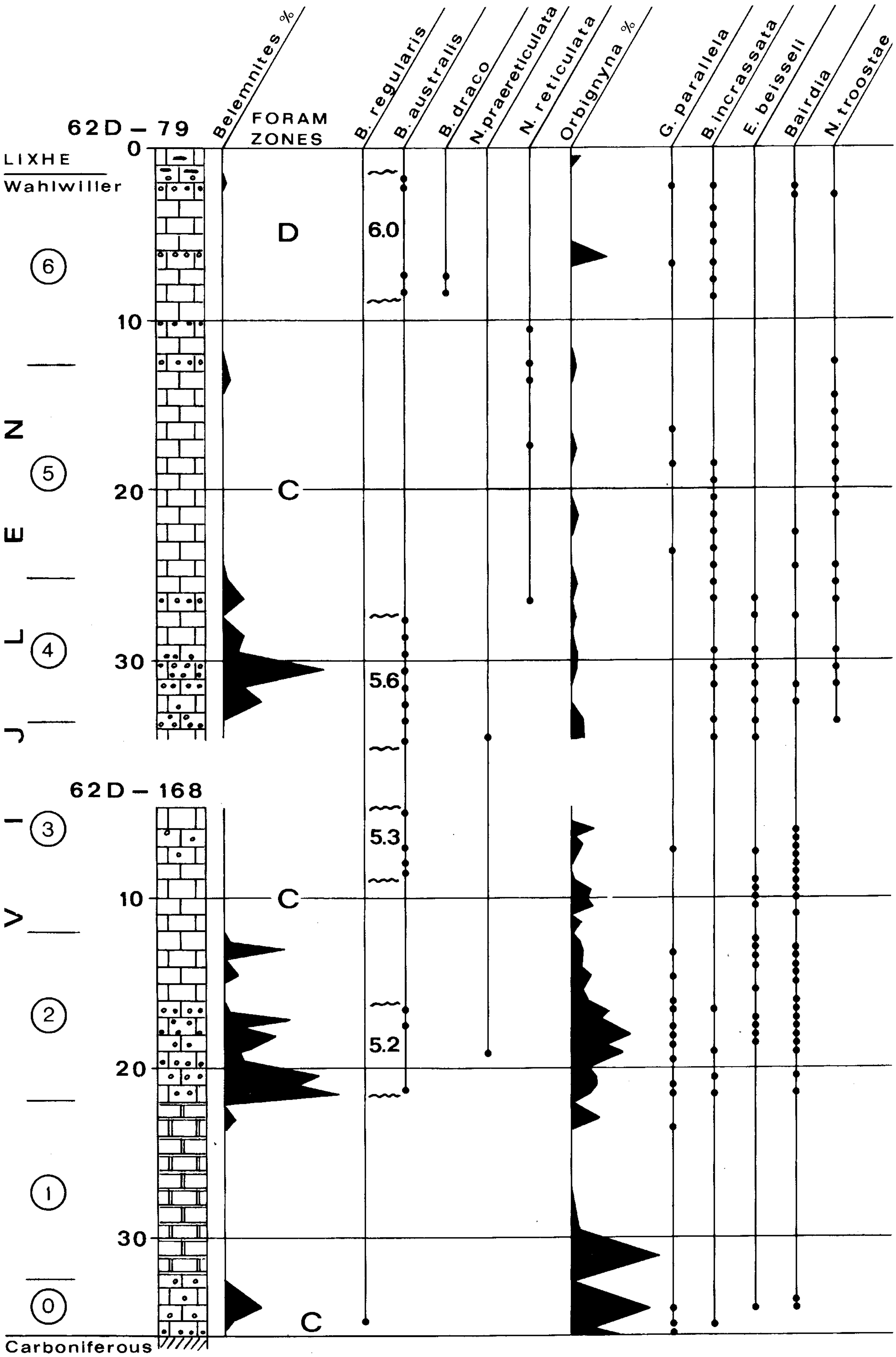
Two groups of microfossils from the 0.125-1.0 mm sieve fraction have been studied: forams and ostracodes. The identification of forams is based on papers by Kaever (1961), Hofker (1966) and Koch (1977). Deroo (1966), Herrig (1966), Clarke (1982, 1983) and Nuyts (1989) have been followed for the determination of the ostracodes. Only a few of the more than fifty foram species and about twenty ostracode taxa are considered here because of their possible value for the local ecostratigraphy (restricted range within the Vijlen Chalk, abrupt changes in relative frequency, clustered occurrences). Naturally, this selection is not exhaustive. The distribution of the selected taxa will be dealt with per section and compared with the relative frequency of belemnite clasts and agglutinated forams (almost exclusively belonging to the genus *Orbignyna*) in the 1.0-2.4 mm sieve fraction. Subsequently, a best-fit correlation between the various sections will be proposed.

The selected foram species are *Bolivinoides regularis*, *Bolivinoides australis*, *Bolivinoides draco* (subspecies *B. draco draco* and *B. draco miliaris*), *Neoflabellina permutata* (= *N. numismalis-efferata* in Hofker, 1966), *Neoflabellina praereticulata*, *Neoflabellina reticulata*, *Glandulina parallela*, *Bolivina incrassata*, *Eponides beisseli*, *Globorotalites micheliniana*, *Globorotalites hiltermanni* and *Nonionella troostae*. The ostracode taxa are the genus *Bairdia* and the species *Bythoceratina laevis*.

3.1.- MAMELIS (62D-79 and 62D-168)

As already stated sections 62D-79 (Mamelis sunken road) and 62D-168 (Mamelis borehole; 5643 in Kimpe *et al.*, 1978, Enclosure III) are complementary without an appreciable gap or overlap (fig.5). Eighty samples have been analyzed on their microfossil contents. The chalkstone of the 21.5-32.5 m interval in the Mamelis borehole (ecozone 1) has yielded an extremely poor microfauna due to post-sedimentary cementation. The assemblages from this interval are therefore not discussed here.

The presence of the belemnites *Belemnitella* ex gr. *junior* and *Belemnella cimbrica* in intervals 6 and 5 respectively (cf. Keutgen & Van der Tuuk, 1990) suggests that the boundary between the Late Early Maastrichtian and Early Late Maastrichtian occurs in one of these intervals or perhaps at the boundary between them.



62D – 79
62D – 168
LIXHE
Wahlwiller
Carboniferous
VIJLENE
FORAM ZONES
D
C
C
C
6.0
5.6
5.3
5.2
Belemnites %
B. regularis
B. australis
B. draco
N. praereticulata
N. reticulata
Orbignyna %
G. parallela
B. incrassata
E. beisseli
Bairdia
N. troostae

Bolivinoides regularis (fig.6: O,P; fig.11: K) is restricted to the basal portion of the Mamelis borehole (interval 0). Hofker (1966) did not record this species. It is largely confined to the Early Early Maastrichtian in NW Germany (Koch, 1977).

Bolivinoides australis (fig.6: S-W) occurs in three more or less distinct clusters: a lower one in interval 2, a second one comprising the upper portion of interval 3 and the larger portion of interval 4, and the upper one in interval 6. The mean number of pustules on the last chamber increases from 5.2 in the lower to 6.0 in the upper cluster. The gradual increase of the mean number of pustules on the last chamber of *Bolivinoides* is a well-known phenomenon in the Late Campanian to Early Late Maastrichtian of Southern Limburg and Belgium (Hofker, 1958, 1961). Values between 5.0 and 6.0 are common in Hofker's (1966) foram zone C, whereas a value of 6.0 is considered to point to foram zone D (cf. Meessen *in*: Robaszynski *et al.*, 1985).

The 7-9 m interval of the sunken road section (interval 6) has yielded *B. draco* (fig.6: Q, R; fig.11: A). The specimens are identical to those described by Hofker (1966) from foram zone D in the Jongensschool quarry at Vijlen (62D-129). They match the description of *B. draco draco* in Koch (1977). Since Hofker's (1966) foram zone D is defined by the presence of *B. draco*, we assign the top of the Vijlen Chalk in its type section (above 9 m) to foram zone D. It should be emphasized, however, that *B. draco* also occurs in the basal portion of foram zone E and in foram zone C (cf. Meessen *in*: Robaszynski *et al.*, 1985). The specimens from foram zone C presumably belong to a different subspecies: *B. draco miliaris*. *B. draco draco* ranges from the Late Early Maastrichtian to the Late Late Maastrichtian in NW Germany (Koch, 1977).

Specimens of *Neoflabellina* are rare. *N. praereticulata* (fig.6: L) only occurs in two samples: at 19 m in the borehole, and at the base of the sunken road section. Rare specimens of *N. reticulata* (fig.6: M, N) characterize the 9.5-26.5 m interval of the sunken road section. The gradual change from *N. praereticulata* into *N. reticulata* within foram zone C wasdocumented by Hofker (1958, 1961, 1966). It should be noted, however, that the ranges of these two species overlap in the Early Early Maastrichtian of NW Germany (Koch, 1977).

The distribution pattern of *G. parallela* (fig.6: C, D) shows an abrupt change in frequency at 22 m in the Mamelis borehole (top of interval 2). Below that level, the species commonly occurs in small numbers. Higher up, it becomes rather rare, both in the borehole and in the sunken road section.

Samples with *B. incrassata* (fig.6: E) form three distinct clusters in the borehole and sunken road sections. The lower and upper clusters closely match those of *B. australis*, this in contrast to the middle cluster. *B. incrassata* also occurs in a single sample near the base of the borehole section.

Most remarkable is the absence of *E. beisseli* (fig.6: F) in the intervals 5 and 6 above 22.5 m in the sunken road section. Below that level it is relatively common in both sections. This distribution pattern is in sharp contrast with that of the same species in the Halembaye section (south of Maastricht), where *E. beisseli* ranges from the upper half of the Vijlen Chalk into the lower half of the overlying Lixhe Chalk (Hofker, 1966). In the Vijlen area, however, this species is practically absent in the upper half of the Vijlen Chalk, for example at Vijlen, Wahlwiller and Gulperberg (cf. Hofker, 1966).

N. troostae (fig.6: G-K) is restricted to the sunken road section, where it is relatively common, except for the upper portion between 2.5 and 11.5 m. Hofker (1962, 1966) distinguished *N. troostae troostae* and *N. troostae ornamentata*. *N. troostae troostae* would be "more elongate and more compressed" (Hofker, 1962, p.36). The material studied by us, however, suggests that *N. troostae ornamentata* is but an extreme variant of *N. troostae*.

A most peculiar distribution pattern is that of *Bairdia* (fig.6: Z). This ostracode genus ranges from the Palaeozoic into Recent, and is one of the most common taxa in the Late Cretaceous of Southern Limburg. At Mamelis, however, we can recognize an interval in which the genus is very frequent (Mamelis borehole), an interval in which it occurs sporadically (lower third of sunken road section), and an interval in which it is practically absent (upper two thirds of sunken road section apart from two samples in Wahlwiller Conglomerate).

3.2.- WAHLWILLER (62B-528)

The Wahlwiller borehole (62D-528, GB3764) is of importance, because it has been drilled at the type locality of the Wahlwiller Horizon, which forms the boundary between the Vijlen Chalk and overlying

Fig. 5.- Distribution of selected microfossil taxa in Mamelis sections 62D-168 (Mamelis borehole) and 62D-79 (Mamelis sunken road) compared with percentage distribution of belemnite clasts and large agglutinated forams (mainly *Orbignyna*). The mean number of pustules on the last chamber of *B. australis* is indicated to the left of the *B. australis* column. The encircled figures in the left column refer to bioclast intervals 0-6 as discussed in chapter 1.1.

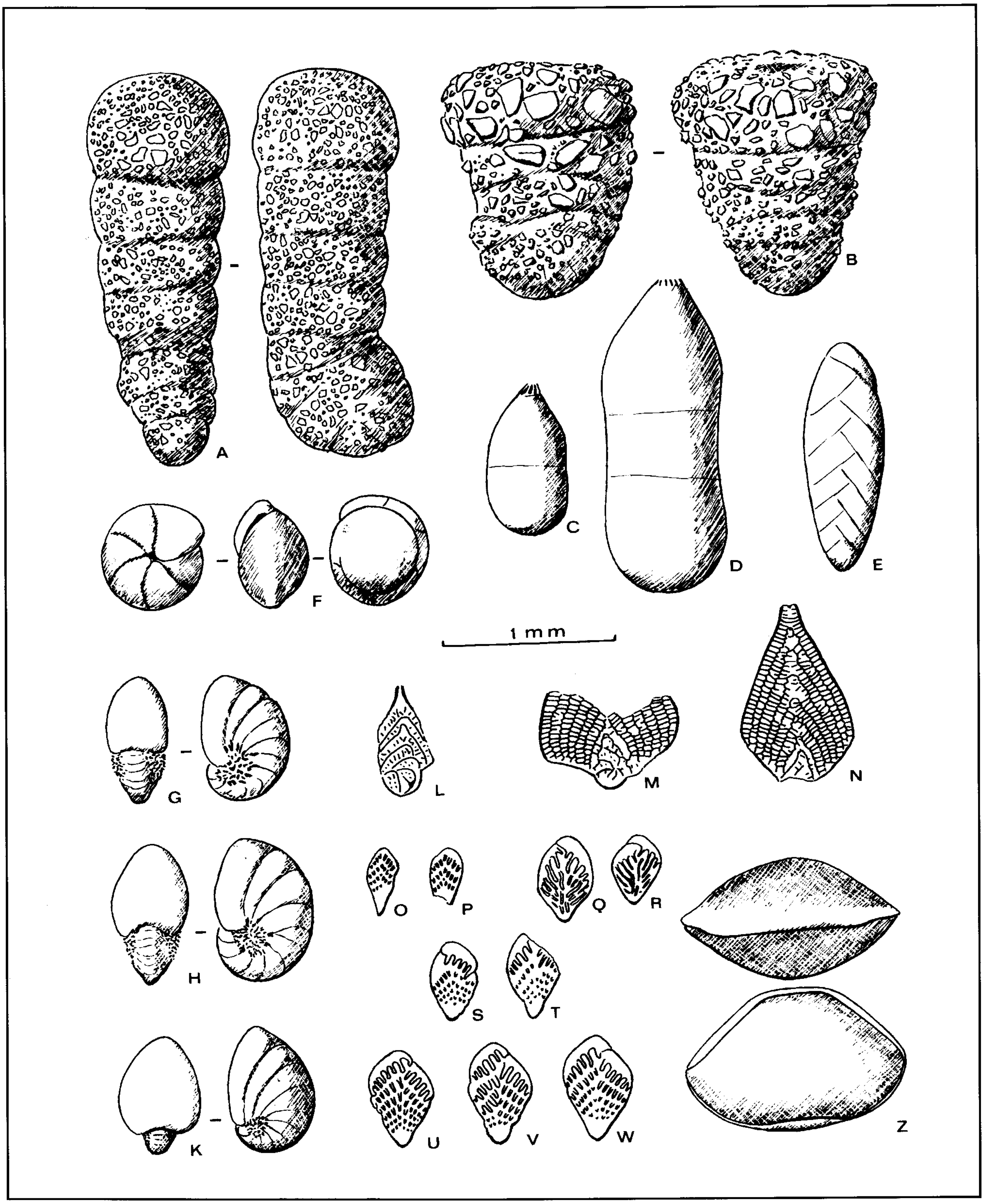


Fig. 6.- Selected forams (A-W) and ostracodes (Z) from the Mamelis reference section for the Vijlen Chalk (Mamelis sunken road: 62D-79, and Mamelis berehole: 62D-168).

A: *Orbignyna ovata,* 62D-168, 14.0 m;
B: *Orbignyna aquisgranensis*, 62D-168, 17 m;
C-D: *Glandulina parallela*, 62D-168; C:23.5 m, D: 13 m;
E: *Bolivina incrassata*, 62D-79, 21.5 m;
F: *Eponides beisseli*, 62D-168, 17.5 m;
G-K: *Nonionella troostae*, 62D-79; G: 30.5 m, H-K: 29.5 m;
L: *Neoflabellina praereticulata*, 62D-79, 34.5 m;
M-N: *Neoflabellina reticulata*, 62D-79; M: 26.5 m, N: 17.5 m;
O-P: *Bolivinoides regularis*, 62D-168, 35.3 m;
Q-R: *Bolivinoides draco draco*, 62D-79, 7.5 m;
S-W: *Bolivinoides australis*; S-T: 62D-168, S: 17.5 m, T: 7 m;
U-W: 62D-79, U: 29.5 m, V: 28.5 m, W: 30.5 m;
Z: *Bairdia* sp., 62D-168, 18.5 m.

Lixhe Chalk (cf. Felder, 1975). The forams from the Vijlen Chalk were studied by Hofker (1966). Perhaps because of the small sample size, the foram assemblages appear to be less diverse than those from the nearby (3 km distance) Mamelis sunken road section (cf. fig.7).

B. australis has only been recognized in one sample. Its stratigraphic position roughly matches that of the upper cluster of *B. australis* at Mamelis. *B. draco* has not been observed in the borehole (see remarks *in*: Hofker, 1966). The single occurrence of *N. reticulata* is within the range of that species at Mamelis. The distribution pattern of *B. incrassata* suggests a rough correlation with the two clusters in the Mamelis sunken road section. The top of the range of *E. beisseli* closely matches that at Mamelis. The first appearance of *N. troostae* coincides with the top of the *E. beisseli* range, this in contrast with the Mamelis sunken road section, where it is some 7 m below the top of *E. beisseli*. The top of the interval with *N. troostae* at Wahlwiller, however, can be correlated with the top of the clustered occurrence of that species at Mamelis.

Despite limited data, it seems possible to trace at least some of the lower and/or upper boundaries of clustered foram taxon occurrences over a distance of nearly 3 km from Mamelis to Wahlwiller. This observation is interpreted as an argument in favour of the supposition that the relative frequency changes of these taxa are due to local paleoenvironmental variations.

3.3.- BOVENSTE BOS (62D-27)

The Bovenste Bos Horizon, by definition the lower boundary of the Vijlen Chalk (W.M. Felder, 1975), has been studied in a temporary trench in this abandoned quarry. Hofker (1966) provided data on the foram assemblages from this quarry. But he limited himself to one sample from the Vijlen Chalk(some 25 cm above the base), whereas the highest sample from the underlying Beutenaken Chalk had been taken some 2 m below the top of that chalk member.

Keutgen & Van der Tuuk (1990) showed that the important changes in the belemnite succession occurred within the burrowed chalk at the top of the Beutenaken Chalk. They recognized an incomplete succession of Late Late Campanian through Early Early Maastrichtian into Late Early Maastrichtian belemnite zones within a less than 2 m thick interval. The Early Early Maastrichtian belemnite assemblages only occur in the glauconitic infill of the burrows (Keutgen & Van der Tuuk, 1990). The infill of these burrows forms the basal portion of the Vijlen Chalk, since the burrows simply pipe down the Bovenste Bos Horizon (the contact between the Beutenaken Chalk and overlying Vijlen Chalk) in the topmost Beutenaken Chalk (W.M. Felder, pers. comm.).

Therefore, for the present study a continuous succession of 10 cm samples has been taken from this critical interval. This was completed by four 50 cm samples in the uppermost portion of the section (fig.8).

One specimen of *B. draco* at 0.7 m (fig.11: C) resembles *B. draco miliaris*, a species ranging from the Late Late Campanian into the basal Late Early Maastrichtian in NW Germany (Koch, 1977).

B. regularis (fig.9: J, K; fig.11: K) occurs in two samples (1.0 m and 1.4 m). Its presence in the interval with the belemnite *B. obtusa* matches the Early Early Maastrichtian range of this taxon in NW Germany. As mentioned above, this species also occurs at the base of the Mamelis borehole (interval 0).

B. australis (fig.9: L-O) occurs in practically only all samples. Specimens below 0.7 m possess only five pustules on the last chamber. This is the interval assigned to the Late Late Campanian on the basis of belemnites. Specimens from the interval with *B. obtusa* have a mean number of pustules on their last chamber of 5.2, whereas the mean number of pustules on the last chamber of those from the Late Early Maastrichtian Lower *sumensis* Zone is 5.4. It is emphasized that the intervals with the values of 5.2 and 5.4 cannot be traced in the Mamelis sections. At Mamelis, the intervals with a mean number of pustules on the last chamber of *B. australis* of, respectively, 5.2 and 5.3 belong to the Upper *sumensis* Zone.

The presence of *N. permutata* in the 0.5-1.1 m interval (fig.10: W-Z; fig.12: A)) matches the Late Late Campanian to Early Early Maastrichtian range of this species in NW Germany (Koch, 1977). Hofker (1966, table 1 "ad 7") mentioned the presence of *N. permutata* (described by him as *N. numismalis-efferata*; *N. numismalis* or *N. efferata*) in the Beutenaken and lower Vijlen Chalk.

Most remarkable is the co-occurrence of *N. praereticulata* and *N. reticulata* in the interval with the Early Early Maastrichtian belemnite *B. obtusa* (fig.10: A-V), a phenomenon already known in NW Germany (cf. Koch, 1977). *N. praereticulata* also occurs in the Late Late Campanian Beutenaken Chalk.

G. parallela (fig.9: D) is rare. The first specimen may occur already in the Beutenaken Chalk (at 0.4 m).

There is a distinct cluster of *B. incrassata* (fig.9: E) roughly matching the interval with *B. obtusa*. This cluster may thus be correlated with the single occurrence of this species at the base of the Mamelis

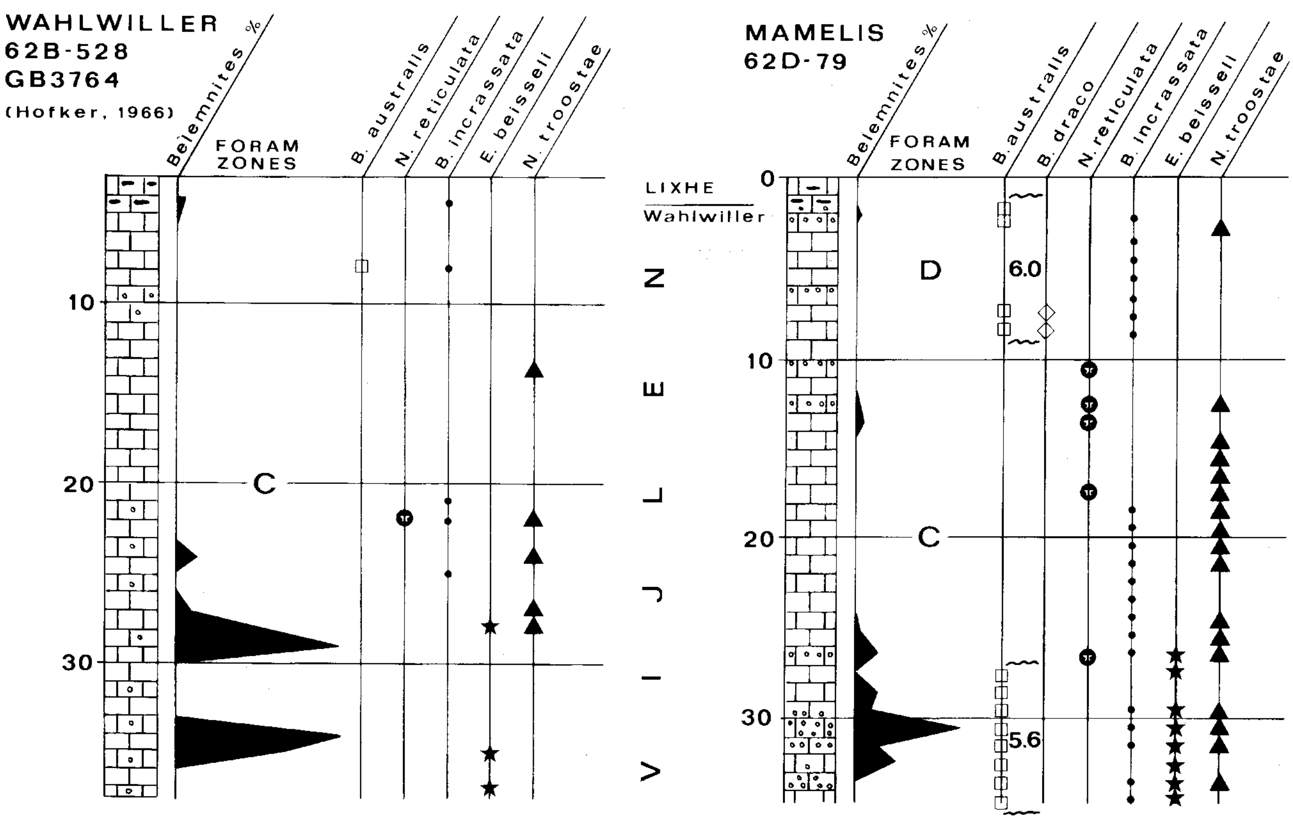


Fig. 7.- Distribution of belemnite clasts and selected foram species in upper portion of Vijlen Chalk in Wahlwiller (62B-528) and Mamelis sunken road (62D-79) sections. Foram distribution in Wahlwiller based on Hofker (1966).

borehole (interval 0) because of its co-occurrence with *B. regularis* in both cases.

Typical specimens of *E. beisseli* (fig.9: F) already occur in the top of the Beutenaken Chalk, along with *G. micheliniana* (fig.9: H) and *G. hiltermanni* (fig.9: G). The last two species presumably disappear at the top of the Beutenaken Chalk in Southern Limburg. Their presence in the interval with the belemnite *B. obtusa* does not necessarily point to an extension of their range in the Early Early Maastrichtian, since the top of the Beutenaken Chalk is situated between 1.5 and 1.8 m in this section.

Bairdia (fig.9: P) occurs in almost all samples from the Beutenaken and Vijlen Chalk.

Two samples within the interval with *B. obtusa* have yielded *Bythoceratina laevis* (fig.13: A, B). In Southern Limburg and its environs, this very distinctive ostracode had only been recognized in the "Early Maastrichtian hardground" (with the belemnite "*B. lanceolata*" auct.) in sections at North, Zeven Wegen, Grindaal (also written "krindaal") and Slenaken (cf. Deroo, 1966). In Northern Germany and Danmark, however, *B. laevis* ranges from the Late Campanian throughout the Maastrichtian (Clarke, 1983), presumably due to differences in paleoenvironment.

3.4.- ZEVEN WEGEN (62D-15b)

This is the stratotype of the Zeven Wegen Chalk (W.M. Felder, 1975). The 1.5 m thick (0.7 m according to Hofker, 1966), partly indurated glauconitic greensand in between the Zeven Wegen Chalk and the overlying Vijlen Chalk contains two belemnite graveyards, one at the base and one near the top (cf. Hofker, 1966). The distinction between two belemnite graveyards was not made by Van der Tuuk (in: Robaszynski *et al.*, 1985), who mentioned the presence of the belemnites *Belemnitella mucronata*, *Belemnitella mucronata "minor"*, *Belemnella lanceolata inflata* and *Belemnella "occidentalis"* (the last two species were later assigned to *B. obtusa* by Keutgen & Van der Tuuk, 1990) from this interval. The only sample from this interval (situated somewhere in the middle of it) studied by Hofker (1966) was attributed to foram zone C.

The present study revealed the presence of two distinct maxima of belemnite clasts within the greensand interval (fig.14). This confirms the existence of two belemnite graveyards. The lower maximum coincides with the presence of the first *N. praereticulata* and *E. beisseli*, as well as the highest (abundant) *G. micheliniana*. This association suggests a correlation with the Beutenaken Chalk (Hofker's foram zone B).

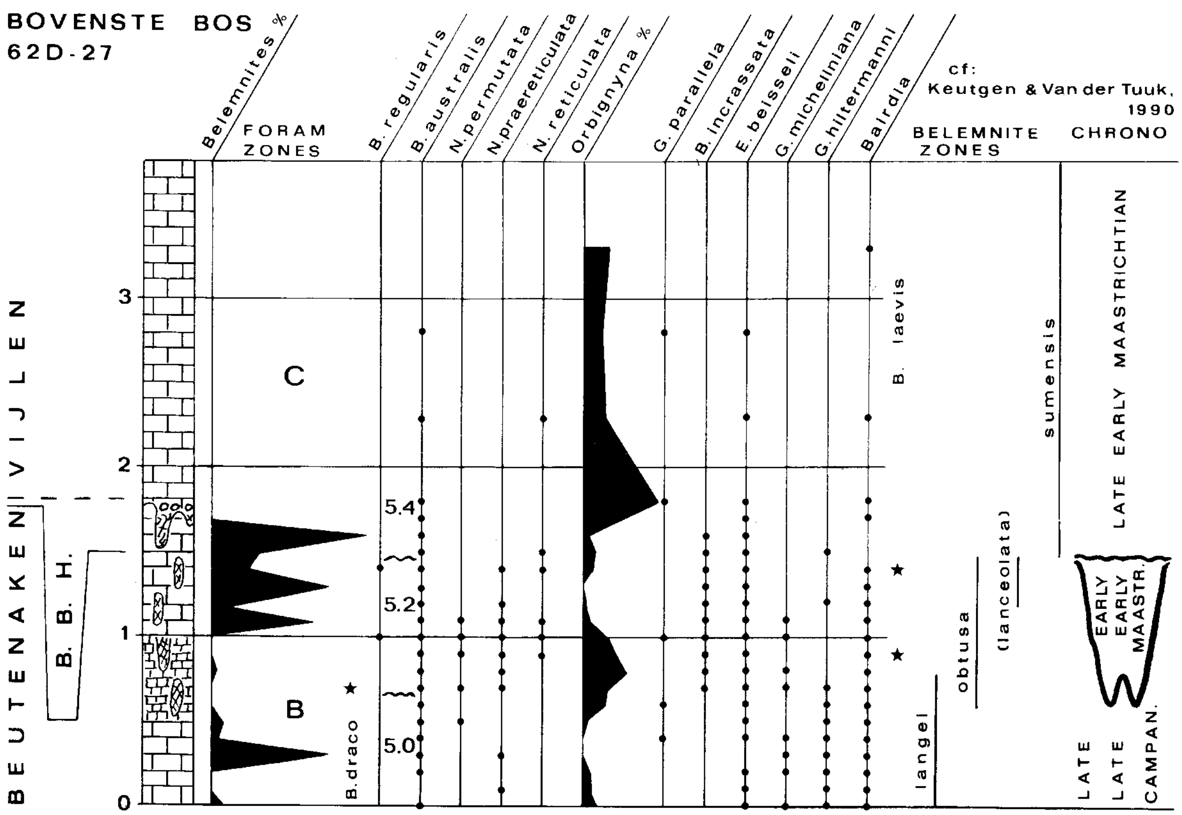


Fig. 8.- Distribution of selected microfossil taxa in Bovenste Bos section (62D-27) compared with percentage distribution of belemnite clasts and large agglutinated forams (*mainly Orbignyna*). The mean number of pustules on the last chamber of *B. australis* is shown to the left of the *B. australis* column. Belemnite zones and chronostratigraphic interpretation (right columns) are after Keutgen & Van der Tuuk (1990). The presence of rare *B. lanceolata* in the uppermost portion of the burrowed interval (Keutgen & Van der Tuuk, 1990) is tentatively interpreted as an indication that shallow burrows already existed during *lanceolata* time. Deeper tiers may have been burrowed (by different organisms?) later in *obtusa* time.

The upper maximum of belemnite clasts is characterized by the near absence of *G. micheliniana* (only a single worn specimen was discovered), as well as by the presence of *B. regularis* (fig.11: L), *B. australis* (with a mean number of pustules on the last chamber of 5.3), *B. draco miliaris* (fig.11: D), *N. permutata* (fig.12: B, C), *N. reticulata, G. parallela, B. incrassata* and *B. laevis* (fig.13: C, D)). This association closely matches that of the Early Early Maastrichtian infill (with *B. obtusa*) of the burrows in the Bovenste Bos section. The occurrence of *B. regularis* also suggests a correlation with interval 0 of Mamelis.

3.5.- JONGENSSCHOOL VIJLEN (62D-129)

The former quarry has been refilled completely. Otherwise, it might have been the logical candidate as a stratotype of the Vijlen Chalk. The composite section (fig.15) is based on data from the abandoned quarry (listed as 62D-10, but here included in 62D-129) and from a 20 m deep borehole (62D-129; 4366 in Kimpe *et al.*, 1978, Enclosure III) that had been drilled in the quarry floor. Foram data were provided by Hofker (1961, 1966) and Kimpe *et al.* (1978, Enclosure III). The forams and ostracodes from the borehole have been restudied for this report.

Samples with *B. australis* form four distinct clusters. The highest cluster was assigned to foram zone D by Hofker (1966) on account of its co-occurrence with *B. draco draco* (cf. fig.11: B) it can be correlated with the upper portion of the Mamelis sunken road section (interval 6). The mean number of pustules on the last chamber of *B. australis* in that interval varies between 5.6 (Hofker, 1961) and 5.9 (Kimpe *et al.*, 1978). The second cluster (with a mean number of pustules of 5.3 according to the data in Hofker, 1961) roughly matches the highest occurrences of *N. praereticulata* and *E. beisseli* respectively. This suggests a correlation with the second *B. australis* interval of Mamelis (intervals 3-4). The mean number of pustules on the last chamber in the third cluster varies between 5.2 (this report) and 5.4 (Kimpe *et al.*, 1978). This interval is characterized by the presence of *B. draco miliaris* (fig.11: F-H). Because of its stratigraphic position, some 4-5 m below the second cluster, it is tentatively correlated with the lower *B. australis* interval (interval 2) of Mamelis. A fourth cluster is distinguished between 14 and 16 m in the borehole. The number of specimens in that interval is too low for calculation of the mean number of pustules on the last chamber.

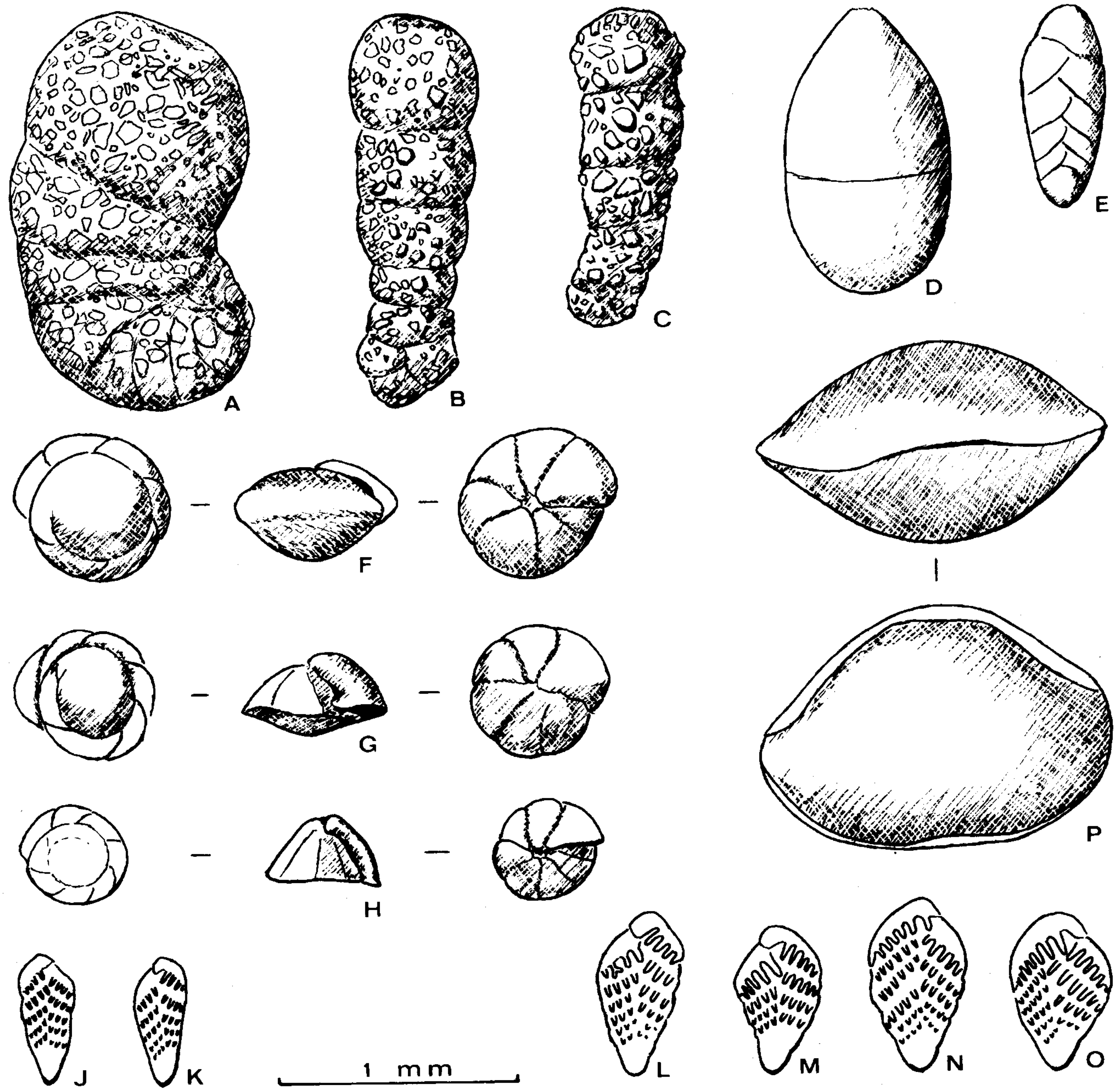


Fig. 9.- Selected forams (A-O) and ostracodes (P) from the type section of the Bovenste Bos Horizon near Epen (Bovenste Bos: 62D-27). Other taxa from this location are shown in figs.10-13.

A: *Orbignyna ovata*, 1.4 m;
B-C: *Orbignyna aquisgranensis*; B: 0.1 m, C: 1.5 m;
D: *Glandulina parallela*, 2.8 m;
E: *Bolivina incrassata*, 1.0 m;
F: *Eponides beisseli*, 0.9 m; G: *Globorotalites hiltermanni*, 1.2 m;
H: *Globorotalites micheliniana*, 1.0 m;
J-K: *Bolivinoides regularis*, 1.0 m;
L-O: *Bolivinoides australis*; L-N: 1.0 m, O: 1.1 m;
P: *Bairdia* sp., 1.4 m.

Remarkable is the presence of *N. permutata* (fig.12: E-F) in nearly all samples below 7 m in the borehole. Samples with *N. reticulata* form two distinct clusters: the upper one in the upper 8 m of the quarry, the lower one below 2 m in the borehole. The upper cluster starts just above the second *B. australis* interval and coincides with the highest occurrence of true *E. beisseli* (cf. Hofker, 1966). A similar coincidence is observed at 26.5 m in the Mamelis sunken road section; it supports the correlation between the second *B. australis* cluster in the Jongensschool quarry and the middle one in the Mamelis sections, as suggested above.

G. parallela is relatively common in the borehole, and rare in the quarry. The frequency change coincides with the top of the third *B. australis* cluster. This matches the frequency change of that species at the top of interval 2 in Mamelis.

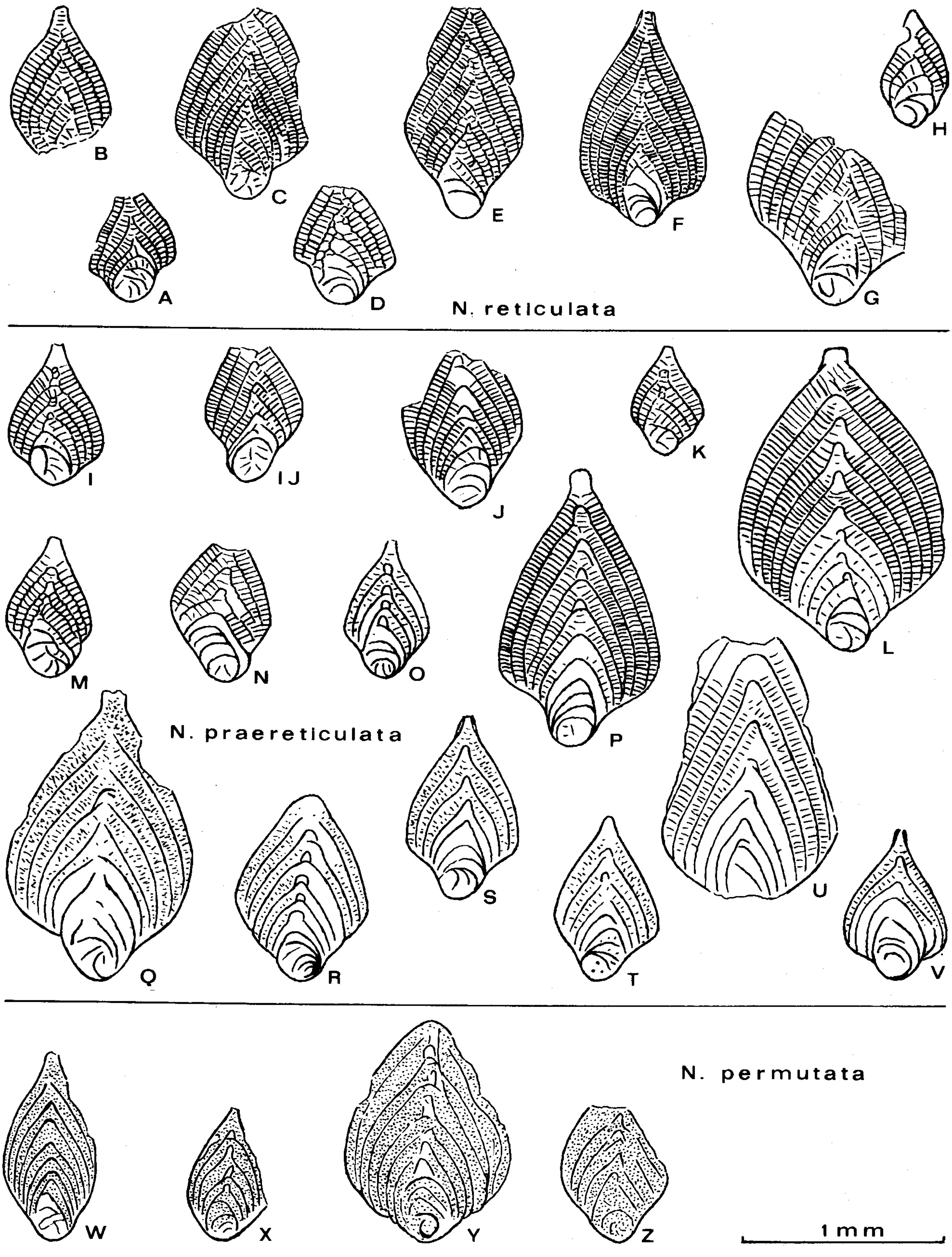


Fig. 10.- Selected specimens of foram genus *Neoflabellina* from type section of the Bovenste Bos Horizon near Epen (Bovenste Bos: 62D-27).
A-H: *Neoflabellina reticulata*; A: 0.9 m, B-D: 1.0 m, E-F: 1.1 m, G: 1.4 m, H: 2.3 m;
I-V: *Neoflabellina praereticulata*; U: 0.1 m, O, R: 0.3 m, Q: 0.7 m,
T: 0.8 m, K, P: 0.9 m, J: 1.0 m, I, V: 1.1 m, S: 1.2 m, L-M: 1.4 m, IJ, N: 1.5 m;
W-Z: *Neoflabellina permutata*; W: 0.9 m, X: 1.0 m, Y-Z: 1.1 m.

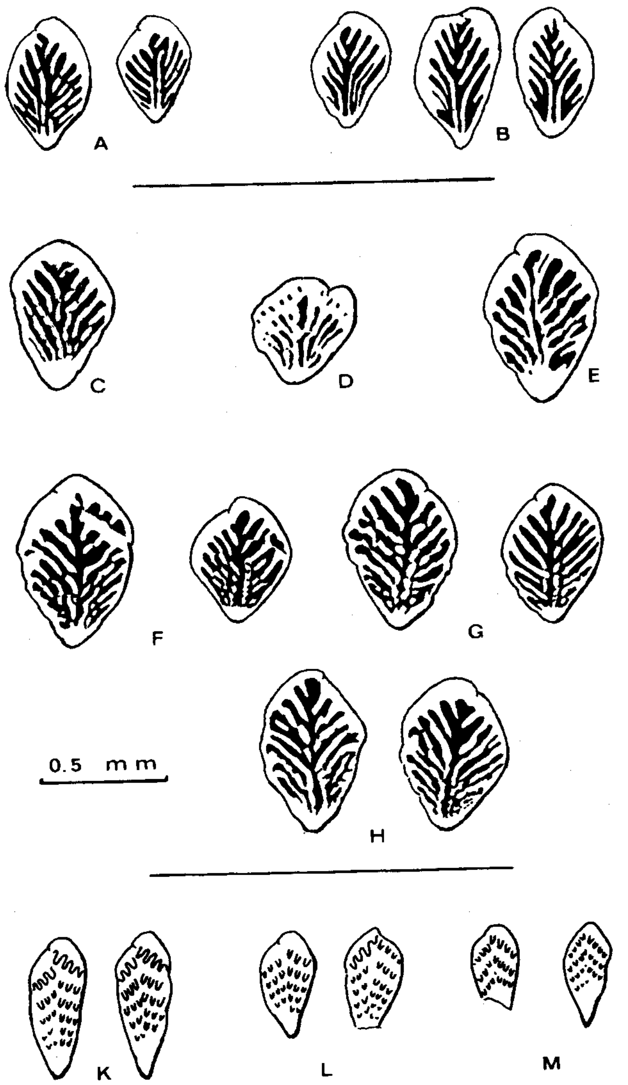


Fig. 11.- Selected species of foram genus *Bolivinoides* from the Vijlen Chalk.

A-B: *Bolivinoides draco draco*, foram zone D of Hofker (1966); A:Mamelis sunken road (62D-79), 7.5 m;
B: Jongensschool Vijlen quarry (62D-129), interval 8-10 m (from: Hofker, 1966, pl. 13, figs. 34-36).
C-H: *Bolivinoides draco miliaris*, foram zone C of Hofker (1966);
C: Bovenste Bos (62D-27), 0.7 m;
D: Zeven Wegen (62D-15b), 13 m;
E: Witte Weg Vijlen (62D-88), 16 m;
F-G: Jongensschool Vijlen borehole (62D-129); F: 4 m, G: 5 m, H: 6 m;
K-M: *Bolivinoides regularis*, base of foram zone C of Hofker (1966);
K: Bovenste Bos (62D-27), 1.0 m;
L: Zeven Wegen (62D-15b), 13 m;
M: Mamelis borehole (62D-168), 35.3 m.

Two clusters of *B. incrassata* have been recognized: one in the upper half of the quarry, and one in the upper half of the borehole. The upper one is tentatively compared with the two clusters in the Mamelis sunken road section, and the lower one with the *B. incrassata* cluster of interval 2 at Mamelis.

The frequent occurrence of *Bairdia* in the upper half of the borehole resembles the frequency pattern of the Mamelis borehole.

N. troostae is restricted to the upper 4 m of the quarry (interval with *B. draco draco*). This distribution pattern clearly differs from that seen at Mamelis.

B. laevis (fig.13: G-K) occurs in three samples. Its highest occurrence is at the base of the third *B. australis* cluster.

3.6.- WITTE WEG (62D-88) / KERK VIJLEN

The microfossil assemblages from this composite section (fig. 16) are relatively poor because of intensive post-sedimentary cementation. The chalkstone of the Kerk section was formerly quarried as "Vijlen Bakovensteen".

Only one *B. australis* cluster has been recognized. The mean number of pustules on the last chamber has not been calculated because of the small number of specimens. The presence of *B. draco miliaris* (fig.11: E) in this interval, the presence of *N. permutata* (fig.12: D) 2 m below it, and the highest occurrence of *B. laevis* (fig.13: E, F) 1 m above the same suggest a correlation of this cluster with the third one in the Jongensschool section, and thus with the lower *B. australis* cluster (interval 2) of Mamelis.

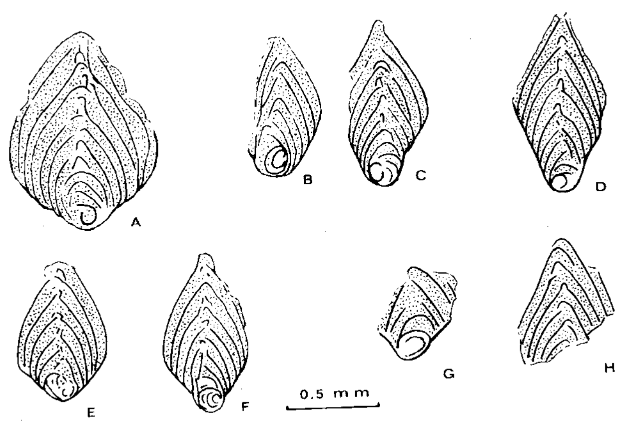


Fig. 12.- Selected specimens of foram species *Neoflabellina permutata* from the Vijlen Chalk.

A: Bovenste Bos (62D-27), 0.9 m;
B-C: Zeven Wegen (62D-15b), 13 m;
D: Witte Weg Vijlen (62D-88), 13 m;
E-F: Jongensschool Vijlen borehole (62D-129); E: 10m, F: 12 m;
G-H: Mamelisserberg (62D-130); G: 19 m, H: 18 m.

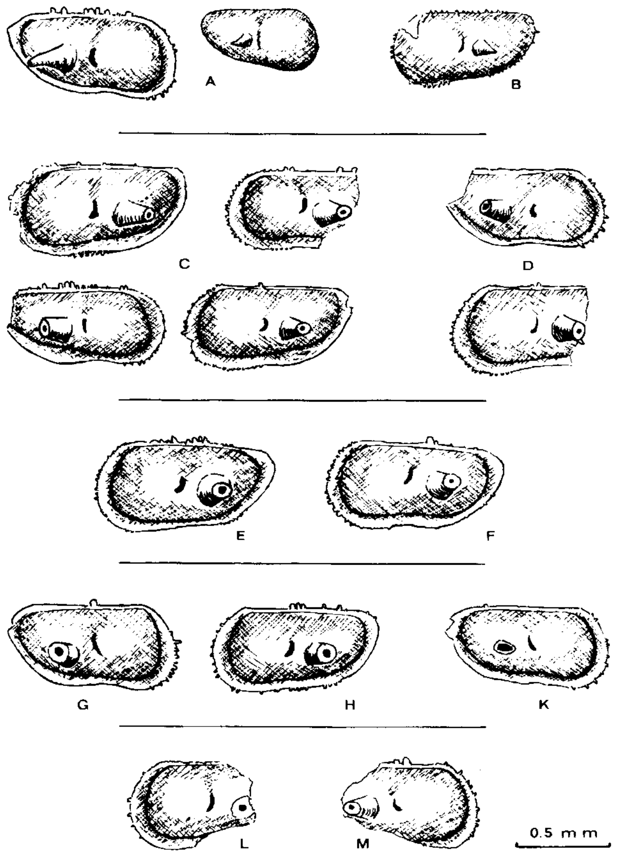


Fig. 13.- Selected specimens of ostracode species *Bythoceratina laevis* from the Vijlen Chalk.

A-B: Bovenste Bos (62D-27); A: 0.9 m, B: 1.4 m;
C-D: Zeven Wegen (62D-15b); C: 13.5 m, D: 13 m;
E-F: Witte Weg Vijlen (62D-88); E: 0 m, F: 18 m;
G-K: Jongensschool Vijlen borehole (62D-129); G: 8 m, H: 9 m, K: 16 m;
L-M: Mamelisserberg (62D-130); L: 18 m, M: 19 m.

3.7.- **PANHUIS** (62D-156)

Kimpe *et al.* (1978) refer to this borehole (5516) in their Enclosure III. They attributed the chalk on top the Vaals Formation to Hofker's (1966) foram zone C. A distinct maximum of belemnite clasts in the 1.0-2.4 mm sieve fraction occurs between 6.5 and 8 m. This belemnite maximum and the underlying glauconitic chalk (8.0-12.7 m) are tentatively compared with interval 0 of the Mamelis borehole. The microfauna has not been restudied for the present report.

3.8.- **MAMELISSERBERG** (62D-130)

This borehole was referred to as section 4427 on their Enclosure III by Kimpe *et al.* (1978). They mentioned the presence of both *B. draco* and *B. australis* (with a mean number of pustules on the last chamber of 5.4) at 25 m. The microfossil assemblages from this borehole have been restudied insofar as samples were available (fig.17). This was the case for the interval above 12 m, at 15 m, and at 18 and 19 m. Despite the incomplete sample succession, the following remarks can be made.

Although the distribution pattern of *B. australis* appears to be rather irregular there are two intervals in which it seems to be more common: one at 9-12 m (mean number of pustules on the last chamber: 5.6) and one at 17-19 m (mean number of pustules on the last chamber: 5.2). Moreover, there is the above mentioned presence of the species at 25 m (mean number of pustules on the last chamber: 5.4). For the time being, we consider these as three different *Bolivinoides* clusters, which can be correlated with the second, third and fourth cluster of the Jongensschool Vijlen section respectively.

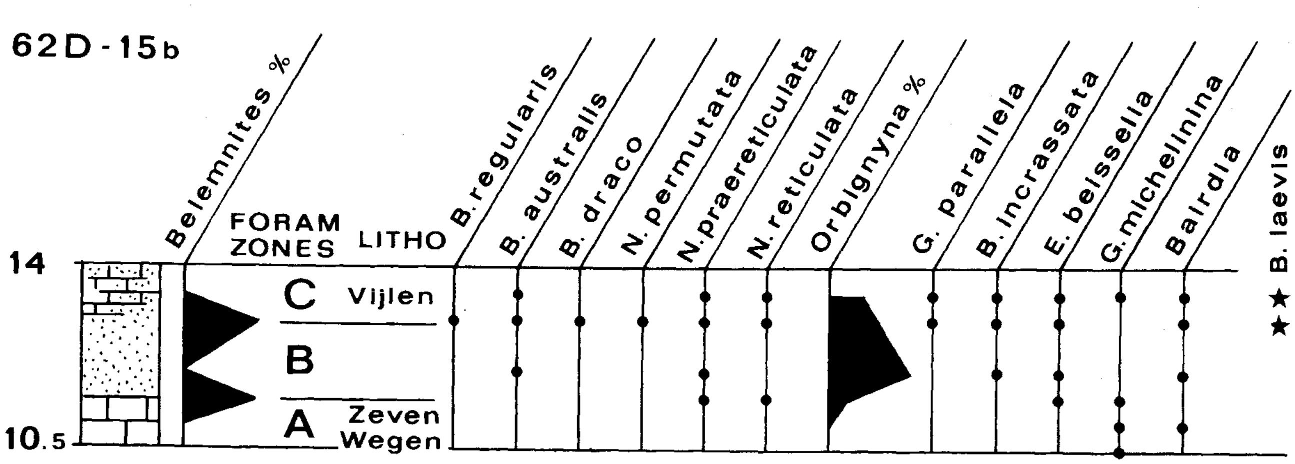


Fig. 14.- Distribution of selected microfossil taxa in Zeven Wegen section (62D-15b) compared with percentage distribution of belemnite clasts and large agglutinated forams (mainly *Orbignyna*).

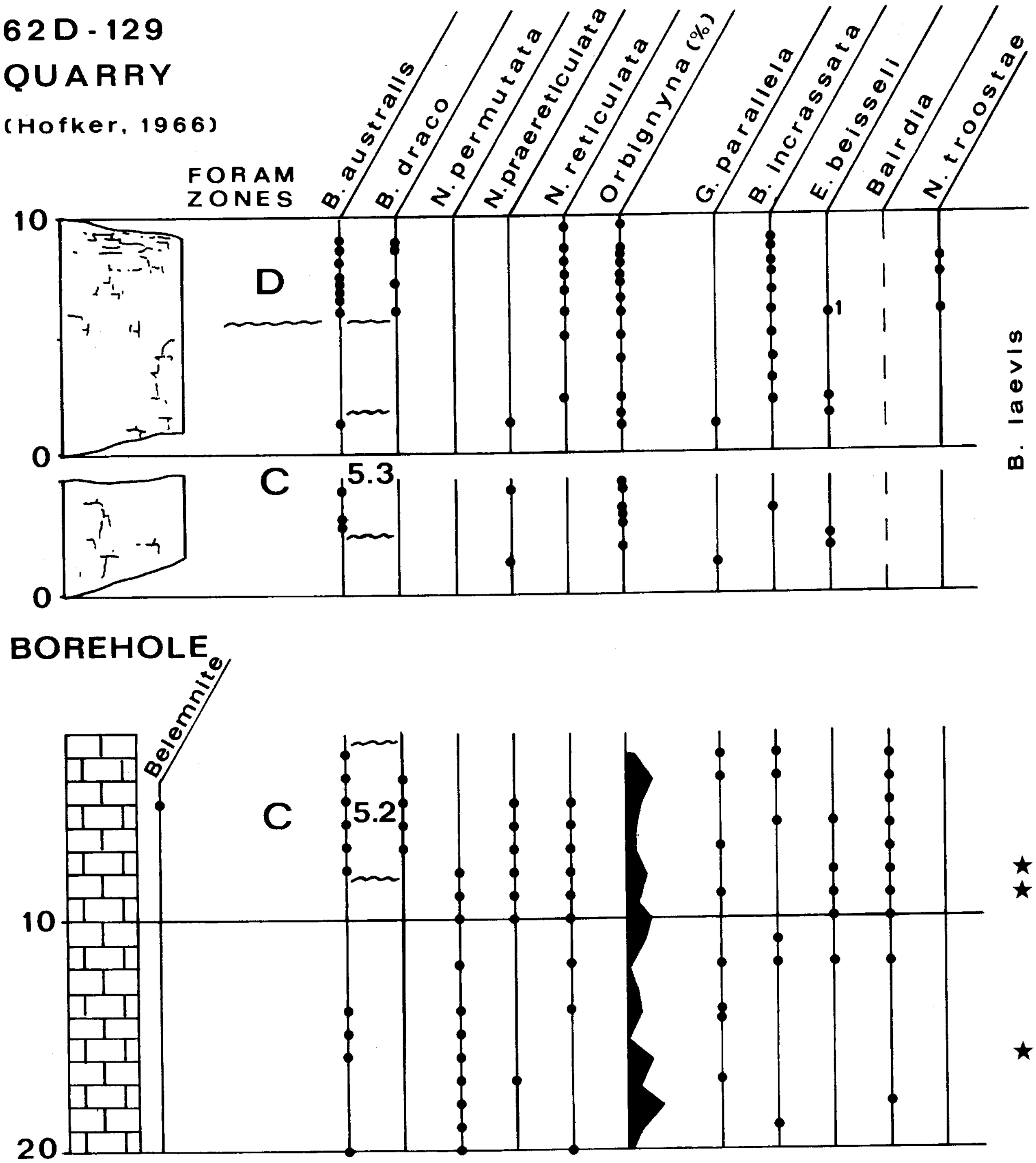


Fig. 15.- Distribution of selected microfossil taxa in Jongensschool Vijlen sections (62D-129; abandoned quarry and borehole) compared with percentage distribution of belemnite clasts (only a single clast was recognized) and large agglutinated forams (mainly *Orbignyna*) in the borehole. Distribution of forams in quarry sections from Hofker (1966). It cannot excluded that the quarry sections (partly) overlap each other (compare distribution of *N. praereticulata*, *G. parallela* and *E. beisseli*). The highest occurrence of *E. beisseli* in the quarry (occurrence marked by «1»; Hofker's sample H86) is questionable. Hofker (1966) listed the specimen(s) as *E. frankei* in his table 12. However, on plate 13, fig.56 he figured a specimen from the same sample identified as *E. beisseli*. Moreover, in table 1 («ad p.7») he stated that *E. frankei* only appears halfway foram zone F. We have disregarded this questionable occurrence in our discussions.

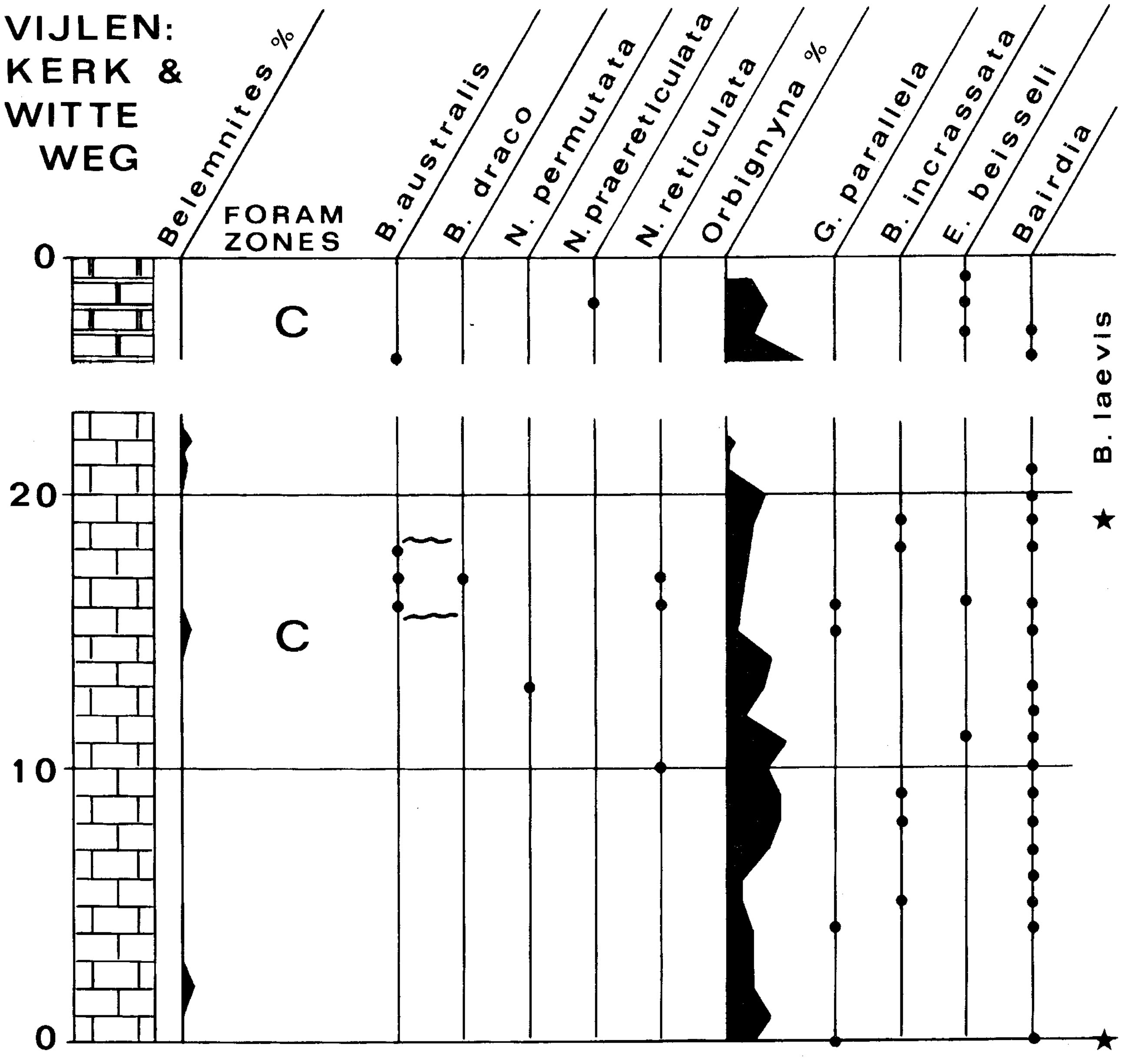


Fig. 16.- Distribution of selected microfossil taxa in Witte Weg and Kerk Vijlen sections (temporary trenches) compared with percentage distribution of belemnite clasts and large agglutinated forams (mainly *Orbignyna*).

B. draco in the lowermost *B. australis* cluster is tentatively attributed to *B. draco miliaris*. This occurrence is one cluster lower than in the Witte Weg and Jongensschool sections.

The co-occurrence of *N. permutata* (fig.12: G, H) and *B. laevis* (fig.13: L-M) in the second *B. australis* cluster corroborates the correlation of that cluster with the one in the Witte Weg and the third one in the Jongensschool section.

The highest occurrence of *E. beisseli* at 7 m, slightly below the lowermost appearance of *N. troostae*, closely resembles the situation in the Wahlwiller borehole. It is therefore correlated with the top of *E. beisseli* in the Mamelis sunken road section.

3.9.- NYSWILLER (62B-767)

Kimpe *et al.* (1978) mentioned the presence of *B. draco* near the top of the Vijlen Chalk in this borehole (indicated as section 6529 on their Enclosure III). *B. australis* with a mean number of pustules on the last chamber of 5.3 was recognized by them some 2 m lower in the same section. Kimpe *et al.* (1978) compared these samples with those of intervals 2 in the Mamelis borehole. We presume, however, that these foram samples are to be correlated with interval 6 in the Mamelis sunken road section. The microfossils from this borehole have not been restudied for this report.

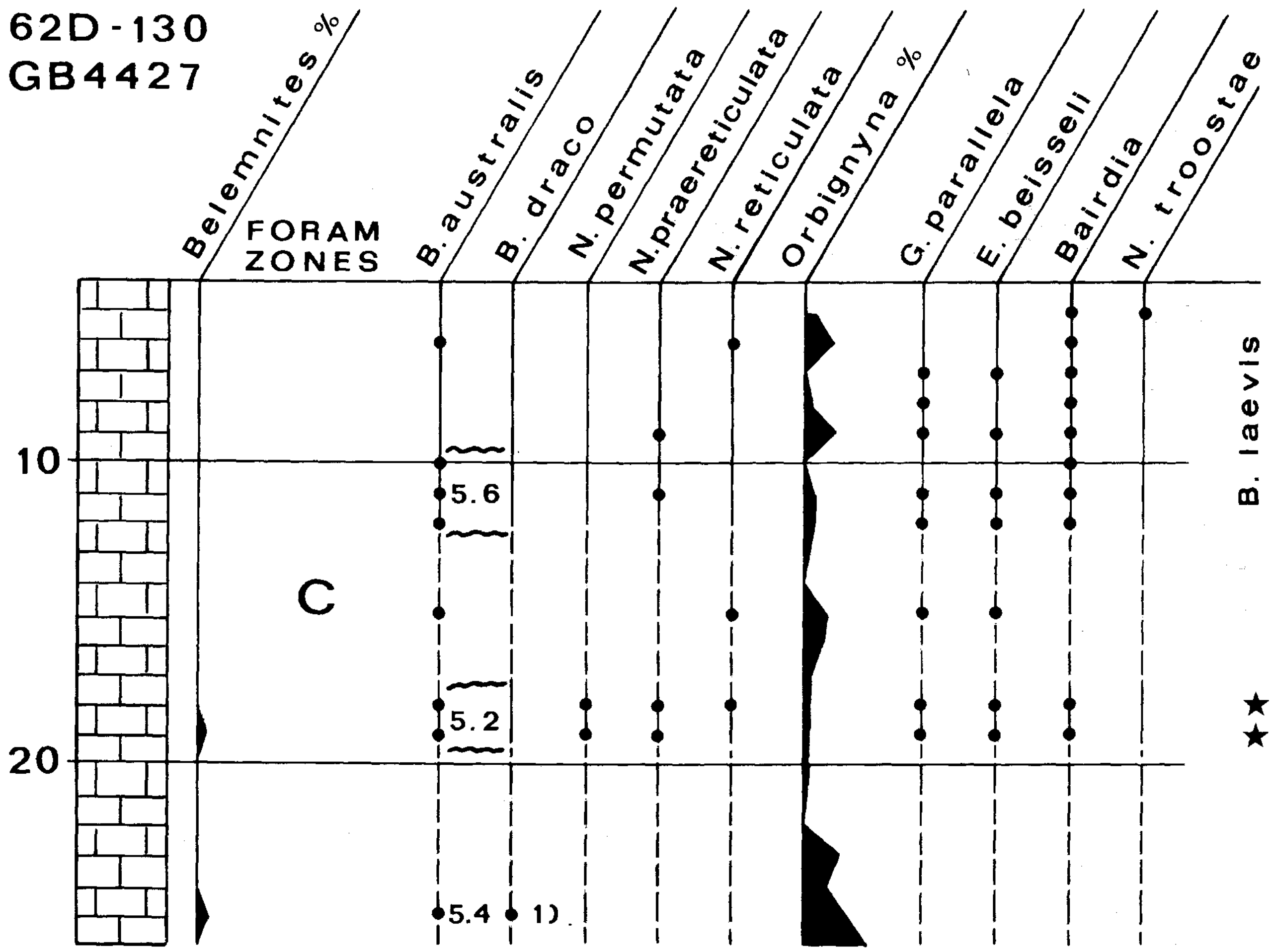


Fig. 17.- Distribution of selected microfossil taxa in Mamelisserberg section (62D-130) compared with percentage distribution of belemnite clasts and large agglutinated forams (mainly *Orbignyna*).

3.10.- HANS-BöCKLER-ALLEE AACHEN

This temporary section (consisting of two closely spaced building sites) has yielded belemnites of the Late Early Maastrichtian Upper *sumensis* zone (Keutgen & Van der Tuuk, 1990). A 3 kg sample from the Hans-Böckler-Allee-II site was obtained through the courtesy of Mr. J.P.H. Reynders (Houthalen). It has yielded a rich and diverse microfossil assemblage, including the following species: *B. australis* (with a mean number of pustules on the last chamber of 5.6), one specimen of *N. praereticulata, G. parallela, B. incrassata*, abundant *E. beisseli* and *N. troostae*, and *Bairdia*. This assemblage closely resembles that of interval 4 in the Mamelis sunken road section.

3.11.- VAALSERSTRASSE AACHEN

This temporary section near the Westfriedhof of Aachen was briefly described by Keutgen & Van der Tuuk (1990). The upper 4 m of this section (with several glauconitic layers containing quartz grains) yielded belemnites of the Late Early Maastrichtian Upper *sumensis* zone. Because of the thickness of this belemnite-bearing interval and its lithostratigraphic position (some 9 m above the base of the Vijlen Chalk according to Keutgen & Van der Tuuk, 1990) we tentatively correlate the upper portion of the Vaalserstrasse section with interval 2 in the Mamelis borehole.

4.- CORRELATION OF SECTIONS

The available data presented here above permit the following best-fit correlation between the various sections (fig.18).

Interval 0 of Mamelis (with a distinct maximum of belemnite clasts in its upper portion) has been correlated with the Early Early Maastrichtian belemnite graveyards (with *B. obtusa*) at the base of the Vijlen Chalk in the Bovenste Bos and Zeven Wegen sections on the presence of *B. regularis*. Interval 0 is also tentatively correlated with undated maxima of belemnite clasts near the base of the Vijlen Chalk in the Panhuis and Nyswiller boreholes.

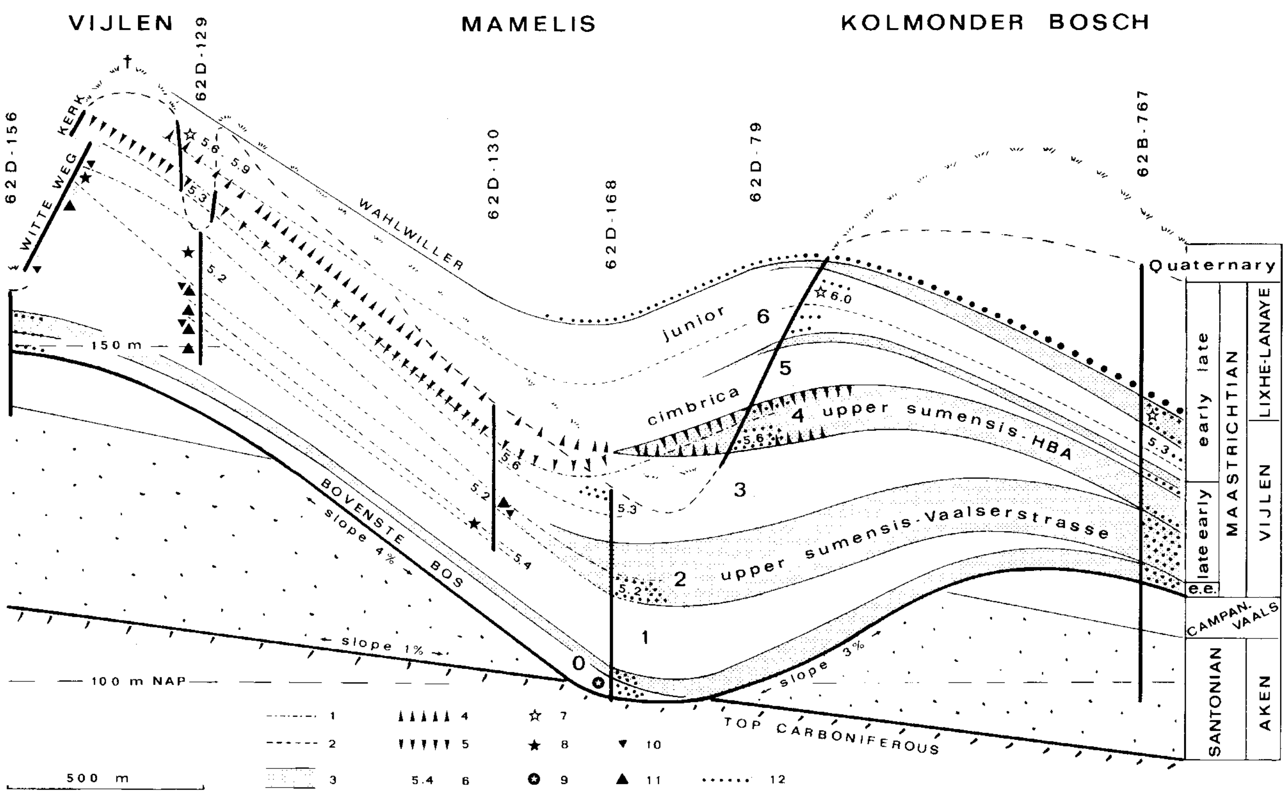


Fig. 18.- Idealized correlation of sections through Vijlen Chalk between Vijlen and Kolmonder Bosch. The approximate position of the *cimbrica* and *junior* belemnite zones is indicated, as well as the correlation of intervals 2 and 4 with the Upper *sumensis* belemnite zone occurrences in the Hans-Böckler-Allee (HBA) and Vaalserstrasse sections near Aachen.
1: top of *B. australis* cluster; 2: base of *B. australis* cluster; 3: interval with belemnite clasts; 4: base of *N. troostae*; 5: top of *E. beisseli* (questionable occurrence of species in 62D-129 (Jongensschool quarry Vijlen not included); 6: mean number of pustules on last chamber of *B. australis*; 7: *B. draco draco*; 8: *B. draco miliaris*; 9: *B. regularis*; 10: *B. laevis*; 11: *N. permutata*; 12: pebble-bearing bed.

Interval 2 of Mamelis and the Late Early Maastrichtian (Upper *sumensis* Zone) belemnite-bearing interval of the Vaalserstrasse Aachen are tentatively correlated on account of their position in the lithostratigraphic columns (15 m and about 9 m, respectively, above the base of the Vijlen Chalk). The belemnite maxima in interval 2 have also been compared with similar peaks in the Nyswiller borehole between 45 and 53 m. The *B. australis* cluster in the lower half of interval 2 of Mamelis can be traced in the sections of the Mamelisserberg, Jongensschool and Witte Weg. In these sections, this cluster is marked by the highest occurrences of *B. draco miliaris*, *N. permutata* and *B. laevis*. The about 10 m thick interval with high percentages of belemnite clasts in Mamelis has been reduced to almost nothing at the base of the second *B. australis* cluster in the nearby Mamelisserberg. Only isolated belemnite clasts occur in this interval in the Jongensschool Vijlen and Witte Weg Vijlen sections.

The correlation between interval 4 of Mamelis and the Late Early Maastrichtian (Upper *sumensis* Zone) belemnite-bearing interval of the Hans-Böckler-Allee Aachen is based on the co-occurrence of *E. beisseli* and *N. troostae*. The peaks of belemnite clasts in this interval are tentatively correlated with those between 40 and 45 m in Nyswiller. The *B. australis* cluster spanning the lower half of interval 4 and the upper half of the underlying interval 3 has been traced in the sections of the Mamelisserberg and Jongensschool, where it matches the top of *E. beisseli*. Most likely, the top of the local *E. beisseli* range is situated at or just above the top of the Kerk Vijlen section. It is emphasized here that the base of the *N. troostae* range occurs just above the highest occurrence of *E. beisseli* in Mamelisserberg and Jongensschool, whereas it coincides with the top of *E. beisseli* in Wahlwiller. Most peculiar is the total absence of belemnite clasts in this interval in the sections of Mamelisserberg, Jongensschool and Kerk Vijlen.

The find of the belemnite *B. cimbrica* in interval 5 (Keutgen & Van der Tuuk, 1990) indicates a Late Early Maastrichtian age for this interval. The small peak of belemnite clasts at its top is tentatively compared with a small peak in Nyswiller at 37 m. Both peaks are preceded by maxima of clasts of prismatic bivalves.

The *B. australis* cluster in the upper half of interval 6 of Mamelis can be traced in Nyswiller and Jongensschool because of its co-occurrence with *B. draco draco*, indicative of Hofker's (1966) foram zone D. The presence of the belemnite *B.* ex gr. *junior* in this interval confirms its Early Late Maastrichtian age.

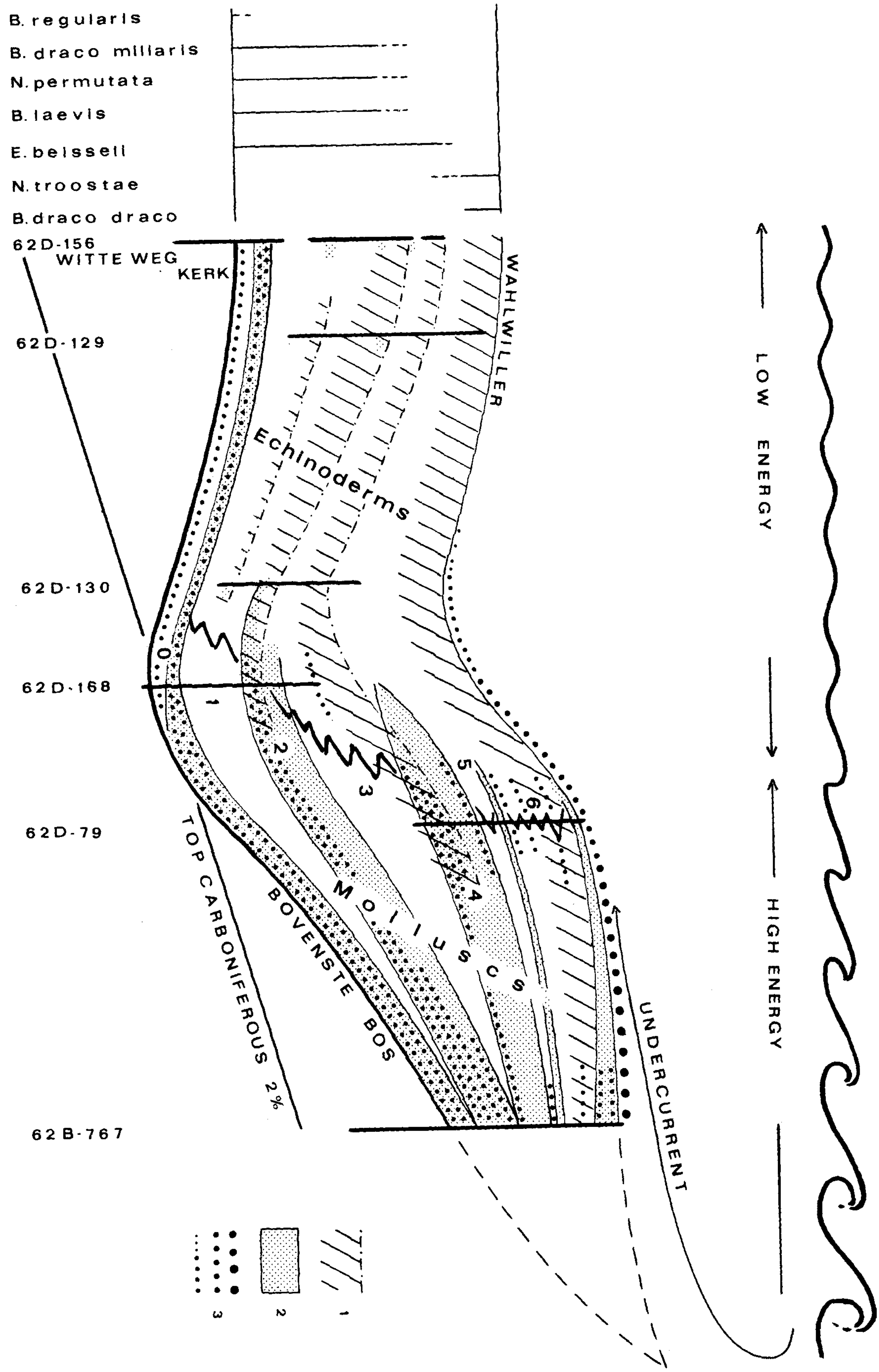


Fig. 19.- Idealized cross-section through Vijlen Chalk deposits at the time of its deposition, in which the top Carboniferous has been tilted back to its presumed position during that period. 1: Strata characterized by *B. australis* clusters; 2: belemnite-bearing intervals; 3: pebble horizons (including Wahlwiller Conglomerate on top of the Vijlen succession.

Naturally, the boundary between the Late Early Maastrichtian and the Early Late Maastrichtian does not necessarily coincide with the boundary between intervals 5 and 6! The thicknesses of both the belemnite maximum at the top of this interval and the overlying Wahlwiller Conglomerate clearly diminish from Nyswiller to Mamelis.

5.- PALEOENVIRONMENT

The best-fit correlation proposed here of sections through the Vijlen Chalk in its type area shows important vertical and lateral variations in thickness and fossil (bioclast) contents (fig.18).

The Vijlen Chalk reaches its maximum thickness in the Mamelis sections (62D-168 and 62D-79): about 65-70 m. Northwards, this thickness rapidly diminishes to 26 m in Nyswiller (over a distance of less than 1 km) and 0 m in the Baneheide borehole (section 6530 in Kimpe *et al.*, 1978, enclosure III) some 2 km further to the north. The thickness is reduced to some 45-50 m in the environs of Vijlen, about 1 km to the south of Mamelis. Moreover, it had been noticed that the Vijlen Chalk rests directly on the Carboniferous basement when it reaches its maximum thickness, whereas elsewhere up to 40 m thick deposits of the Aken and Vaals formations are intercalated. Knapp (1978) and W.M. Felder (*in*: Kuyl, 1980) interpreted these features as an erosion channel or depression in the Vaals-Aken deposits with an infill of Vijlen Chalk. This "erosion channel" runs parallel to the Selzerbeek or Sinselbeek (Sinsel Brook) between Vaals and Wittem. Kimpe *et al.* (1978) suggested that this erosion might have been the result of local halokinetic uplift of the Palaeozoic basement.

The most important changes in the lithofacies and bioclast contents of the Vijlen Chalk apparently coincide with the axis of this "erosion channel", at least in the cross-section studied here. Only one belemnite peak ("belemnite graveyard"), at or near the base of the Vijlen Chalk, can be traced throughout the area from Bovenste Bos and Zeven Wegen through Mamelis to Nyswiller. All the other belemnite maxima disappear between the Mamelis and Mamelisserberg sections.

A slight diachronic withdrawal of the maximum southward extension of these belemnite-rich intervals is suggested by the following observations. A minor relic of the up to 10 m thick interval of belemnite peaks of interval 2 of Mamelis just reaches the Mamelisserberg section, whereas the belemnite peaks of interval 4 presumably disappear completely in between the sections Mamelis sunken road and Mamelisserberg. The thickness of the belemnite peak at the top of interval 6 diminishes from more than 2 m in Nyswiller to less than 1 m in Mamelis.

This diachronic northward withdrawal of the belemnite peaks is matched by a diachronic shift in the same direction of the boundary between echinoderm-dominated and mollusc-dominated bioclast assemblages (fig.19). The frequently large numbers of possibly burrowing irregular echinoids in both echinoderm-dominated and mollusc-dominated bioclast assemblages are indicative of a soft substrate throughout the area during the sedimentation of the Vijlen Chalk.

The fact that the pebble horizons are virtually restricted to the mollusc-dominated parts of the various sections points to a differentiation between a relatively high-energy environment for the mollusc-dominated deposits and a relatively low-energy environment for the echinoderm-dominated deposits. High-energy conditions are frequently linked to relatively shallow (above storm-wave base) near-shore facies, whereas low-energy conditions commonly occur in somewhat deeper (below storm-wave base), more offshore waters. The low-energy environment for the echinoderm-dominated deposits of the Vijlen Chalk is illustrated by the presence of near complete fish skeletons in some layers of this unit in the Vijlenerbosch (cf. Albers & Felder, 1979: 54).

We can visualize such a situation in a model (fig.19) in which the actual slope of the top of the Carboniferous (about 1% to the north in the cross-section on fig.18) is tilted back to its possible position during the deposition of the Vijlen Chalk (about 2% to the south in the cross-section on fig.19). Such an inversion of the tilt of the top of the Carboniferous is corroborated by the tectonic inversion of the Rur Valley Block immediately to the north-east of the present section during that period (cf. Bless *et al.*, 1987, 1993). The Late Maastrichtian relaxation of this inversion of the Rur Valley Block presumably resulted in a gradually diminishing tilt of the top of the Carboniferous basement from (slightly more than) 2% during deposition of the Vijlen Chalk through about 1% during the accumulation of the Lixhe-Lanaye strata to perhaps only 0.5% during the deposition of the Kunrade Chalk (fig.20).

The concomitant overlap of Santonian and Early Campanian Aken and Vaals deposits by the Early-Late Maastrichtian Vijlen, Lixhe-Lanaye and Kunrade chalk presumably was a discontinuous process. Each phase was marked by chalk deposition in the south and formation of a wide beach plain by the erosion of the Aken-Vaals sands in the north. The "erosion channels" in the Aken-Vaals sands are thus interpreted as fossil beach plains. Their southern "slope" was

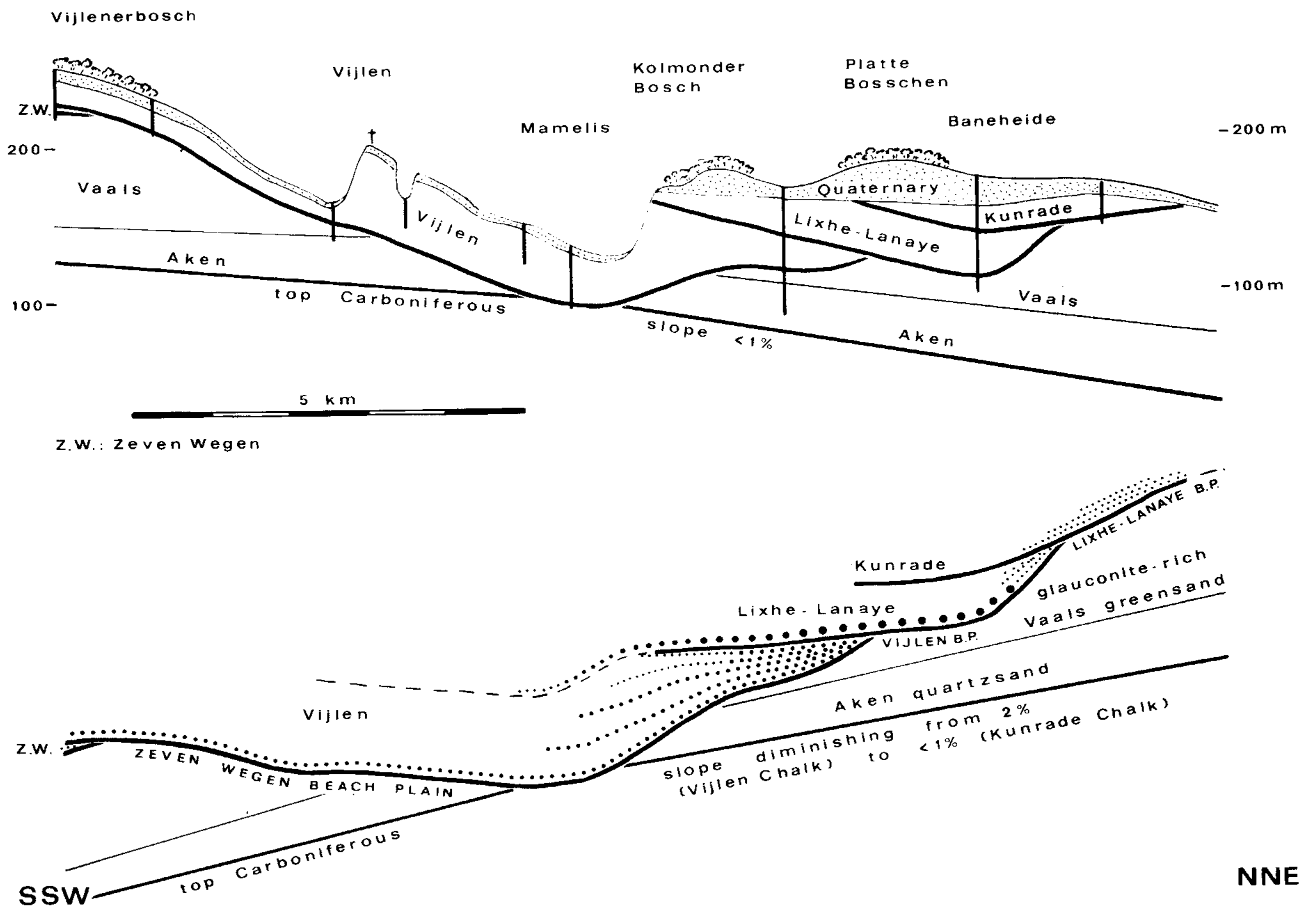


Fig. 20.- Reconstruction of Late Campanian-Maastrichtian overstep (lower half of figure) on Aken-Vaals deposits at southwestern flank of Rur Valley Block based on present-day cross-section between Vijlenerbosch and Baneheide (upper half of figure; modified after Kimpe *et al.*, 1978; Kuyl *et al.*, 1980; Kuyl, 1983). The transgression started with the incipient relaxation of the Rur Valley Block tectonic inversion during the deposition of the Zeven Wegen (and Beutenaken) Chalk when a wide beach plain was formed between Vijlenerbosch and Mamelis. At that time the slope of the top of the Carboniferous basement may have been well over 2%. The step by step relaxation produced a gentler slope of the top Carboniferous which allowed the Maastrichtian sea to transgress further northeasterly over the Rur Valley Block. Eventually, at least the deeper part of the Rur Valley Block itself would be inundated as well (Bless *et al.*, 1993).

formed by tidal abrasion of the foreshore, whereas the northern "slope" acted as backshore. The beach plain now underlying the Vijlen Chalk between Vijlen and Mamelis was formed during the deposition of the Late Campanian Zeven Wegen-Beutenaken Chalk, whereas the beach plain underlying the Lixhe-Lanaye Chalk developed during the deposition of the Vijlen Chalk.

The model in fig. 19 clearly shows that the mollusc-dominated, commonly glauconite-rich deposits with frequent pebble beds are roughly limited to a slightly shallower environment than the echinoderm-dominated sediments. This fits the model of a shallow subtidal (above storm-wave base), sometimes perhaps intertidal, nearshore environment dominated by (storm) wave action and tidal currents and undercurrents for the mollusc-dominated deposits. Part of the glauconite in these layers (but not all the glauconite ! cf. Priem *et al.*, 1975) could have been reworked from the glauconite-rich Vaals greensands. The mollusc clasts (notably the belemnite guards) possibly represent abrasion-resistant elements which accumulated as lenses of shell debris on the beach and which were swept back into the sea by exceptionally heavy storms and/or spring-tides. The chalkstone pebbles are perhaps fragments of calcrete which were reworked by the same mechanism from these beach plains. Quartzite pebbles may have been derived from the Aken and Vaals Formations. Occasional phosphate pebbles and phosphatized macrofossils in the pebble-bearing beds may originate from intertidal or supratidal environments in a foreshore or backshore facies. An example of a beach deposit containing all these elements of age as the Vijlen Chalk can be studied on the Lousberg near Aachen, where a "basal conglomerate" of possible Vijlen age is found between the Vaals Greensand and the flint-bearing Vetschauer Chalk.

The obvious correlation between the top of some of the *Bolivinoides* clusters and the belemnite-rich intervals of intervals 2, 4 and 6, and the associated appearance or disappearance of local marker species are somehow related to the rhythmic succession of belemnite-rich and belemnite-poor intervals in the Mamelis sections. This succession perhaps reflects repeated changes in relative sea level which may have been caused by regional tectonic movements, by eustatic sea level rise and fall, or by a combination of these factors.

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