

THE CAMPANIAN-MAASTRICHTIAN BOUNDARY IN THE CHALKY FACIES CLOSE TO THE TYPE-MAASTRICHTIAN AREA

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The paper develops results related to the macro- and micropalaeontological content of the chalks known on either sides of the Campanian-Maastrichtian boundary in the type-Maastrichtian area. This boundary is studied in the Halembaye quarry (NE of the Belgian Limburg) and in the area around Beutenaken (SE of the Netherlands Limburg). Analytical results are presented for both biostratigraphical and palaeoecological aspects.

Biostratigraphical evidence is given with the distribution of macrofossils, especially Belemnites and other Cephalopods, and of microfossils such as benthic and planktonic Foraminifera, Nannoplankton and Dinoflagellates. Palaeoenvironmental characteristics are suggested after quantitative study on fossil groups giving good palaeoecological information such as mesofossils, Ostracods, Spores and pollen grains. Thus, from one of another fossil group, biostratigraphical zones and ecozones are defined.

The proposal by the International Subcommission on Cretaceous Stratigraphy for beginning an extended Maastrichtian stage with the appearance of *Belemnella lanceolata* is followed up here.

With this concept, the Zeven Wegen Member containing *Belemnitella mucronata* and *Belemnitella mucronata "minor"* is considered as Upper Campanian, the Beutenaken Member with *Belemnella lanceolata inflata* and *Belemnella "occidentalis"* is lower Lower Maastrichtian, the Vijlen Member with *Belemnitella junior* is Upper Maastrichtian (lower part). Long absences of sedimentation separate the three members and are marked by hardgrounds, but reworked material is present only at the very base of each member.

The vertical distributions of macrofossils, Foraminifera, Nannoplankton, Dinoflagellates, Spores and pollen grains, mesofossils and Ostracods are presented on several charts and their stratigraphical and ecological value are commented on.

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RÉSUMÉ

La limite Campanien-Maastrichtien est étudiée dans le Limbourg belgo-néerlandais où se trouve le Maastrichtien type, et plus spécialement à la carrière d'Halembaye et dans plusieurs localités autour de Beutenaken. Des résultats analytiques sont apportés quant à la distribution verticale d'organismes marqueurs dans les craies situées de part et d'autre de cette limite, tant aux plans biostratigraphique que paléoécologique.

La biostratigraphie est assurée par l'exposé de la distribution verticale des principaux marqueurs parmi les macrofossiles-Bélemnites et autres Céphalopodes — ainsi que parmi les microfossiles tels que les Foraminifères planctoniques et benthiques, le Nannoplancton et les Dinoflagellés. Les caractéristiques du paléoenvironnement des diverses craies sont déduites de l'étude quantitative de groupes fossiles considérés comme bons marqueurs écologiques, par exemple, les mésofossiles, les Ostracodes et les Spores-Pollens. Suivant sa valeur propre, chacun des groupes permet de définir des zones biostratigraphiques ou des écozones.

Par ailleurs, la proposition de la Sous-Commission Internationale de Stratigraphie du Crétacé faisant débiter l'étage Maastrichtien avec l'apparition de la Bélemnite *Belemnella lanceolata* est adoptée dans ce travail.

En tenant compte de cette définition, la craie blanche de Zeven Wegen à *Belemnella mucronata* et *Belemnella mucronata "minor"* est attribuée au Campanien supérieur, la craie de Beutenaken à *Belemnella lanceolata inflata* et *Belemnella "occidentalis"* est attribuée à la partie inférieure du Maastrichtien inférieur tandis que la craie grise de Vijlen à *Belemnella junior* appartient à la partie inférieure du Maastrichtien supérieur. De longues périodes d'arrêt de sédimentation séparent les trois unités lithologiques et sont soulignées par des hard-grounds. Pourtant il semble que des remaniements n'aient été enregistrés que sur quelques centimètres à un ou deux décimètres à la base de chaque unité lithologique.

Les extensions verticales des différentes espèces de macrofossiles, de Foraminifères, Nannoplancton, Dinoflagellés, Spores-Pollens, mésofossiles et Ostracodes sont présentées dans une série de tableaux et leurs valeurs stratigraphique et écologique sont discutées.

Mots-clefs : Limite stratigraphique, Campanien, Maastrichtien, Biostratigraphie, Faune belemnite, Stratotype, Pays-Bas, Belgique, Limbourg.

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1. — INTRODUCTION

In the past decades, the boundary between the Campanian and the Maastrichtian stages was linked to the interpretation of authors of what was considered as the Maastrichtian stage and especially the base of this stage. The status of the Maastrichtian stage has been reviewed or reconsidered several times following its creation by DUMONT in 1849, and more accurately by LERICHE

(1927); JELETZKY (1951); VAN DER HEIDE (1954); BERG-

If we follow these proposals, one can put forward the question of what is or what has become (in a biostratigraphical sense) the Campanian-Maastrichtian boundary in the Maastricht area. Therefore, the first purpose of this paper is to present in the most accurate way possible the

vertical distribution of species of the main palaeontological groups occurring in the Campanian-Maastrichtian chalky facies exposed close to the Maastricht locality. Preliminary results of this study were presented at the "Colloque sur le S nonien" held in Marseille in October 1983 (see ROBASYNSKI *et al.*, 1985). Moreover, to explain some of the peculiarities of the vertical and lateral fossil distribution, the palaeoecological conditions of sedimentation of the various chalk facies are specified by the quantitative study of several good ecological marker groups.

2. — GEOGRAPHICAL SITUATION AND LITHOLOGICAL DESCRIPTION OF STUDIED SECTIONS (P.J.F. and F.R.)

Some of the quarries or outcrops studied in this work have been previously described (completely or partly) by RUTOT (1894); FRANCKEN (1947); CALEMBERT (1953, 1956); CALEMBERT & MEIJER (1956); CALEMBERT, MEIJER & MONJOIE (1970); HOFKER (1966); DEROO (1966); FELDER (1975); ALBERS (1976); VILLAIN (1977); STREEL *et al.* (1977); FELDER (1978); FELDER *et al.* (1980).

2.1. THE "CIMENTS PORTLAND LI GOIS" (C.P.L.) QUARRY AT HALEMBAYE (BELGIAN LIMBURG)

The C.P.L. quarry is situated on the left bank of the Meuse river, about 10 km south of Maastricht (Fig. 1). From the base to the top, some 90 m of calcilutites and calcarenites, more or less flinty, are worked for the fabrication of Portland cement (Fig. 2).

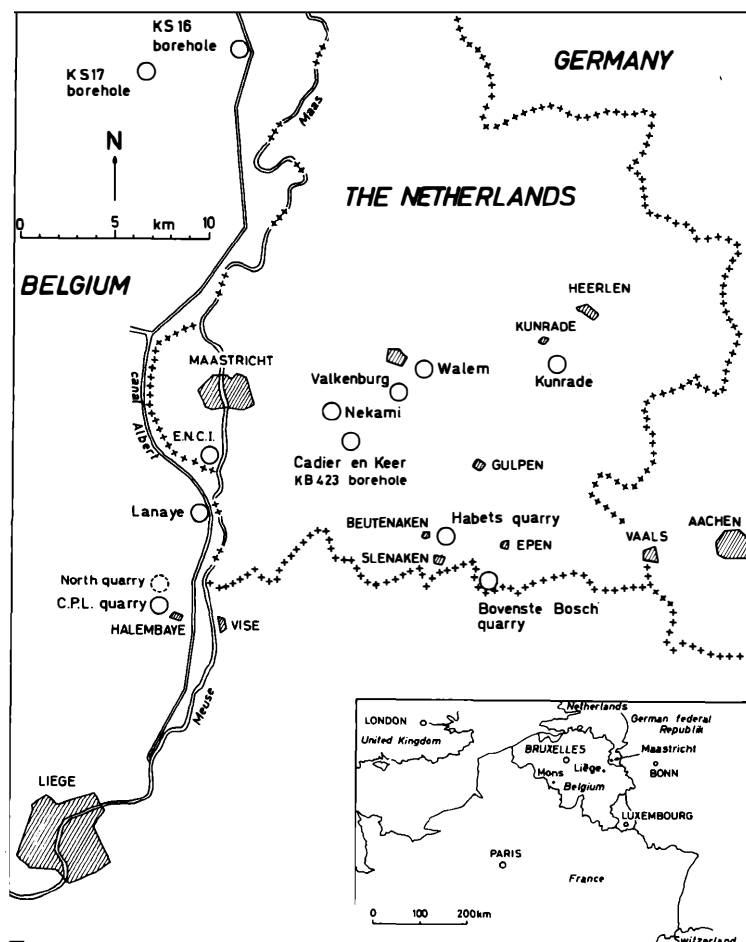


FIGURE 1
Location map of quarries and outcrops studied

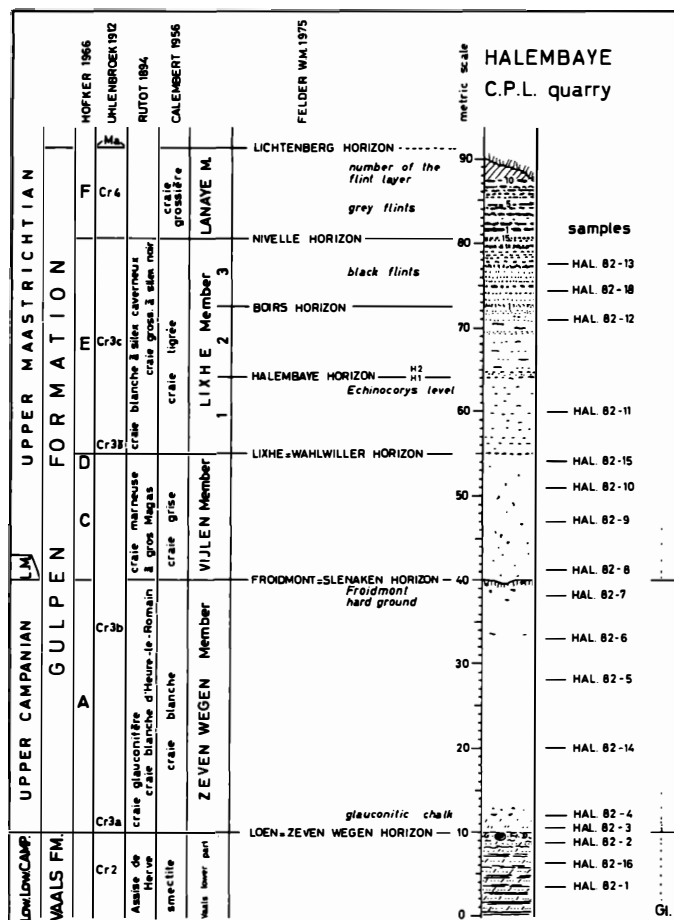


FIGURE 2. — Lithology and sampling in the CPL quarry (Ciments Portland Liégeois) at Halembaye, Belgium (Gl = glauconite)

Two formations are partly exposed in the Halembaye quarry, the Vaals Formation at the base, overlain by the Gulpen Formation.

Remark : "Halembaye" is the spelling used in the 1:25 000 topographic map Tongeren-Herderen 34/5-6, 1976 edition, published by the Institut Géographique National of Bruxelles. Sometimes the spelling "Hallembaye" is also used, for example in commercial maps and in some past or recent literature.

2.1.1. The Vaals Formation

The Vaals Formation, which has a maximum thickness of 150 m in the eastern part of South-Limburg, is only some 20 m thick around Halem-baye. The outcropping strata in the C.P.L. quarry belong to the lower part of the Vaals Formation

(see paragraphs 5.1.4. and 5.3.1.). It consists of glauconite-bearing silt, with clayey and marly beds. Weathered sections show a rhythmic succession of hard and soft layers. Belemnites and Pelecypods (mainly *Ostrea*) are the only common macrofossils. The upper part of the Vaals Formation is absent (due to erosion or interruption of the sedimentation).

2.1.2. The Gulpen Formation

This formation is subdivided into six members which are presented in ascending order.

2.1.2.1. *The Zeven Wegen Member*

- The member is 29 m thick and consists of white, fine grained chalk with a few small black

flint nodules. The base of the member is formed by a glauconitic chalk layer of 0.5-0.3 m thick = Cr3a of UHLENBROEK (1912). At the top, a well developed hardground occurs, including many burrows filled with material introduced from younger, overlying beds (cf. BROMLEY, 1975, and BROMLEY in FELDER *et al.*, 1980). Sometimes, the glauconitic layer at the base bears a rich echinoderm fauna: *Echinocorys* spp., *Echinocorys conicus* (AGASSIZ), *Galeola papillosa* (KLEIN), *Galerites sulcatoradiatus* (GOLDFUSS) and *Micraster coranguinum schroederi* STOLLEY. Other main macrofossils are Pelecypods and Belemnites as *Belemnitella mucronata* (SCHLOTHEIM) and *Belemnitella mucronata "minor"* JELETZKY.

2.1.2.2. The Vijlen Member

The thickness and composition of this member differ from place to place. In the C.P.L. quarry the Vijlen Member is about 14.5 m thick and the chalk is grey-white with light grey flints and some fine-grained glauconite. The chalk is rich in macrofossils, especially Brachiopods (*Magas, Terebratulina* and *Cretirhynchia*), Echinoids and Belemnites as *Belemnitella junior* (NOWAK). The thickness of this member increases some kilometres to the north to more than 50 m and also the glauconite content increases. To the south the thickness decreases to less than 8 m chalk, with hardly any glauconite.

2.1.2.3. The Lixhe Members

Based on the occurrence of flint, three Lixhe Members are recognized.

— The Lixhe 1 Member

It consists of white to grey calcilutites with irregular dark-grey to black flints. The base is characterized by the first black flint layer which can be followed through the quarry and the surrounding area. The top of the member is the next black flint layer (Halembaye 1) which can be followed over a large distance. The two flint layers have a distance of about 8.5 m. The calcilititic chalk is rich in macrofossils (mainly the same Brachiopods as in the Vijlen Member). The upper part is extremely rich in Echinoids (*Echinocorys* level). Belemnites as *Belemnitella junior* are also common.

— The Lixhe 2 Member

This consists of white to grey calcilutites with many irregular dark-grey to black flints. At the base two well-developed flint layers (Halembaye 1 and Halembaye 2) occur. Above these two layers

follows a bed with randomly distributed flints, whereas in the upper part of the member the flints are bedded in layers which increase in thickness. The thickness of the total member varies between 7.5 m and 10 m. The calcilititic chalk is extremely poor in macrofossils. Only fragments of Belemnites and Echinoids are found.

— The Lixhe 3 Member

In this member flints occur in 15 well-developed layers which can be recognized throughout the region. About eight metres thick, the calcilutites are white to grey and poor in macrofossils. Only in its upper part occur Crinoids and Belemnites, normally in the chalk layers without flint

2.1.2.4. The Lanaye Member

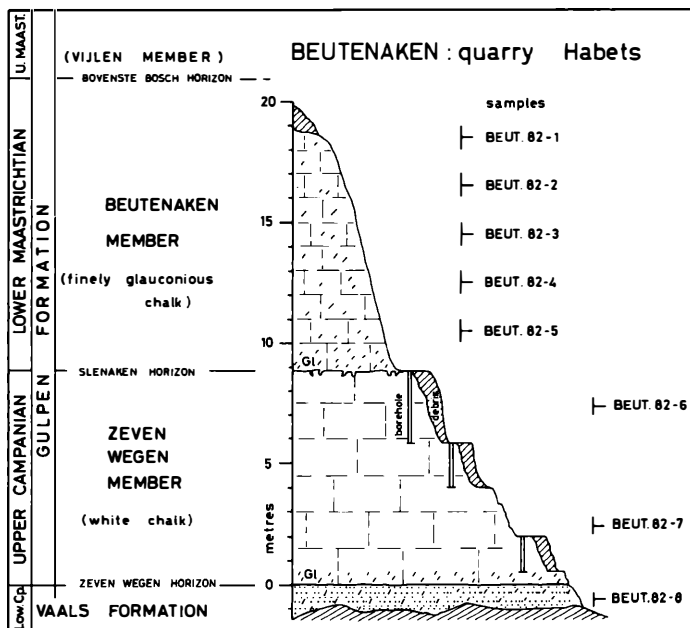
In the C.P.L. quarry the Lanaye Member forms the top of the exposed Cretaceous. Only the lower portion of this member is exposed in the most northern part of the quarry (from the Nivelles Horizon to flint layer no 10). The flint layers in the Lanaye Member can be recognized through the whole area. The total member contains 23 flint layers and is up to 20 m thick. It is true calcarenite, white to grey or yellow. In the lower part (up to flint layer no 10), Crinoids and Belemnites are common macrofossils. In the upper part (above flint layer no 10), the calcarenite becomes rich in macrofossils (Brachiopods, Pelecypods, Crinoids, Echinoids, Bryozoans and Octocorals). In this part occur also *Hemipneustes striatoradiatus* (LESKE), *Allopleuron hoffmanni* (GRAY), *Mosasaurus hoffmanni* (MANTELL) and *Mosasaurus lemonnieri* DOLLO (cf. MEIJER, 1984; PLUSNIER & COUPATEZ, 1969).

In the Halembaye quarry, the grain size increases upwards from the fine-grained and soft chalk at the base of the Gulpen Formation into coarse-grained calcarenite in the Lanaye Member.

2.2. THE QUARRY HABETS AT BEUTENAKEN (NETHERLANDS LIMBURG)

This quarry is an old abandoned quarry on the eastern slope of the valley cut out by the Gulp river. It is the type location of the Beutenaken Member (Fig. 3). However, the top of the Beutenaken Member is not exposed in the quarry itself, but some metres higher up in the valley slope. The exposed chalk of the Beutenaken Member is white to yellow with some glauconite, increasing at the base. The base is a glauconitic chalk. Below the Beutenaken Member, the Zeven Wegen Member consists of white-yellow chalk. At the top, a poorly

FIGURE 3
The sampling in the quarry Habets at Beutenaken, Netherlands (Gl = glauconite)



developed hardground occurs. The higher part of the chalk contains nearly no glauconite, whereas in the lower part the glauconite content increases and forms a glauconitic chalk. Macrofossils are rare, but occasionally Belemnites and heteromorph Ammonites are found. At the base of the quarry some metres of the middle Vaals Formation are exposed, consisting of a sandy silt with some marly layers.

2.3. THE BOVENSTE BOSCH QUARRY AT EPEN (NETHERLANDS LIMBURG)

This is a small, abandoned and decayed quarry on the southern slope of the Geul Valley at Epen (Fig. 4). The Cretaceous rocks are largely covered by slope debris. The section shows the upper portion of the Zeven Wegen Member, the Beutenaken Member and the basal part of the Vijlen Member. A borehole in the quarry demonstrated that the Zeven Wegen Member is about 10 m thick, and is overlying marly sands of the Vaals Formation.

The poorly fossiliferous, very fine-grained, whitish-yellow chalk of the Zeven Wegen Member has yielded a few echinoids (*Echinocorys* sp.,

Galeola papillosa KLEIN) and internal moulds of heteromorph Ammonites. The chalk is capped by an indistinct hardground, the Slenaken hardground.

The overlying yellow-grey, glauconitic chalk of the Beutenaken Member is also very fine-grained and poor in macrofossils, except for Belemnites in the basal, very glauconitic layer on top of the Slenaken hardground. The top of the Beutenaken Member is also marked by a hardground: the Bovenste Bosch hardground. This hardground can be rich in (partly reworked) fossils amongst which there are many Belemnites.

The level is overlain by a basal conglomerate, consisting of rounded fragmented Belemnites and phosphatized fossils, limestone, quartz and quartzite pebbles. These are embedded in a glauconitic chalk matrix. Because of the abundance of belemnite fragments, this basal conglomerate is known as the "Belemnite graveyard". Upwards, this layer passes into a yellow-grey, fine-grained, glauconitic chalk with a wealth of macrofossils: Belemnites, Echinoids such as *Echinocorys limburgicus* (LAMBERT), *Echinogalerus belgicus* (LAMBERT), *Cardiaster granulosus* (GOLDFUSS), *Galerites sulcatoradiatus* (GOLDFUSS), Brachiopods such as Terebratulidae, Rhynchonellidae, and Craniidae, bivalve fragments, and Cephalopods: Nautiloidea, Ammonoidea

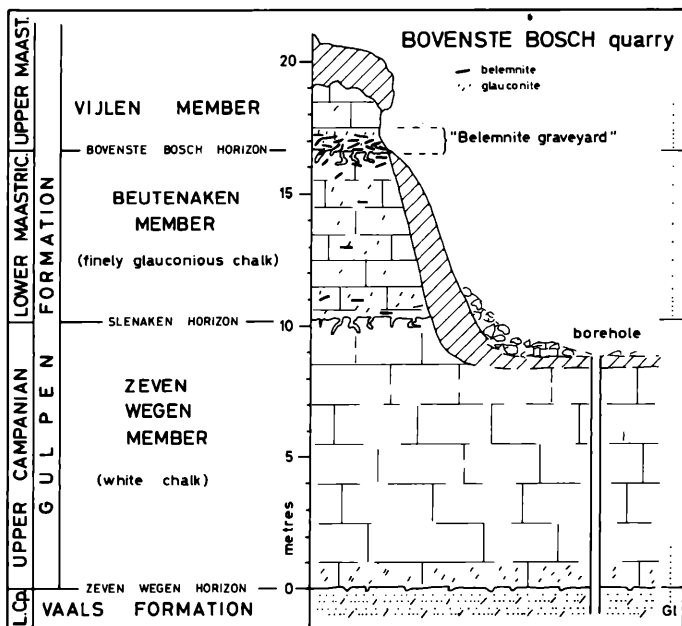


FIGURE 4

The Bovenste Bosch quarry at Epen, Netherlands, with the position of the "Belemnite graveyard" (Gl=glauconite)

2.4. THE BOREHOLE KB 423 AT CADIER EN KEER (NETHERLANDS LIMBURG)

In the borehole KB 423 at Cadier en Keer (Fig. 5), the Vijlen Member has been found at a depth between 58.30 m and 78.00 m. This consists

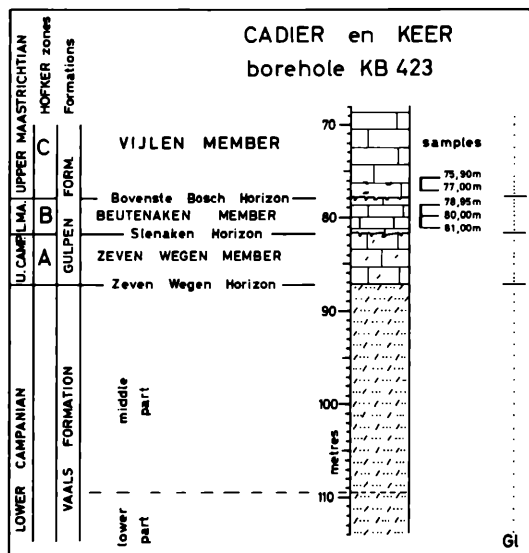


FIGURE 5

The sampling in the Cadier en Keer borehole KB423, Netherlands (Gl=glauconite)

of a light-grey chalk with small, light-grey flints and fine- to coarse-grained glauconite. At the base, just above the Bovenste Bosch hardground, a glauconitic layer (77.60 m - 78.00 m) occurs, bearing many Belemnites. The Beutenaken Member (between 78.00 m - 79.00 m) consists of a light-grey chalk with some glauconite and burrows filled with glauconitic chalk. The lower part (between 79.90 m and 81.80 m) of this member consists of a grey-greenish chalk with many glauconite grains and some small, rounded pebbles. In this layer, Belemnites are common. The Zeven Wegen Member (between 81.80 m and 83.90 m) consists of grey chalk with glauconite which is sometimes bedded in layers. Between 83.90 m and 87.25 m the chalk is grey-green with much glauconite. Macrofossils are rare except for Belemnites. The Vaals Formation consists of silt, sometimes sandy or clayish, with chalk and glauconite. Locally the Pelecypod *Cuculaea* sp. is common

3. — THE BASE OF THE MAASTRICHTIAN STAGE (F.R.)

3.1. HISTORICAL REVIEW OF THE CONCEPT OF MAASTRICHTIAN STAGE (Fig. 6)

In his "Essai sur la géologie du Nord de la France", D'OMALIUS (1808) reported the existence of a "calcaire grossier de Maestricht" (= Maestricht coarse limestone, named by him "tuffeau" in 1828 and 1842), containing "quartz pyromaque à la base" (= flints at the base, named by him "silex gris" = grey flints in 1828). He wrote also that this "calcaire" was "plus récent que la craie" (= younger than the chalk).

DUMONT (1832) also used the term "calcaire de Maestricht" the base of which he defined by the presence of "bancs continus de silex gris" (= continuous grey flints beds).

In 1840, D'ORBIGNY (in the "Céphalopodes" part of the "Paléontologie française") described the "terrain de craie blanche" (= white chalk formation) including the "calcaire de Maestricht" (but neither the "étage sénonien" nor the "système maestrichtien" were defined at this time). The same author, in the "Gastéropodes" part of the "Paléontologie française" (1843), created the term "terrain sénonien" (= Senonian formation) for all the chalks around Sens in France (but in this work he did not refer to the "calcaire de Maestricht").

The "système maestrichtien" was created by DUMONT in 1849 accepting a "glauconie sableuse" (= glauconitic calcarenite, or coprolitic level, or *Dentalium* level) at its base which "repose sur le terrain sénonien" (= which rests on the Senonian formation).

Thus, historically, the Senonian and the Maastrichtian do not represent the same time interval, the "Maestrichtien" of DUMONT being younger than the "Sénonien" of D'ORBIGNY. Nevertheless, in his "Prodrome", D'ORBIGNY (1850) included several fossil species of the "calcaire de Maestricht" in his Senonian and, in 1852, he incorporated in the Senonian the "Tufau de Maestricht" which represented DUMONT's "système maestrichtien" created three years before.

In 1857, COQUAND created the Coniacian, Santonian, Campanian and Dordonian stages (but the Dordonian is considered by numerous authors — as NEUMANN, 1980 — as a particular facies of the Campanian).

Later on, BINCKHORST (1859) and UBAGHS (1866) also included the "tuffeau de Maestricht" in the Senonian. In 1860, STARING created the "Gulpensch Krijt" (= Gulpen Formation). But DEWALQUE (1868) is the first who clearly distinguished between the "Senonien" and the "Maestrichtien" systems. He was followed by RUTOT and VAN DEN BROECK (1887) who supported this distinction in the successive explanations of the geological map of Belgium (1892-1929). Moreover, RUTOT (1894) used the correct spelling "Maastrichtian" as at the time of creation of the "système" (1849), the type-locality had been under Netherlands legislation since 1830 (at that time "Maestricht" became "Maastricht"), cf. also VAN DER HEIDE (1954). It should be noticed that HAUG (1911) used the term Senonian with a very wide sense including Coniacian, Santonian, Campanian, Maestrichtian and Danian. His example was followed by a number of French geologists, although this concept was not based on a historical reality.

In 1912, the "calcaire de Maestricht", which referred to a whole Maastrichtian at that time, was subdivided into Ma, Mb, Mc and Md units by UHLENBROEK (after a first proposal in 1905). In the same year, the "Lanceolata Beds (*Belemnites lanceolata* Zone)" were first identified by ARKHANGELSKY (1912) who assigned them to the Lower Maastrichtian" (*vide* NAIDIN, 1983). This lowered extension of the Maastrichtian was also recommended by LERICHE (1927) who characterized the base of the stage by the incoming of several fossil species as *Scaphites constrictus*. For LERICHE, this Maastrichtian is distinct from the Senonian and it is absent in the Paris Basin.

But it is only after JELETZKY's publication on Belemnites (1951) that most of the biostratigraphers in the Boreal realm accepted the concept of an extended Maastrichtian stage beginning with the first appearance of *Belemnella lanceolata*. It is the opinion supported, for example, by VAN DER HEIDE (1954); ROMEIN (1962); SCHMID (1967); FELDER (1975); CHRISTENSEN (1975); SCHULZ (1979); SCHULZ & SCHMID (1983), etc.

3.2. THE PRESENT DEFINITION OF THE BASE OF MAASTRICHTIAN STAGE

In October 1983, during the Symposium on Cretaceous Stage Boundaries held in Copenhagen, a definition of the base of the Maastrichtian stage was proposed: "It was widely accepted to keep the base of the Maastrichtian close to the

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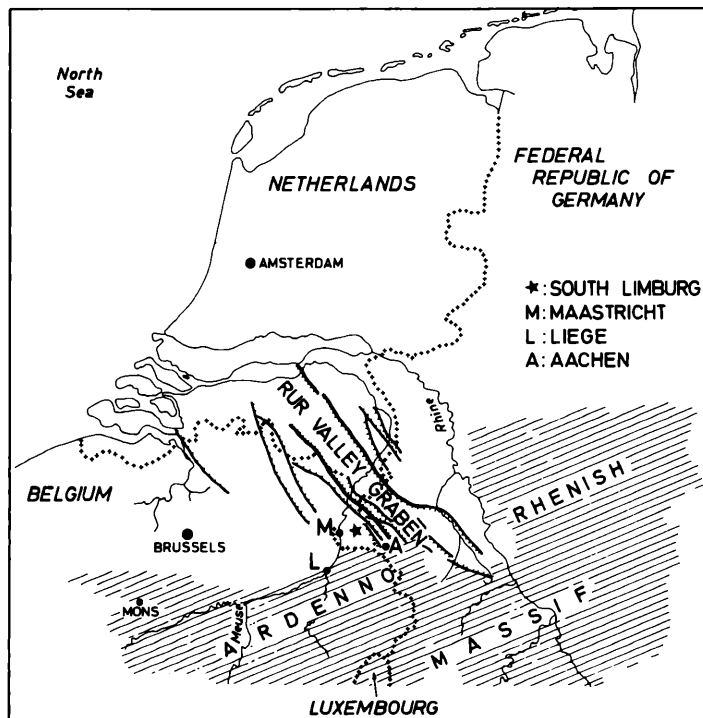


FIGURE 7

General location map showing position of South-Limburg in southeastern Netherlands, as well as principal geological structures (Ardenno-Rhenish Massif to the SE and Rur Valley Graben or Central Netherlands Graben to the NE). Note occurrence of large faults parallel to the Rur Valley Graben

appearance of *Belemnella lanceolata*, as this datum is so well defined and widely accepted in the Boreal Realm" (BIRKELUND *et al.*, 1984).

This recommendation is followed here.

4. — WHAT IS THE MAASTRICHTIAN IN THE TYPE REGION (M.J.M.B., P.J.F., F.R.)

4.1. THE "TYPE SECTION" OF THE MAASTRICHTIAN

With DUMONT's concept of "système maestrichtien", the type section occurs at Maastricht, in the E.N.C.I. quarry, below the Lichtenberg farm. It consists of the four units of the calcarenitic "Maas-trichtsch krijt" (=Maastricht Formation) named Ma to Md by UHLENBROEK (1905, 1912) and later described by ROMEIN (1962).

Following the extended concept of the Maestrichtian, below the Maastricht Formation the Lanaye, Lixhe, Vijlen and Beutenaken Members of the Gulpen Formation are to be included in the

Maastrichtian because the Beutenaken Member contains *Belemnella lanceolata inflata* appearing almost at the same level as *Belemnella lanceolata* (SCHULZ, 1979; SCHULZ *et al.*, 1984).

A good historical review on the evolution of the sense of the Maastrichtian as a well informed description of Late Cretaceous lithological units of Limburg is given by DEROO (1966).

4.2. CORRELATION OF LOCAL SECTIONS IN THE MAASTRICHT REGION (M.J.M.B., P.J.F. and J.P.M.Th.M.)

Depositional history of the Late Cretaceous sediments in South Limburg and surrounding areas

The Late Cretaceous deposits of South-Limburg and surrounding areas show lateral variations in their lithology and important gaps (marked by strongly diachronous erosion horizons which are partly developed as hardgrounds). These reflect the intricate tectonic history of this region situated between the Rur Valley Graben (or Central Nether-

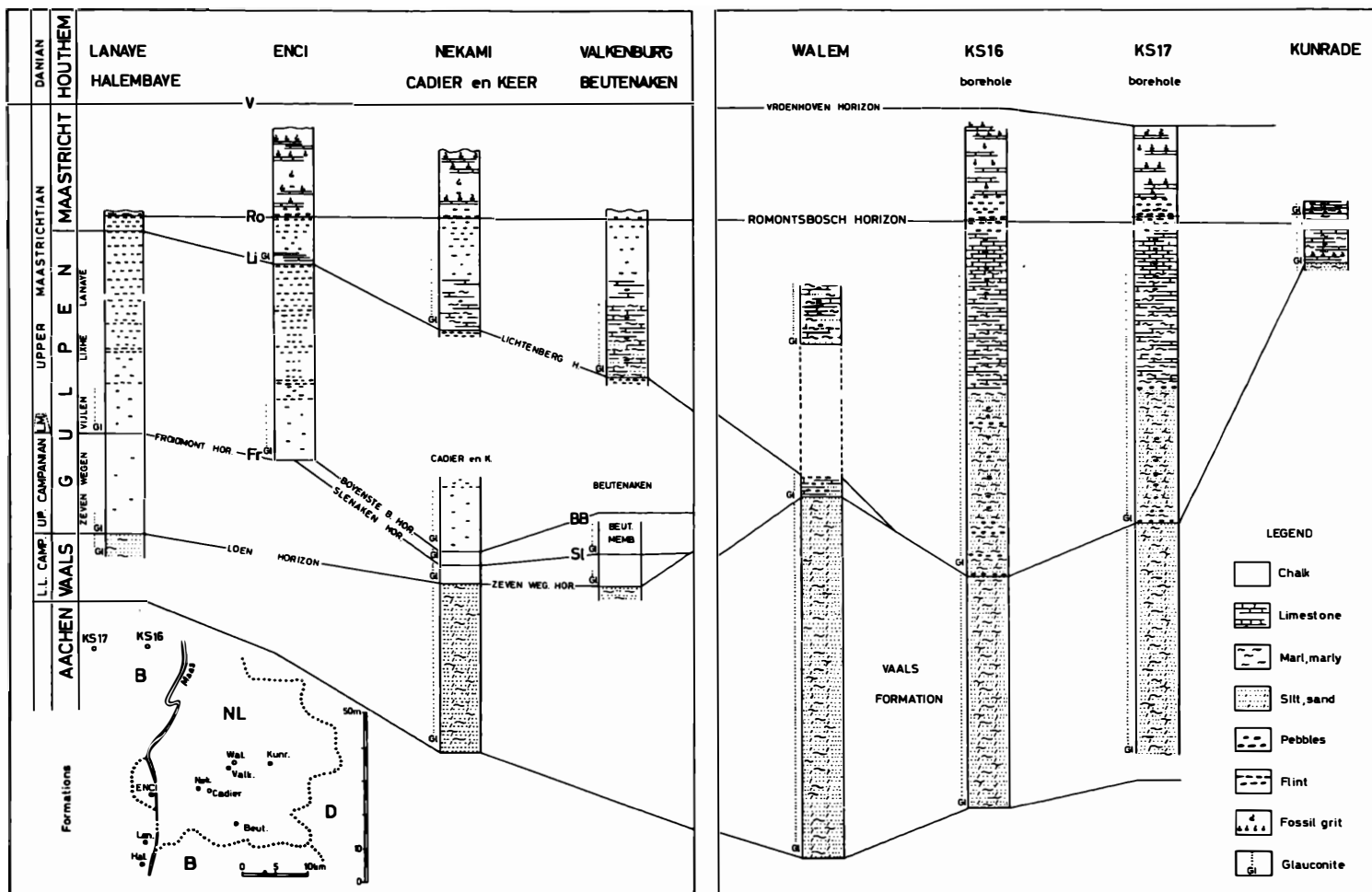


FIGURE 8

Correlation chart of local lithostratigraphical sections for the Campanian-Maastrichtian in South-Limburg

lands Graben) to the north-east and the Ardenn-Rhenish Massif to the south-east (Fig. 7). The most important gap occurs around the Campanian-Maastrichtian boundary which has been recognized within the Gulpen Formation. The Gulpen Formation itself wedges out towards the north-east, where the underlying Vaals Formation and the overlying Maastricht Formation seem to be more completely developed. At the same time, the critical interval — comprising the Campanian-Maastrichtian boundary — is absent in the Halembaye-Lanaye sections, where the Gulpen Formation shows its maximum development. This interval is best developed in the Beutenaken section, where the boundary beds of the Upper Campanian and Lower Maastrichtian are separated by the Slenaken erosion horizon or Slenaken hardground (Fig. 8).

Sedimentation in South-Limburg started during the Santonian (Fig. 9) with the deposition of the Aachen Formation, consisting of — sometimes cross-bedded — clays and sands. The frequent presence of plant remains (locally developed as lignite beds, elsewhere consisting of silicified trunks with numerous pelecypod burrows suggesting a beach environment), is indicative of a nearshore to onshore deposit for this formation. The Aachen Formation is best developed in the Aachen area. Towards the north-west, only some thin remnants of the upper (sandy) portion of the same have been preserved.

The younger Vaals Formation is of Campanian age. In many places, this deposit directly rests upon Palaeozoic rocks.

A basal conglomerate is locally present. The sediments consist of marine, slightly calcareous to marly sands and silts with varying amounts of authigenic glauconite (hence the former name "Aachen Greensand"). The abundance of authigenic glauconite and burrows suggests a frequently very shallow marine environment. Bivalves and belemnite guards abound in some layers. By means of benthic Foraminifera, the Vaals Formation can be subdivided into a lower, middle and upper portion.

Deposition of the Vaals Formation was followed by a period of erosion and/or non-deposition. Erosion took place a.o. in the areas of Halembaye and Beutenaken where, respectively, the middle to upper and the upper Vaals Formation are absent below the basal beds of the Gulpen Formation. Non-deposition occurred a.o. in the Walem area where the upper Gulpen Formation (Lanaye Member) is overlying the upper Vaals Formation,

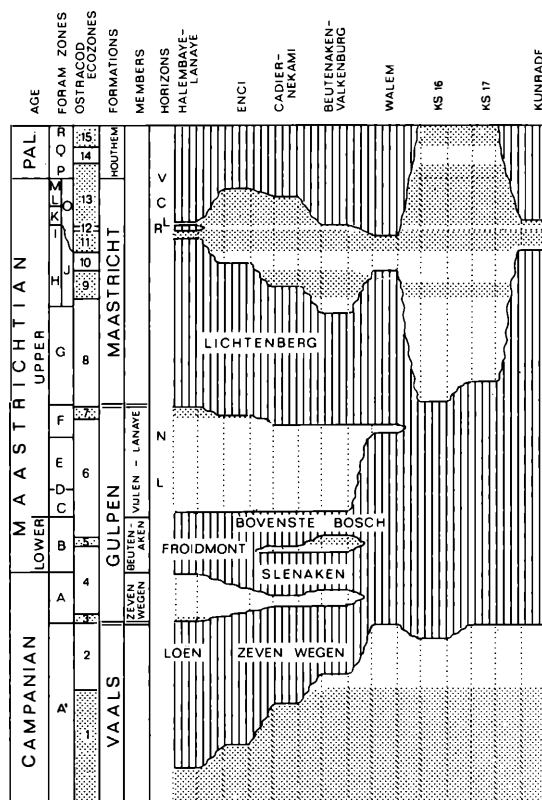


FIGURE 9

Schematic lithostratigraphical and chronostratigraphical chart from Campanian and Maastrichtian in South-Limburg (chronostratigraphical units not to scale). Lines : no sediments; dotted surface : ornamented Ostracods; undotted surface : smooth Ostracods. Note that in this scheme it is accepted that the "upper Vaals" Formation (characterized by the benthic Foraminifera assemblages A' middle and A' upper and by the ostracod ecozone 2) is older than the Gulpen Formation. Also it is accepted that the "lower Maastricht" Formation (corresponding to the ostracod ecozone 8 and the mesofossil ecozone 4) is younger than the Gulpen Formation. However, recently some indications have been discovered which suggest that these deposits might be the lateral (nearshore) equivalent of the Gulpen Formation (FELDER *et al.*, Prof. Pap. Belgian Geol. Survey, in preparation).

and in the KS16-KS17 boreholes and Kunrade areas where the Gulpen Formation is completely absent and the lower Maastricht Formation rests directly on the upper Vaals Formation.

The lowermost part of the Gulpen Formation (Zeven Wegen Member) is of Upper Campanian age. The basal portion of the Zeven Wegen Member bears large amounts of sand and glauconite ("Craie glauconifère" of RUTOT, 1894).

Several erosion horizons or hardgrounds within the Gulpen Formation indicate repeated interruption of the sedimentation and even erosion during the latest Campanian until the Upper Maastrichtian. Lower Maastrichtian deposits are restricted to the Beutenaken Member of limited lateral extension and characterized by glauconite and belemnite guards of Lower Maastrichtian age. The lowermost Upper Maastrichtian deposits within the Gulpen Formation (Vijlen to Lixhe-3 Members) are overstepped towards the north-east by the topmost Gulpen sediments of the Lanaye Member.

The sediments of the Gulpen Formation consist of marine, very fine-grained chalk (calclutites to calcisiltites) with an upward increasing amount of chert (usually concentrated in widespread beds which can be traced throughout the area). Bivalves and belemnite guards abound in some layers. The sediment and the fossil assemblages suggest that deposition occurred in an open marine environment that was slightly deeper than that of the Vaals Formation.

A renewed period of erosion and/or non-deposition is represented by the Lichtenberg Horizon separating the Maastricht Formation from the underlying Gulpen Formation (in the south-west) or Vaals Formation (to the north-east). The oldest deposits of the Maastricht Formation are found in, respectively, the Campine area (KS16-KS17) and around Valkenburg-Walem. From Valkenburg to Lanaye, the lower Maastricht Formation gradually oversteps always younger sediments of the Lanaye Member of the Gulpen Formation.

The oldest (marly) deposits of the Maastricht Formation bear an upward decreasing admixture of glauconite and silt/sand. Higher upwards, a sequence of alternating hard/soft chalk occurs with locally shale and coal pebbles derived from Upper Carboniferous rocks which presumably had been exposed to erosion somewhere to the north-east. This sequence may be slightly diachronous and is replaced towards the south-west by fine-grained to coarse-grained chalk (calclutites to calcarenites) with flint layers. A number of hardgrounds in the higher portion of the Maastricht Formation suggests a repeated interruption of the sedimentation. Also the boundary between the Maastricht Formation and the Early Tertiary (Paleocene) Houthem Formation is marked by a hardground (Vroenhoven hardground). The rather diverse fossil assemblages of the Maastricht Formation are frequently shallow marine facies.

The rather complex depositional history of the Late Cretaceous sediments in the South-Limburg

area may be best explained by accepting rotational movements of the basin floor parallel to the NW-SE striking faults of the Rur Valley Graben. The rate of subsidence was highest in the north-east (Walem-Valkenburg and Campine areas) during the deposition of the Vaals and Maastricht Formations, and highest to the south-west (Hallembaye area) during the deposition of the Gulpen Formation. This overall pattern has been complicated by the fact that this basin floor was broken up into smaller tectonic units showing differential rates of subsidence (cawkwalk movements).

Thus, in such a depository context, it appears that the Maastrichtian cannot be defined on one section only, the thicknesses and lateral facies variations being relatively too important. In this way, to seize the connections between the different lithological units, it is more realistic to use a type region to understand the Maastrichtian of Limburg (the Netherlands and Belgium).

A different solution might be found in accepting that the upper portion of the Vaals Formation (upper A' Foraminifera Zone) and the lower portion of the Maastricht Formation (ecozone 4 according to mesofossils) might be the northern, lateral equivalent of the Gulpen Formation. In that case, the Campanian-Maastrichtian boundary might be recognized some day also in a possibly nearshore environment, where abundant belemnite guards seem to occur. This possibility will be dealt with in another paper by FELDER *et al.* in the Professional Papers of the Geological Survey of Belgium. In that case, the sedimentary gaps would be much smaller than accepted here and in the previous literature.

5. — BIOSTRATIGRAPHY : ANALYTICAL RESULTS

5.1. CEPHALOPODS : BELEMNITES (L.A. VDT.)

5.1.1. Introduction

In Limburg, the Netherlands and Belgium, belemnite guards can be the most usable macrofossils for biostratigraphical purposes, because they are found more frequently and are less facies-bound than other macrofossils. Therefore, a good knowledge of the stratigraphical range of the several belemnite species is desirable. The more so as the boundaries between the stages and substages of the upper part of the Cretaceous in the Boreal realm are largely based on Belemnites.

The following belemnite species are found in the Upper Cretaceous of Limburg: *Gonioteuthis quadrata* (BLAINVILLE), *Belemnitella mucronata* (SCHLOTHEIM), *Belemnitella mucronata* "minor" sensu JELETZKY, *Belemnitella junior* NOWAK, *Belemnella lanceolata inflata* (ARKHANGELSKY), *Belemnella "occidentalis"* sensu BIRKELUND, *Belemnella casimirovensis* (SKOLOZDROWNA). All these belemnite species are found in the localities of Halembaye and Beutenaken, with the exception in both localities of *Belemnella casimirovensis*. In these localities the Campanian-Maastrichtian boundary is clearly marked at the base of the Maastrichtian layers by a rich belemnite bed related to a gap of sedimentation.

For the Upper Cretaceous sediments of the "Ciments Portland Liégeois" quarry (C.P.L.) at Halembaye, we can recognize the following belemnite zones: the *Gonioteuthis quadrata* Zone, the *Belemnitella mucronata* Zone and the *Belemnitella mucronata* "minor" Zone of the Campanian; and the *Belemnitella junior* Zone of the Maastrichtian.

In the Upper Cretaceous sediments of Beutenaken five belemnite zones can be recognized: the *Belemnitella mucronata* Zone and the *Belemnitella mucronata* "minor" Zone of the Campanian; the *Belemnella lanceolata* Zone, the *Belemnella "occidentalis"* Zone and the *Belemnitella junior* Zone of the Maastrichtian. The belemnite guards of *Belemnella lanceolata inflata* and *Belemnella "occidentalis"* are very abundant at the top of the Beutenaken Member.

It is striking that the *Belemnella lanceolata* Zone is extant only in Beutenaken and not in Halembaye. Here the *Belemnella lanceolata* Zone is marked only above the Froidmont hardground by the presence of rare, reworked guards of *Belem-*

nella lanceolata inflata preserved in local depressions.

Note: The locality Beutenaken is taken in a wider sense than only the Habets quarry near Beutenaken, because of the pooriness of the available material. With the locality "Beutenaken" is meant in this paper the area around Beutenaken with the localities as shown in the map (Fig. 10).

5.1.2. Historical review

In the 19th century and a large part of the 20th century, Limburg Belemnites were commonly referred to as "*Actinocamax quadratus*" for the Lower Campanian forms and "*Belemnites mucronatus*" for all other Belemnites (e.g. BINCKHORST, 1861; BOSQUET, 1860; SCHLÜTER, 1876; HOLZAPFEL, 1888; VAN DER WEIJDEN, 1943). This situation continued to exist until some workers on Belemnites reviewed the older literature and made more differentiated lists (JELETZKY, 1951). Real fieldwork was done for the first time by SCHMID (1959) who made the first useful biozonation in Limburg based on Belemnites. After the detailed lithostratigraphical studies of FELDER (1975 a, 1975 b) it was possible for VAN DER TUUK & BOR (1980) to make a more detailed lithostratigraphically correlated biozonation, mainly based on SCHMID (1959).

5.1.3. Description of the material

Nowadays, belemnite systematic is still unsatisfactory. In order to avoid unnecessary confusion, a short description of the material is given. However, one must not consider the present paper as a complete systematical work. For that, the following papers are suggested: BIRKELUND (1957); CHRISTENSEN (1975); JELETZKY (1949, 1951); SCHULZ (1979). Material that was more or less badly worn is herein

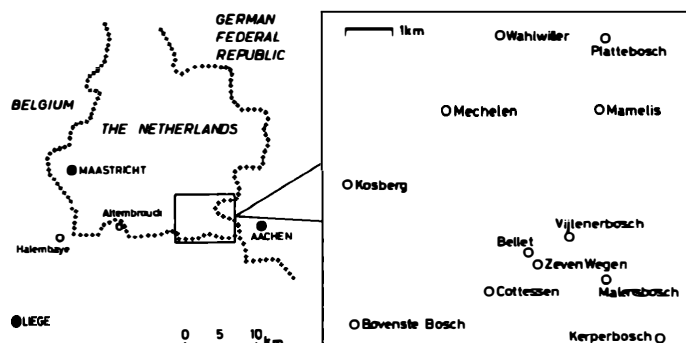


FIGURE 10

Map of localities studied in the Beutenaken region for their cephalopod content

considered to be reworked. Guards that are referred to as *in situ* were found in such a good state that they are considered to be originally embedded. Parts of guards that could not be determined because of their fragmental character were not used in this study. The number of retained specimens is roughly indicated in the stratigraphical tables by the terms: rare (< 3 specimens), present (3 - 10 specimens), common (11 - 25 specimens) and abundant (> 25 specimens).

The Belemnites were placed at my disposal by the Museum of Natural History at Maastricht (collection W.M. Felder) and the Teylers Museum at Haarlem (collection of the author). Belemnite terminology is shown in Fig. 11.

Order : Decapoda LEACH, 1818

Family : Belemnitidae D'ORBIGNY, 1845

Genus : *Gonioteuthis* BAYLE, 1878

Gonioteuthis quadrata (BLAINVILLE, 1827)

Plate 1, fig. 1a-1b

A slender guard with a blunt apex on which a short mucro is present. Slightly lanceolate in ventral view, highly conical in lateral view. The average length is 60 mm. The average dorsoventral diameter-length ratio is 0.19. The depth of the pseudoalveolus is 10 mm. A short ventral fissure is present. The surface of the guard is marked with longitudinal depressions, double furrows and vascular imprints. Almost the complete surface is covered with transverse, corrugated granules. Characteristic of this species is the subrhomboidal appearance of the pseudoalveolus in anterior view.

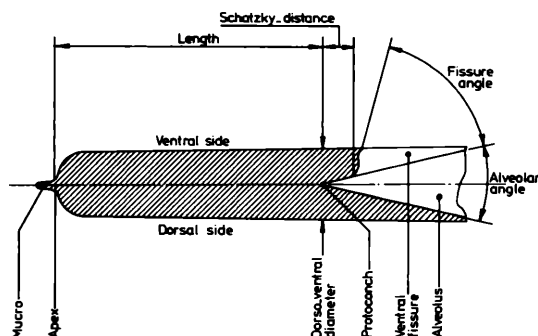


FIGURE 11

Morphological features of belemnite guards

Remarks : The length is the distance between the apex and the protoconch. There is a pseudoalveolus when the material around the alveolus is not completely calcified, and thus not preserved.

Genus : *Belemnitella* D'ORBIGNY, 1840

Belemnitella mucronata (LINK, 1807)

(Synonym : *Belemnitella mucronata senior* NOWAK, 1913; see CHRISTENSEN *et al.*, 1975)

Plate 1, fig. 2a-2b and 3a-3b

A large guard with a blunt apex on which a well definable mucro is present. Cylindrical or slightly lanceolate in ventral view and highly conical in lateral view. Ventrally flattened. The average length of adult specimens is about 80 mm. The dorsoventral diameter-length ratio has an average of 0.28. The alveolar angle is about 20° and the fissure angle between the bottom of the ventral fissure and the wall of the alveolus varies between 5° and 50°. The average Schatzky distance is 7 mm. The surface of the guard is marked with longitudinal depressions, double furrows and some longitudinal striation and vascular imprints. *Belemnitella mucronata* is larger and more conical in lateral view than *Belemnitella mucronata "minor"*. The vascular imprints are better developed than at *Belemnitella mucronata "minor"*.

Belemnitella mucronata "minor" sensu JELETZKY, 1949; and *sensu* BIRKELUND, 1957

Plate 2, fig. 1a-1b and 2a-2b

A rather large guard with a blunt apex, on which a hardly definable mucro is present. Slightly lanceolate in ventral view, slightly conical, subcylindrical or lanceolate in lateral view. The average length of adult specimens is 64 mm. The dorsoventral diameter-length ratio has an average of 0.24. The alveolar angle is about 20° and the fissure angle varies between 15° and 90°. The average Schatzky distance is 8.4 mm, but never less than 5 mm. The surface of the guard is marked with longitudinal depressions, double furrows and some longitudinal striae and vascular imprints. *Belemnitella mucronata "minor"* is thicker, less conical and the surface is more smooth than in *Belemnitella junior* NOWAK.

Remarks : The described form was referred to as "*Belemnitella langei*" by VAN DER TUUK (*in* ROBASYNSKI *et al.*, 1985), which was considered to be synonymous with *Belemnitella mucronata "minor"* JELETZKY. The species *Belemnitella langei* is nowadays generally considered to be different from

Belemnitella mucronata "minor", and has only been found in Krons Moor (Germany) and in the Soviet Union (CHRISTENSEN, pers. comm.).

***Belemnitella junior* NOWAK, 1913**

Plate 3, fig. 2a-2b and 3a-3b

A large guard with a short mucro. Slightly lanceolate in ventral view and conical in lateral view. The length of adult specimens can reach 135 mm. The dorsoventral diameter-length ratio has an average of 0.20. The alveolar angle is about 23° and the fissure angle varies between 17° and 43°. The average Schatzky distance is 7.5 mm. The surface of the guard has a wrinkled appearance, caused by dense vascular imprints and longitudinal striae.

Genus : *Belemnella* NOWAK, 1913

***Belemnella lanceolata inflata* (ARKHANGELSKY, 1912)**

(Synonym : *Belemnella* aff. *lanceolata* SCHLOTHEIM, 1813, *sensu* BIRKELUND, 1957, tab. 3, fig. 4).

Plate 2, fig. 3a-3b

A very slender guard with a blunt apex, on which a hardly definable mucro is present. Highly lanceolate in ventral view and slightly lanceolate or subcylindrical in lateral view. Ventrally flattened. The average length of adult specimens is 70 mm. The dorsoventral diameter-length ratio has an average of 0.16. Juvenile specimens are much more slender. The alveolar angle is about 14° and the fissure angle varies between 10° and 80°. The Schatzky distance varies between 0 and 2.4 mm. The surface is marked with hardly visible vascular imprints. *Belemnella lanceolata inflata* is more slender and more lanceolate than *Belemnella "occidentalis"* *sensu* BIRKELUND, 1957, and has a more sinuous bottom on the ventral fissure.

Remarks : The described form was named "*Belemnella lanceolata*" by VAN DER TUUK (*in* ROBASYNSKI *et al.*, 1985), which was a general determination of the more slender forms of *Belemnella* in the Beutenake Member and at the very base of the Vijlen Member. A more precise determination by naming these forms *Belemnella inflata* was proposed by CHRISTENSEN (pers. comm.). As both *Belemnella lanceolata* and *Belemnella lanceolata inflata* occur in the lower Lower Maastrichtian, there are no stratigraphical consequences for this paper.

***Belemnella "occidentalis"* *sensu* BIRKELUND, 1957**

Plate 3, fig. 1a-1b

Mostly rather slender guard with a well definable mucro. Highly lanceolate in ventral view, subcylindrical or conical in lateral view. The average length of adult specimens is 51 mm. The dorsoventral diameter-length ratio has an average of 0.22. Juvenile specimens are much more slender. The alveolar angle is about 17° and the fissure angle varies between 10° and 40°. The Schatzky distance varies between 0 and 3 mm. The surface is marked with fine vascular imprints. *Belemnella "occidentalis"* has a thicker and less lanceolate guard than *Belemnella lanceolata* (SCHLOTHEIM, 1813) and the bottom of the ventral fissure is less sinuous than that of *Belemnella lanceolata*.

Remark : The studied material is unfortunately not well enough preserved to make a more precise determination possible. It is therefore very possible that we are dealing with the forms *Belemnella obtusa* SCHULZ or *Belemnella sumensis* JELETZKY as described by SCHULZ (1979).

5.1.4. Stratigraphical observations

The stratigraphical distribution of the below mentioned belemnite guards in the localities of Halem Baye and Beutenaken is given in Fig. 12 and Fig. 13. *Gonioteuthis quadrata* (of the Lower Campanian) occurs *in situ* in the Vaals Formation at the C.P.L. quarry at Halem Baye and is found in the upper part of this formation more frequently. In the basal conglomerate or glauconitic chalk of the Gulpen Formation, numerous reworked guards of *Gonioteuthis quadrata* can be found. *Belemnitella mucronata* occurs *in situ* in the whole Zeven Wegen Member at Halem Baye and in the basal conglomerate of the Beutenaken Member at Beutenaken. *Belemnitella mucronata* "minor" occurs *in situ* in the upper part of the Zeven Wegen Member at Halem Baye and Beutenaken and is found reworked at the base of the Beutenaken Member at Beutenaken. *Belemnitella junior* occurs *in situ* in the upper part of the Gulpen Formation (Vijlen Member up to the Lanaye Member) at Halem Baye and in the Vijlen Member at Beutenaken. *Belemnella lanceolata inflata* occurs *in situ* in the Beutenaken Member at Beutenaken and is abundant in its upper part. Reworked guards can be found in the basal conglomerate of the Vijlen Member at Beutenaken and at the base of the Vijlen Member at Halem Baye.

It is pointed out here that SCHULZ & SCHMID (1983) describe the finding of *Belemnella cimbrica* BIRKELUND at the base of the Vijlen Member in Halem Baye. The present author was not able to incorporate this material in this paper on a short notice.

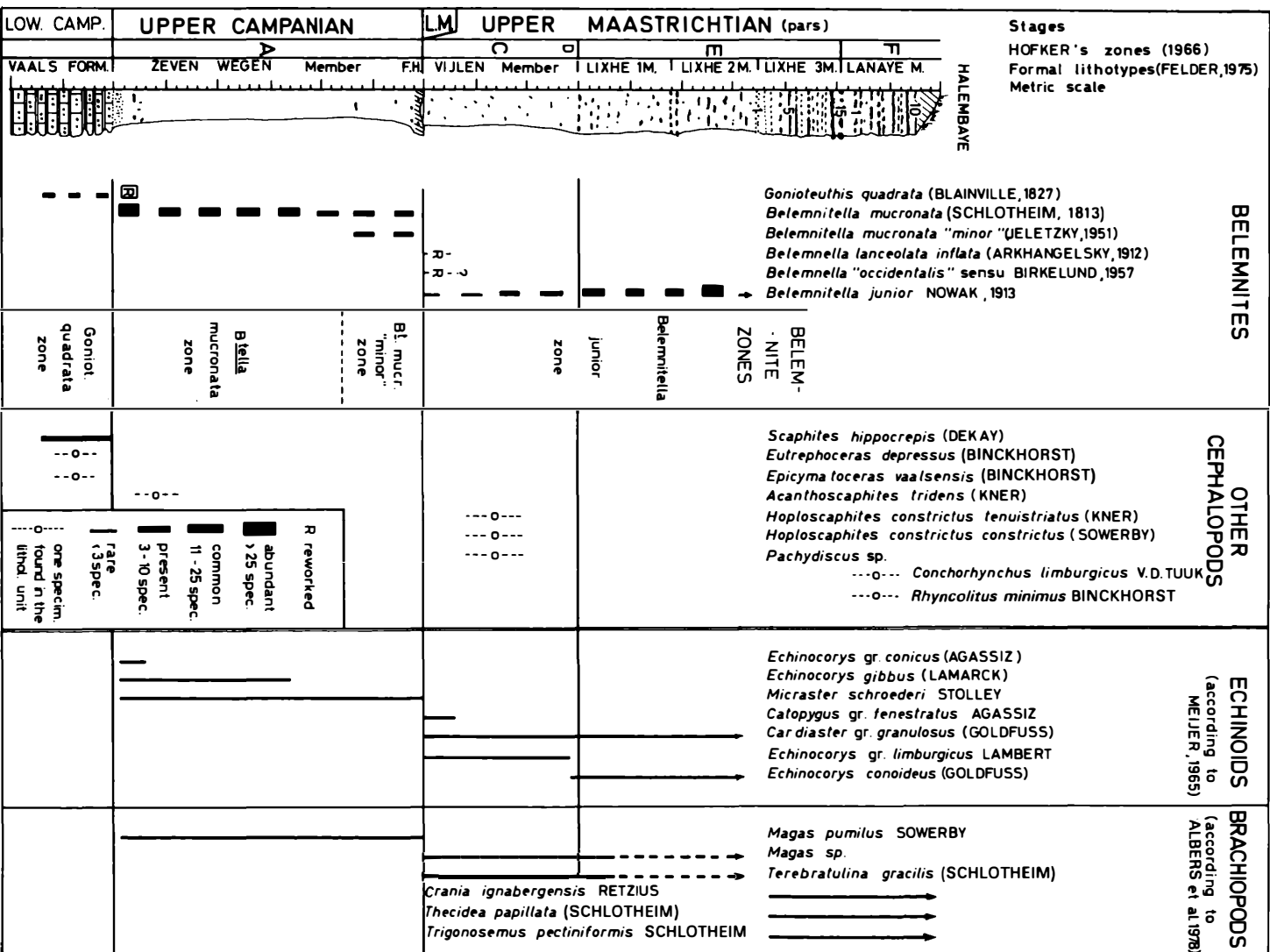


Figure 12

Vertical distribution of Belemnites and other Cephalopods in the quarry CPL at Halem Baye. The distribution of some Echinoids and Brachiopods is added according to MEIJER, 1965, and in ALBERS et al., 1978

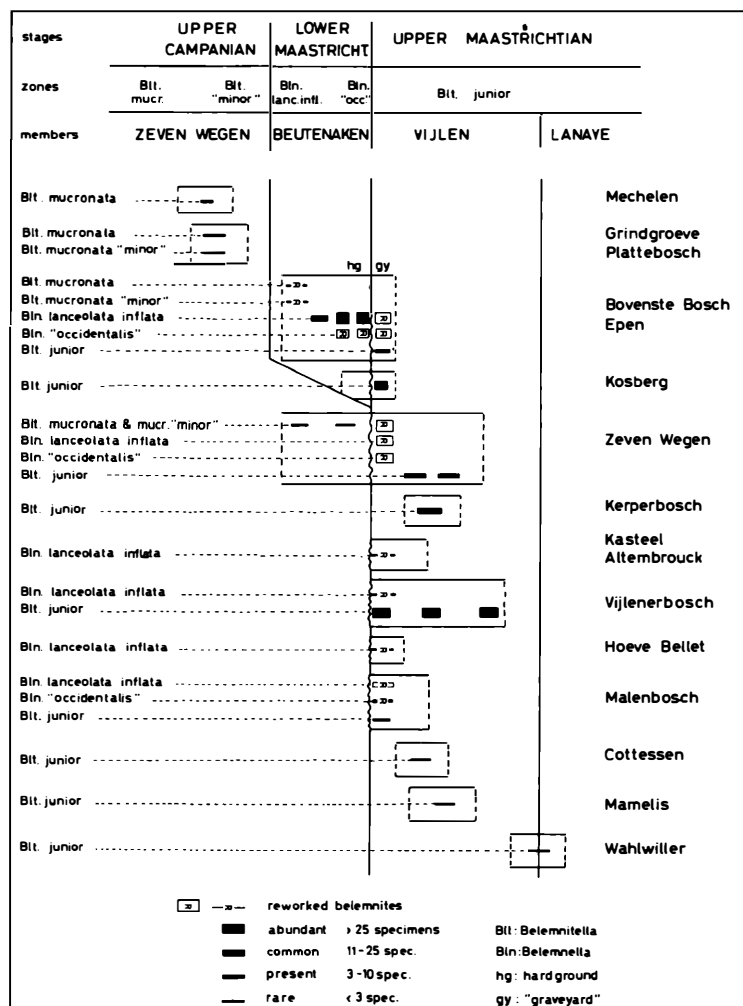


FIGURE 13
Vertical distribution of Belemnites
in the Beutenaken region

Belemnella "occidentalis" occurs reworked only in the upper part of the Beutenaken Member at Beutenaken and at the base of the Vijlen Member at Beutenaken and several other localities.

A belemnite zonation for the Upper Cretaceous of Limburg has been provisionally established by SCHMID (1959) and VAN DER TUUK & BOR (1980). Although the Cretaceous sections of Limburg are far from continuous, in the present paper a further attempt is made to establish a biozonation based on belemnite guards. A European belemnite zonation has been composed, among others, by JELETZKY (1951), BIRKELUND (1957), CHRISTENSEN (1975) and SCHULZ *et al.* (1983) as shown in Fig. 14.

According to CHRISTENSEN (1975), the Central European Subprovince was characterized by members of the evolutionary lineage during the Santonian and Lower Campanian: *Gonioteuthis westfalica*, *G. westfalica*, *G. granulata*, *G. granulata*, *G. quadrata* and *G. quadrata gracilis*. In the Upper Campanian the genus *Belemnitella*, represented by *Belemnitella mucronata* and *Belemnitella mucronata "minor"*, expanded its distribution area from the Central Russian Subprovince to cover the whole North European Subprovince. At the transition from the Campanian to the Maastrichtian, the genus *Belemnella* appears, early forms only in the Central Russian Subprovince. Lower Maastrichtian forms

	Belemnite Zones in NW Europe	Belemnite Zones in Limburg
UPPER MAASTRICHTIAN	<i>Belemnella casimirovensis</i> <i>Belemnitella junior</i>	<i>Belemnella casimirovensis</i> <i>Belemnitella junior</i>
LOWER MAASTRICHTIAN	<i>Belemnella fastigata</i> <i>Belemnella cimbrica</i> <i>Belemnella sumensis</i> } B. "occidentalis" <i>Belemnella obtusa</i> } sensu BIRKELUND, 1957	? <i>Belemnella cimbrica</i> ? <i>Belemnella "occidentalis"</i>
	<i>Belemnella pseudobtusa</i> <i>Belemnella lanceolata</i>	<i>Belemnella lanceolata (inflata)</i>
UPPER CAMPANIAN	<i>Belemnitella "langei"</i> <i>Belemnitella mucronata "minor"</i> <i>Belemnitella mucronata</i>	<i>Belemnitella mucronata "minor"</i> <i>Belemnitella mucronata</i>
LOWER CAMPANIAN	<i>Gonioteuthis quadrata gracilis</i> /B. <i>mucronata</i> <i>Gonioteuthis quadrata gracilis</i> <i>Gonioteuthis quadrata quadrata</i> <i>Gonioteuthis granulataquadrata</i>	<i>Gonioteuthis quadrata</i>

FIGURE 14

Belemnite zones in Limburg compared to belemnite zones of NW Europe (according to JELETZKY, 1951; BIRKELUND, 1957; CHRISTENSEN, 1975; SCHULZ *et al.*, 1983)

as *Belemnella lanceolata inflata* and *Belemnella "occidentalis"* are known from most parts of the North European Subprovince. The Upper Mastrichtian is characterized by *Belemnitella junior* and *Belemnella casimirovensis*. The latter is confined to the upper part of this substage.

5.1.5. Definition of Late Cretaceous belemnite zones in Limburg (see also VAN DER TUUK & BOR, 1980)

Gonioteuthis quadrata Taxon-range-zone

Definition: Interval from the first to the last occurrence of *Gonioteuthis quadrata*.

Authors: SCHMID (1957); ERNST (1964).

Lithostratigraphical correlation: Vaals Formation.

Age: Lower Campanian.

Belemnitella mucronata Interval-zone

Definition: Interval between the first occurrence of *Belemnitella mucronata* and the first occurrence of *Belemnitella mucronata "minor"*.

Author: JELETZKY (1948).

Lithostratigraphical correlation: Gulpen Formation, lower part of the Zeven Wegen Member.

Age: Upper Campanian (lower part).

Belemnitella mucronata "minor" Taxon-range-zone

Definition: Interval from the first to the last occurrence of *Belemnitella mucronata "minor"*.

Author: JELETZKY (1951).

Lithostratigraphical correlation: Gulpen Formation, upper part of the Zeven Wegen Member.

Age: Upper Campanian (partly upper part).

Belemnella lanceolata Interval-zone

Definition: Interval between the first occurrence of *Belemnella lanceolata* and the first occurrence of *Belemnella "occidentalis"*. In Limburg, this zone is marked by the presence of *Belemnella lanceolata inflata*.

Lithostratigraphical correlation: Gulpen Formation, Beutenaken Member.

Age: Lower Maastrichtian (lower part).

Belemnella "occidentalis" Interval-zone

Definition: Interval between the first appearance

rance of *Belemnella "occidentalis"* and the first appearance of *Belemnella cimbrica*.

Remark : in the Beutenaken Member, this zone is represented only by reworked material.

Lithostratigraphical correlation : Gulpen Formation, upper part of the Beutenaken Member.

Age : Lower Maastrichtian (lower part) to Upper Maastrichtian (lower part).

***Belemnitella junior* Partial-range-zone**

Definition : Interval from the first occurrence of *Belemnitella junior* s.l. to the first occurrence of *Belemnella casimirovensis*.

Author : JELETZKY (1951).

Lithostratigraphical correlation : Gulpen Formation, Vijlen Member up to the Lanaye Member, and the Maastricht Formation, except for the uppermost part of the Meerssen Member.

Age : Upper Maastrichtian (lower part).

***Belemnella casimirovensis* Taxon-range-zone** (not present in Halembye and Beutenaken)

Definition : Interval from the first to the last occurrence of *Belemnella casimirovensis* (SKOLOZ-DROWNA, 1932).

Author : JELETZKY (1951).

Lithostratigraphical correlation : Maastricht Formation, uppermost part of the Meerssen Member.

Age : Upper Maastrichtian (lower part).

5.1.6. Conclusions

The boundary between the Campanian and the Maastrichtian is marked in Beutenaken as well as in Halembye by a remarkable lithological discontinuity consisting of a hardground (Froidmont hardground). With the discontinuity coincide :

- the extinction of both Campanian species *Belemnitella mucronata* and *Belemnitella mucronata "minor"* at the top of the hardground capping the Zeven Wegen Member;
- the appearance of the Lower Maastrichtian *Belemnella lanceolata inflata* at the base of the Beutenaken Chalk at Beutenaken and the base of the Vijlen Chalk at Halembye.

It is pointed out that only rare guards of representatives of the genus *Belemnella* were found in Halembye. So as *Belemnella lanceolata inflata* is very rare and reworked at Halembye, one may conclude that the Lower Maastrichtian is

more strongly reduced at Halembye than it is at Beutenaken. The absence of almost all of the Lower Maastrichtian at Halembye is the reason why the type-Maastrichtian area (Netherlands and Belgian Limburg) is not favourable to constitute a reference for layers below the Vijlen Member. Only the Beutenaken Member belongs certainly to the Lower Maastrichtian. Both in Halembye and in Beutenaken the whole Zeven Wegen Member is characterized by the occurrence of well-preserved guards of the Upper Campanian belemnite species *Belemnitella mucronata* and *Belemnitella mucronata "minor"*. The Zeven Wegen Member is therefore considered to be Upper Campanian. Both in Halembye and Beutenaken a hardground is present at the top of the Zeven Wegen Member. This hardground (Froidmont hardground) contains guards of *Belemnitella mucronata* and *Belemnitella mucronata "minor"*, that show clear signs of post-mortem transport. It is not clear whether these guards are genuinely reworked or if abrasion is the result of deposition in a condensed sequence. At Beutenaken, the Beutenaken Member lies on top of this hardground and contains *Belemnella lanceolata inflata*. When one takes into account the frequent occurrence and the condition of preservation of the guards, we are probably dealing with a condensed sequence. The Belemnites indicate that the Beutenaken Member has been deposited in the Lower Maastrichtian.

The Beutenaken Member characterized by *Belemnella lanceolata inflata* is not present at Halembye. On top of the Beutenaken Member is a bed with reworked guards of *Belemnella "occidentalis"*. These guards are numerous in Beutenaken and their presence is questionable at Halembye. Perhaps we are dealing in Halembye with guards of *Belemnella cimbrica* at the base of the Vijlen Member (SCHULZ & SCHMID, 1983). The Vijlen Member is found on top of the Beutenaken Member at Beutenaken and on top of the Zeven Wegen Member at Halembye with occurrences of *Belemnitella junior* from the Upper Maastrichtian.

ACKNOWLEDGEMENTS

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5.2. OTHER CEPHALOPODS (L.A. VDT) AND OTHER MACROFOSSILS

Apart from Belemnites, 12 species of Cephalopods occur in the localities Halembaye and Beutenaken. Only a small part of these species are mentioned in (old) literature. In outcrops of the Vaals Formation in the vicinity of Cottensen, Teuven and Vaals, the Lower Campanian Ammonoids *Scaphites hippocrepis* (DEKAY, 1827), *Placentoceras meeki* BÖHM, 1898; *Euhomaloceras incurvatus* (DUJARDIN, 1837) and ? *Sciponoceras bohemicum* (FRITSCH, 1872), and the Lower Campanian Nautiloid *Epicymatoceras vaalsensis* (BINCKHORST, 1861) were found. In the Vaals Formation of the C.P.L. quarry at Halembaye the Nautiloids *Epicymatoceras vaalsensis* (BINCKHORST, 1861) and *Eutrophoceras depressus* (BINCKHORST, 1861) were found. In the Vijlen Member, the Maastrichtian Ammonoids *Acanthoscaphites tridens* (KNER, 1848) and *Hoploscaphites constrictus tenuistriatus* (KNER, 1848) were found in outcrops west of Beutenaken. In the Vijlen Member of Halembaye (Fig. 12), the Upper Maastrichtian Ammonoids *Pachydiscus* sp., *Hoploscaphites constrictus tenuistriatus* (KNER, 1848) and *Hoploscaphites constrictus constrictus* (SOWERBY, 1818) NOWAK 1911, were found (VAN DER TUUK, in prep.). In the upper part of the Halembaye quarry (Lanaye Member) several calcareous parts of the cephalopod jaws *Conchorhynchus limburgicus* (VAN DER TUUK, 1982) and *Rhyncholites minimus* BINCKHORST (1861) were found. Among several specimens of jawparts of Glyceridae (Polychaetia), there are a few specimens which might be hooks of cephalopod tentacles in the Smectite (Vaals Formation) of Halembaye. But this has not been confirmed yet. It is pointed out here that all the above mentioned Cephalopods are extremely rare with the exception of the Ammonoids *Scaphites hippocrepis* and *Euhomaloceras incurvatus* and that there are no other Cephalopods known in the Zeven Wegen Member, the Beutenaken Member and the Lixhe Member than Belemnites. So one may conclude that Cephalopods other than Belemnites are not very useful for stratigraphical purposes in the Vaals and Gulpen Formations.

According to literature, the vertical distributions of some Echinoids (after MEIJER, 1965) and Brachiopods (in ALBERS *et al.*, 1978) are presented in Fig. 12.

5.3. FORAMINIFERA

Foraminifera from the Late Cretaceous to Paleocene calcilutites and calcarenites of Limburg have been known for about half a century. Main studies were made by VAN RIJNSINGE (1932, Foraminifera of the Houthem Formation), SCHIJFSMA (1946, Foraminifera of the Vaals Formation), HOFKER (1949, 1955, 1956, 1957, 1958, 1961, 1966 :Foraminifera of Late Cretaceous - Paleocene formations), MEIJER in CALEMBERT *et al.*, (1977, index benthic Foraminifera from Late Cretaceous formations); BELLIER & VILLAIN (1975, planktonic Foraminifera); VILLAIN (1977, partly benthic Foraminifera); MEESSEN in STREEL *et al.*, (1977, benthic Foraminifera, with use of the *Bolivinoidea* lineage); MEESSEN *et al.*, (1978); MEESSEN in BLESS *et al.*, (1981); MEESSEN, ROBASZYNSKI in ROBASZYNSKI *et al.*, (1985, preliminary results of the present work).

5.3.1. Benthic Foraminifera (J.P.M.Th.M.)

The samples collected at Halembaye, Beutenaken and Cadier en Keer have been investigated on their benthonic foraminiferal content. The Foraminifera were identified according to the criteria of HOFKER (1957, 1966) and dated according to HOFKER's 1966 foraminiferal zonation. The Foraminifera assemblages are listed in Fig. 16 and Fig. 17. The dating of samples is also based on the orthogenesis of the *Bolininoides decorata-australis-gigantea* lineage (Fig. 15) as described in detail by HOFKER (1958 a, 1961). The Foraminifera lineage *Bolininoides decorata-australis-gigantea* displays a gradually increasing number of pustules on the last chamber (HOFKER 1958 a, 1961). *Bolininoides decorata* possesses 3 to 4 pustules on the last chamber in Foraminifera Zone A. The mean number of pustules on the last chamber of *Bolininoides australis* increases from 4 to 5 in Foraminifera Zone B, through 5 to 6 in Foraminifera Zone C, and 6 in Foraminifera Zone D, into 6 to 7 in Foraminifera Zone E. Eventually, *Bolininoides gigantea* possesses a mean number of 7 to 9 pustules on the last chamber in Foraminifera Zone F.

Comments on the foraminiferal content of the samples studied

● Samples Halembaye 82-12 and 82-11 : Maastrichtian, Foraminifera Zone E. The following characteristic species have been recognized : *Al-lomorphina bullata*, *Neoflabellina reticulata*, *Præbulimina laevis* and *Reussella cimbrica*. In sample Halembaye 82-11, the mean number of pustules

lithological units	HOFKER's Zones	samples	number of pustules on the last formed chamber					averages	
			3	4	5	6	7		8
LIXHE	E	Halembaye 82-12			1	5	2		-
		Halembaye 82-11			7	24	14	2	6.2
VIJLEN	D	Halembaye 82-15				1			-
		Halembaye 82-10			3	1			-
	C	Halembaye 82-9		1	20	17	1		5.5
		Halembaye 82-8			6	3			-
		Cadier e.K. 75.9-77 m			no Bolivinoïdes				-
BEUTENAKEN	B	Beutenaken 82-1		1	1				-
		Beutenaken 82-2		6	6				4.5
		Beutenaken 82-3			no Bolivinoïdes				-
		Beutenaken 82-4			no Bolivinoïdes				-
		Beutenaken 82-5			no Bolivinoïdes				-
		Cadier e.K. 78.95-80 m			no Bolivinoïdes				-
		Cadier e.K. 80-81 m			no Bolivinoïdes				-
ZEVEN WEGEN	A	Halembaye 82-7	7	31					3.8
		Halembaye 82-6	8	20					3.7
		Halembaye 82-5	24	31					3.6
		Halembaye 82-4	18	13					3.4
		Halembaye 82-3	17	3					3.2
		Beutenaken 82-6			no Bolivinoïdes				-
		Beutenaken 82-7	2	4					-
VAALS		Halembaye 82-2			no Bolivinoïdes				-
		Halembaye 82-1			no Bolivinoïdes				-
		number of specimens							

FIGURE 15

The orthogenesis of the *Bolivinoïdes decorata-australis* lineage

on the last chamber of *Bolivinoïdes australis* is 6.2. This value is within the range between 6 and 7 pustules, which HOFKER (1958 a, 1966) considered characteristic for *Bolivinoïdes australis* in Foraminifera Zone E. Remarkable is the occurrence of *Bolivinoïdes draco* in sample Halembaye 82-11.

- Sample Halembaye 82-15: Maastrichtian, Foraminifera Zone D. The following "characteristic" species has been recognized: *Bolivinoïdes draco*. It should be noted — contrary to previous knowledge — that this species is not restricted to this Foraminifera Zone, but has also been recognized in Zones C and E.

- Samples Halembaye 82-10, 82-9 and Cadier en Keer 75.90 m - 77.00 m: Maastrichtian, Foraminifera Zone C. The sample Cadier en Keer was very poor and by that no characteristic species have been recognized. In the Halembaye samples the following characteristic species have been recognized: *Bolivina incrassata*, *Neoflabellina praereticulata*, *Pseudoparrella alata* and *Bolivinoïdes australis* with a mean number of pustules on the last

chamber of 5.5. This value is within the range between 5 and 6 pustules, which HOFKER (1958 a, 1961) considered characteristic for *Bolivinoïdes australis* in Foraminifera Zone C. *Bolivinoïdes draco* has been recognized in this zone in at least one horizon, where the mean number of pustules on the last chamber of *Bolivinoïdes australis* is about 5.4 (KIMPE *et al.*, 1978).

- Samples Beutenaken 82-1, 82-2, 82-3, 82-4, 82-5 and Cadier en Keer 78.95 m - 80.00 m and 80.00 m - 81.00 m: Maastrichtian, Foraminifera Zone B. The following characteristic species have been recognized: *Eponides beisseli*, *Neoflabellina praereticulata*, *Orbignyna aragonitica*, *Osangularia lens*, *Praebulimina laevis*, *Siphogaudryina (Heterostomella) foveolata*, *Spiroplectammina laevis* and *Verneuilina limbata*. In sample Beutenaken 82-2, *Bolivinoïdes australis* has a mean number of pustules on the last chamber of 4.5. This value is within the range between 4 and 5 pustules, which HOFKER (1958 a, 1961) considered characteristic for *Bolivinoïdes australis* in Foraminifera Zone B.

● Samples Halembaye 82-7, 82-6, 82-4, 82-3 and Beutenaken 82-6 and 82-7 : Campanian, Foraminifera Zone A. The following characteristic species have been recognized : *Gavelinella clementiana*, *Gavelinopsis monterelensis*, *Globorotalites micheliniana*, *Neoflabellina leptodisca* and *Stensioeina pommerana*. In the Halembaye samples, *Bolivinoidea decorata* shows a mean number of pustules on the last chamber from 3.2 to 3.8. These values are within the range between 3 and 4 pustules which HOFKER (1958 a, 1961) considered characteristic for *Bolivinoidea decorata* in Foraminifera Zone A.

● Samples Halembaye 82-2 and 82-1 : Campanian, lower part of Vaals Formation. (the Foraminifera of the Vaals Formation were described by HOFKER in 1957). The following characteristic species have been recognized : *Gavelinella clementiana* and *Lenticulina multinodosa*.

The foraminiferal zonation of HOFKER (1966) can be used successfully in the type-area of the Maastrichtian and in adjacent parts of Belgium and the Federal Republic of Germany, but the Foraminifera Zones of HOFKER are Assemblage-zones. Therefore, the vertical distribution of the "characteristic" species is not restricted to a single zone, as can be deduced from the distribution charts (Fig. 16 and 17). Their vertical range has been influenced to a considerable extent by palaeoecological conditions. This reduces their value for long-distance correlations (compare the different opinions of HOFKER, 1966, and VILLAIN, 1977, on the correlation between the Late Cretaceous of the Maastricht and Mons area). Important for correlation, also with other basins (HOFKER, 1958 b; VAN HINTE, 1967), is the Foraminifera lineage *Bolivinoidea decorata-australis-gigantea*.

5.3.2. Planktonic Foraminifera (F.R.)

The species of planktonic Foraminifera recovered from the Halembaye and Beutenaken samples are much less abundant than the benthic Foraminifera (Fig. 16 and 17). Very rare in the Zeven Wegen and the Beutenaken Members, they are slightly better represented in the Vijlen and Lixhe Members.

Usually, Heterohelids and *Globigerinelloidea* have little biostratigraphical value. Only species of Globotruncanids may provide some stratigraphical information in using their well-known ranges in the Tethyan realm (ROBASZYNSKI, CARON, GONZALEZ DONOSO, WONDERS *et al.*, 1984). *Globotruncana arca*

ranging from the Campanian throughout the Maastrichtian was found in the Zeven Wegen, Vijlen and Lixhe Members. *Globotruncana cf. ventricosa* and *Globotruncanita stuartiformis* also known in the Campanian-Maastrichtian are present in the Vijlen Member. A specimen close to *Globotruncanella petaloidea* was picked out from the Vijlen Member, and this species is restricted to the Maastrichtian, as *Rosita contusa* cited by BELLIER & VILLAIN (1975) at the top of the Vijlen Member and at the top of the Lixhe Member.

It is obvious that the scarcity of planktonic Foraminifera in the calcilutites and calcarenites studied does not allow their use as biostratigraphical markers in the Limburg area. Only *Globotruncanella cf. petaloidea* and *Rosita contusa* support a Maastrichtian age for the Vijlen and Lixhe Members.

5.4. NANNOPLANKTON (H.M.)

The Campanian-Maastrichtian boundary is somewhat difficult to recognize with nannoplankton because of problems in determining the index species and possible diachronism of their appearances and extinctions from the Tethyan to the Boreal realms. For example, PERCH-NIELSEN (1979, 1983) considered that there are no good markers to draw this boundary which falls into the *Tranolithus phacelosus* Zone. For THIERSTEIN (1978), the disappearance of *Eiffellithus eximius* would be a good datum-line, but the extinction of this form is not synchronous everywhere. ROTH (1978) put the boundary in the *Lithraphidites praequadratus* Zone. More recently, LAMBERT (1980) studied the nannoflora of the type-Campanian area and of some Limburg samples, and VERBEEK (1983) presented a zonation for the Campanian-Maastrichtian of South-Limburg. For the latter author, the Beutenaken Member belongs to his *Quadrum trifidum* Zone which he assumed "to be of Campanian age".

After examination of samples from Halembaye, Beutenaken and Cadier en Keer, the same species described in previous works were recognized. It seems that the datum-lines of several index species are diachronous from the Tethyan to the Boreal realms.

The nannoflora of the Cretaceous Limburg calcilutites and calcarenites is abundant, rather diversified, well preserved, with no evidence of reworking. Diagenesis is generally weak except for

LOW. CAMP.	UPPER CAMPANIAN			LM	UPPER MAASTRICHTIAN (pars)				HALEMBAYE	STAGES
VAALS FORM.	ZEVEN WEGEN Member			VIJLEN Member	LIXHE 1	LIXHE 2	LIXHE 3	LANAYE Memb.		HOFKER 's zones (1966)
										Formal lithotypes (FELDER, 1975)
										Metric scale
										LITHOLOGY
										SAMPLES
HAL 82-1 -										<i>Neoflabellina sphenoidalis</i> (WEDEKIND)
										<i>Globulina lacrima</i> REUSS
										<i>Gavelinella involuta</i> HOFKER
										<i>Cibicides excavata</i> (BROTZEN)
										<i>Lenticulina multinodosa</i> SCHIJFSMA
										<i>Lenticulina ordinarius</i> SCHIJFSMA
										<i>Gavelinella daini</i> (SCHIJFSMA)
										<i>Lenticulina (Saracenaria) triangularis</i> (d'ORBIGNY)
										<i>Frondicularia laevigata</i> MARIE
										<i>Globorotalites micheliniana</i> (d'ORBIGNY)
										<i>Gavelinella clementiana</i> (d'ORBIGNY)
										<i>Stensioeina pommerana</i> BROTZEN
										<i>Ammodiscus cretaceus</i> (REUSS)
										<i>Praebulimina laevis</i> (BEISSEL)
										<i>Lenticulina (Saracenaria) trilobata</i> (d'ORBIGNY)
										<i>Gyroidinoides nitida</i> (REUSS)
										<i>Cibicides subbosqueti</i> HOFKER
										<i>Citharinella gracilina</i> (MARIE)
										<i>Ataxophragmium crassum</i> (d'ORBIGNY)
										<i>Bolivinooides laevigata</i> MARIE
										<i>Bolivinooides decorata</i> (JONES)
										<i>Angulogavelinella gracilis</i> (MARSSON)
										<i>Lenticulina secans</i> (REUSS)
										<i>Orbignyna variabilis</i> (d'ORBIGNY)
										<i>Gavelinella lorreiana</i> (d'ORBIGNY)
										<i>Gavelinopsis voltziana</i> (d'ORBIGNY)
										<i>Lenticulina pseudovalis</i> MARIE
										<i>Spiroplectamina laevis</i> (ROEMER)
										<i>Dorothia pupa</i> (REUSS)
										<i>Gaudryina cretacea</i> (KARRER)
										<i>Gavelinella pertusa</i> (MARSSON)
										<i>Gavelinopsis bembis</i> (MARSSON)
										<i>Marssonella oxycona</i> (REUSS)

BENTHIC FORAMINIFERA

BENTHIC FORAMINIFERA

				BENTHIC FORAMINIFERA	
	—	—	—		<i>Tritaxia dubia</i> (REUSS)
	—	—	—		<i>Neoflabellina leptodisca</i> (WEDEKIND)
	—	—	—		<i>Gavelinopsis monterelensis</i> (MARIE)
	—	—	—		<i>Eponides beisseli</i> SCHIJFMA
	—	—	—	—	<i>Pullenia americana</i> CUSHMAN
	—	—	—	—	<i>Bolivina decurrens</i> (EHRENBERG)
	—	—	—	—	<i>Neoflabellina praereticulata</i> HILTERMANN
	—	—	—	—	<i>Osangularia lens</i> BROTZEN
	—	—	—	—	<i>Orbignyna ovata</i> HAGENOW
	—	—	—	—	<i>Lenticulina (Astacolus) truncata</i> (REUSS)
	—	—	—	—	<i>Bolivinoides australis</i> EDGELL
	—	—	—	—	<i>Bolivina incrassata</i> REUSS
	—	—	—	—	<i>Gavelinopsis complanata</i> (REUSS)
	—	—	—	—	<i>Reussella cristata</i> (MARSSON)
	—	—	—	—	<i>Siphogaudryina (Heterostomella) foveolata</i> (MARS.)
	—	—	—	—	<i>Cibicides beaumontianus</i> (d'ORBIGNY)
	—	—	—	—	<i>Bolivinoides peterssoni</i> BROTZEN
	—	—	—	—	<i>Alabamina dorsoplana</i> (BROTZEN)
	—	—	—	—	<i>Pseudoparrella alata</i> (MARSSON)
	—	—	—	—	<i>Frondicularia linguiformis</i> MARSSON
	—	—	—	—	<i>Guttulina adhaerens</i> (OLSZEWSKI)
	—	—	—	—	<i>Bolivinoides draco</i> (MARSSON)
	—	—	—	—	<i>Dorothia pupoides</i> (d'ORBIGNY)
	—	—	—	—	<i>Neoflabellina reticulata</i> (REUSS)
	—	—	—	—	<i>Allomorphina bullata</i> HOFKER
	—	—	—	—	<i>Stilostomella spinosa</i> (HOFKER)
	—	—	—	—	<i>Reussella cimbrica</i> (TROELSEN)
	—	—	—	—	<i>Heterohelix striata</i> (EHRENBERG)
	—	—	—	—	" <i>complanata</i> (MARIE)
	—	—	—	—	<i>Globigerinelloides gr. aspera</i> (EHRENBERG)
	—	—	—	—	" <i>cf. multispina</i> (LALICKER)
	—	—	—	—	<i>Archaeoglobigerina cretacea</i> (d'ORBIGNY)
	—	—	—	—	" <i>cf. blowi</i> PESSAGNO
	—	—	—	—	<i>Globotruncana cf. bulloides</i> (VOGLER)
	—	—	—	—	" <i>arca</i> (CUSHMAN)
	—	—	—	—	" <i>intern. arca-rosella</i>
	—	—	—	—	" <i>rugosa</i> (MARIE)
	—	—	—	—	" <i>cf. linneiana-ventricosa</i>
	—	—	—	—	<i>Rosita confusa</i> (CUSHMAN) in BELLER & VILL 1975
	—	—	—	—	<i>Globotruncanella stuartiformis</i> (DALBIEZ)
	—	—	—	—	<i>cf. Globotruncanella petaloidea</i> (GANDOLFI)

■ Abundant
 ■ Common
 — Present
 — Rare

FIGURE 16

Vertical distribution of benthic and planktonic Foraminifera for the Halembaye section

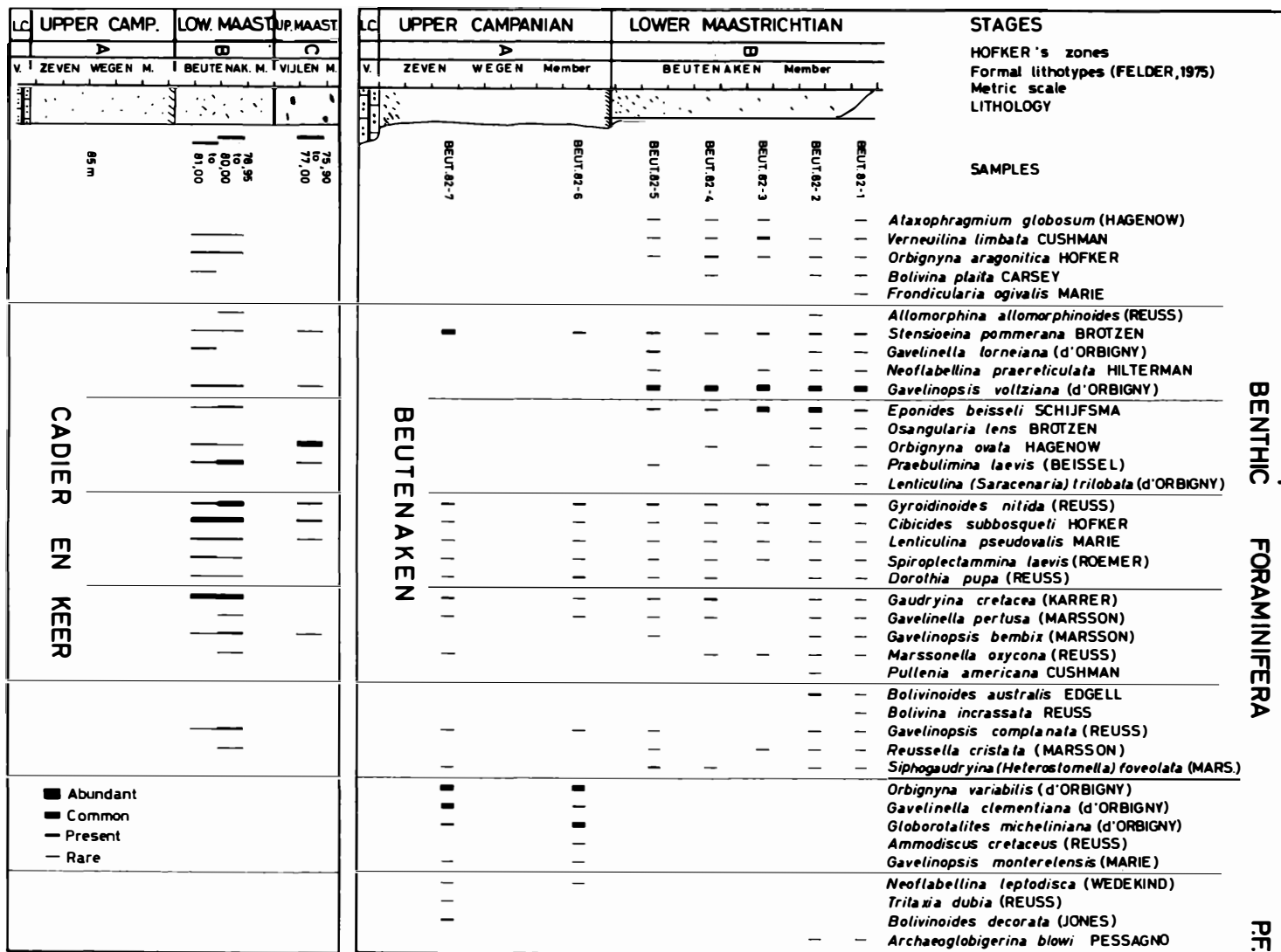
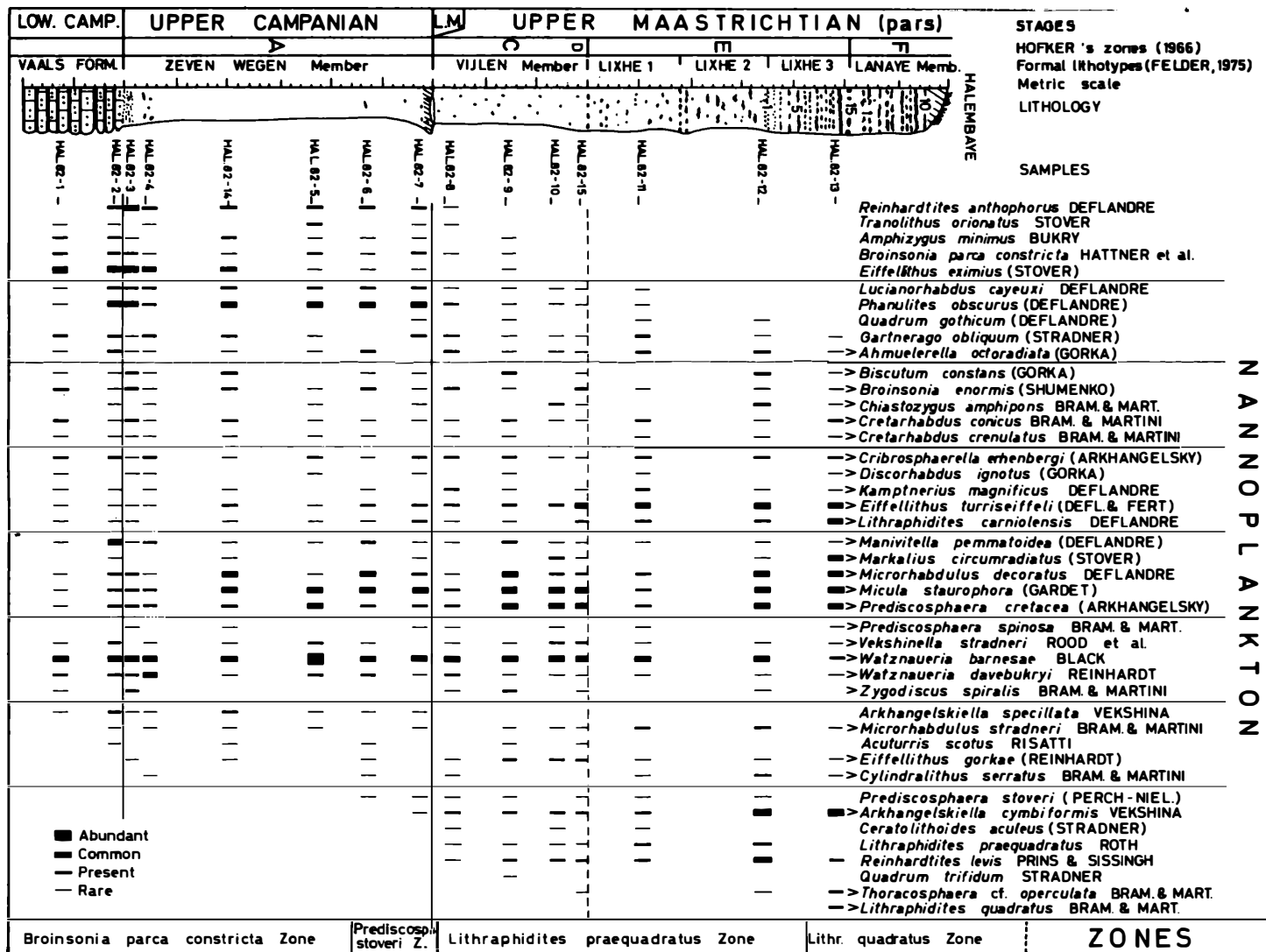


FIGURE 17

Vertical distribution of Foraminifera for the Beutenaken and Cadier en Keer borehole sections



some local secondary calcite recrystallizations (Fig. 18 and 19).

5.4.1. Main biostratigraphical results

The Vaals Formation contains a nannoflora principally composed of *Broinsonia parca constricta*, *Broinsonia enormis*, *Lucianorhabdus cayeuxi* linked with *Phanulites obscurus*, *Watznaueria davebukryi*, *Watznaueria barnesae*, *Micula staurophora*, *Reinhardtites anthophorus* and abundant *Eiffellithus eximius*.

The assemblage belongs to the *Broinsonia parca constricta* Zone which, in Charentes, is Lower to Middle Campanian.

The Zeven Wegen Member at Halembye and Beutenaken is marked by some changes :

— *Eiffellithus eximius* becomes much less abundant;

— *Cylindralithus serratus* and *Eiffellithus gorkae* appear at the base of the Member;

— at the top of the Member the entry is noted of the first and still rare *Arkhangelskiella cymbiformis* and *Quadrum gothicum*;

— *Prediscosphaera stoveri* appears in the upper part of the Member (in the Charentes, this species appears in the Middle to Upper Campanian).

The Beutenaken Member was studied on samples coming from Beutenaken and from the Cadier en Keer borehole. The species *Broinsonia parca constricta* and *Eiffellithus eximius* whose extinction is generally considered in the literature as marking the Campanian-Maastrichtian boundary are present in the Beutenaken Member, as well as *Quadrum trifidum*. The two species *Lucianorhabdus cayeuxi* and *Phanulites obscurus* are also present but less frequent. The species *Lithraphidites praequadratus* and *Reinhardtites levis* appear at the base of the Member.

At the base of the Vijlen Member, several species such as *Broinsonia parca constricta*, *Eiffellithus eximius* and *Reinhardtites anthophorus* disappear. In the Tethyan realm the extinction of these species is considered as marking the Campanian-Maastrichtian boundary. Two possibilities can be evoked to explain their presence in the Vijlen Member (which is Upper Maastrichtian by the occurrence of numerous *Belemnitella junior*) : either these species are diachronous from the Tethyan to the Boreal realms, or they are reworked (but there is no evidence of reworking).

At the base of the Lixhe Member, *Lucianorhabdus cayeuxi* and *Phanulites obscurus* disappear, and below the top of the Member disappear

Prediscosphaera stoveri and *Quadrum gothicum*. The species *Lithraphidites praequadratus* becomes more frequent and at the top appears *Lithraphidites quadratus*.

5.4.2. Biozonation

● The *Broinsonia parca constricta* Zone (author of the *B. parca* Zone : SISSINGH, 1977; emend. CRUX, 1982). It is the interval between the appearance of the index species and that of *Prediscosphaera stoveri*. This definition follows that given by CRUX (1982) which I use in the Paris Basin (and not that proposed by THIERSTEIN, 1976 and VERBEEK, 1977). At Halembye, *Prediscosphaera stoveri* appears in the last third of the Zeven Wegen Member.

● The *Prediscosphaera stoveri* Zone (author : LAMBERT, 1980). In Limburg it is the interval between the appearance of the index species and that of *Lithraphidites praequadratus*. In the Tethyan realm, VERBEEK (1977 and 1983) proposed a *Quadrum gothicum* Zone (interval between the appearances of *Quadrum gothicum* and *Quadrum trifidum*) in place of the *P. stoveri* Zone. This zone is not used in Limburg because of the scarcity in the Boreal realm of both *Q. gothicum* and *Q. trifidum*. Although the extinction of *Q. trifidum* has been used in the Tethyan realm to place the Campanian-Maastrichtian boundary, this species is so rare in the Boreal realm that it has little value. But it is worthy of note that this species is present both in the Beutenaken Member and the Vijlen Member. The distribution of *P. stoveri*, a small form not always differentiated from *P. cretacea*, does not seem latitudinally controlled. This species has been found in England (CRUX, 1982), in Charentes (LAMBERT, 1980) and in the Paris Basin (personal data).

● The *Lithraphidites praequadratus* Zone (author : ROTH, 1978). It is the interval between the appearance of the index species and that of *Lithraphidites quadratus*. *Lithraphidites praequadratus* is a small form evolved from *Lithraphidites carniolensis* and it is not largely used because it seems to be absent in the Tethyan realm although LAMBERT (1980) found it in Charentes. The zone can be considered as an equivalent of the *Arkhangelskiella cymbiformis* Zone *sensu* PERCH-NIELSEN (1972) or *sensu* MARTINI (1976), but not *sensu* SISSINGH (1977).

● The *Lithraphidites quadratus* Zone (author : ČEPEK & HAY, 1969; emend. PERCH-NIELSEN, 1977). It is the interval between the appearance of the index species and the appearance of either *Micula murus* in the Tethyan realm or *Nephrolithus frequens* in the Boreal realm. The index species

L. quadratus was found at Halembaye near the top of the Lixhe Member.

5.5. DINOFLAGELLATES (J.-C.F.)

5.5.1. Previous work

The first studies to obtain an accurate stratigraphical distribution for the dinocysts fossilized in the Campanian-Maastrichtian chalky facies in Belgian and Netherlands Limburg were led by WILSON (1971, 1974). Previously, the observation of flints collected in several points of this region (particularly in Loën, Halembaye, Gulpen) had allowed LEJEUNE-CARPENTIER (1937-1951), CONRAD (1941) and DE WIT (1943, 1944) to describe more or less accurately a small number of dinocyst forms, some of which being characteristic of these levels.

More recently, SCHUMACKER-LAMBRY (1977) briefly reported the results of her own observations and compared them to WILSON's data. But the difference in the sampling has resulted in limiting the comparison. Moreover, in both cases, the small number of samples produced a lack of precision about the distribution of the diverse forms which were found.

Finally, the exhaustive study of the dinocyst content of some flints taken in comparable formations of the Mons basin can be noted (FOUCHER & ROBASZYNSKI, 1977).

5.5.2. Analytical results of the present study

The Halembaye quarry (Fig. 20).

The Campanian-Maastrichtian sediments of the Halembaye quarry are generally very fossiliferous: up until now 52 genera and 83 species or subspecies of dinocysts have been recognized. 60 species or subspecies, belonging to 37 genera, have been counted in the two samples of "Smectite" (Vaals Formation), 54 (33 genera) in the six samples of the Zeven Wegen Member, 35 (23 genera) in the three samples of the Vijlen Member, 23 (14 genera) in the two samples of the Lixhe Member.

Characteristic forms for the different terms of the section.

— *Vaals Formation: "Smectite" (Lower Campanian).*

Amongst the numerous species which have been identified, one third is exclusively present in

this formation (especially *Palaeohystrichophora infusorioides*, *Spinidinium angustispinum* in WILSON), about ten of them disappear at the base of the Zeven Wegen Member (*Acanthaulax saetosa* and *Gonyaulacysta prominoseptata* in WILSON, *Thalassiphora? spinosa*, etc.).

— *Zeven Wegen Member (Upper Campanian).*

The species *Dinogymnium euclaense*, *Exochosphaeridium? acuminatum* in WILSON, *Florentinia? flosculus* and *Phanerodinium fourmarieri* have only been found at the base (sample HAL. 82-3), and *Laticavodinium gracilispinosum* in WILSON only in the upper part (samples HAL. 82-5 and 6). Many specimens of *Gillinia hymenophora* are present at the base and also in the upper part. On the other hand, *Odontochitina wetzeli* in WILSON has been seen in all of the six samples.

— *Vijlen and Lixhe Members (Upper Maastrichtian)*

Northidinium perforatum in WILSON and *Kleithriasphaeridium cf. truncatum* are present both in the Vijlen Member and the Lixhe Members. The Vijlen Member has given some specimens of *Triblastula utinensis* (samples HAL. 82-9 and 10) and rather numerous specimens of *Areoligera tenuicapillata*.

The Cadier en Keer borehole (Fig. 21).

— *Beutenaken Member (Lower Maastrichtian)*

33 genera and 45 species or subspecies of dinoflagellate cysts have been numbered in the two samples of the Beutenaken Member.

We can note the presence in this chalk of *Cannosphaeropsis utinensis*, *Gillinia hymenophora*, *Hystrichodinium pulchrum*, *Odontochitina operculata*, *Palaeoperidinium pyrophorum*, *Xenascus ceratioides*, *Cyclonephelium distinctum*, *Samlandia solida* in WILSON and *Spongodinium delitiense*.

— *Vijlen Member (Upper Maastrichtian).*

Only one sample was studied and its dinocyst population is qualitatively poor: 13 genera and 14 species or subspecies.

The following forms: *Cyclonephelium distinctum*, cf. *Spongodinium delitiense*, *Heterosphaeridium? heteracanthum* and *Pterodinium cingulatum cingulatum* have not been identified in the equivalent strata of Halembaye.

The Beutenaken quarry (Fig. 21)

The seven samples from the abandoned quarry of Beutenaken have only given a limited and badly preserved population of dinocysts, no doubt due to weathering.

— Zeven Wegen Member (Upper Campanian)

16 genera and 18 species are represented in the two samples which have been analysed, all of them being present in Halembaye.

— Beutenaken Member (Lower Maastrichtian)

The examination of five samples has allowed one to count 18 genera and 22 species or subspecies of dinocysts, and to add some species to the inventory previously mentioned. In the Cadier en Keer borehole, the noticeably missing species were: *Heterosphaeridium* ? *heteracanthum*, *Chytroesphaeridia solida* in WILSON, *Odontochitina wetzeli* in WILSON, *Senoniasphaera reticulata* in WILSON, *Cleistosphaeridium* ? *multifurcatum*, *Chytroesphaeridia everricula* in WILSON.

5.5.3. Biostratigraphical dinocyst species

Thus, in the present case, we can draw three zonal limits with the dinocysts.

- The first limit corresponds to the Vaals Formation-Zeven Wegen Member boundary (or Lower Campanian-Upper Campanian boundary) and is marked by: the appearance of *Odontochitina wetzeli*, *Gillinia hymenophora* and *Chytroesphaeridia solida*; the disappearance of *Palaeohystrichophora infusorioides* and *Spinidinium angustispinum*.

- The second limit is situated in the upper part of the Zeven Wegen Member (below the Campanian-Maastrichtian boundary) and is characterized by: the appearance of the genera *Areoligera* (especially with the species *senonensis* and *coronata*) and *Cladopyxidium*, the disappearance of *Aldorfia deflandrei*.

- The third limit corresponds to the Beutenaken Member-Vijlen Member boundary (Lower Maastrichtian-Upper Maastrichtian boundary) and is shown by: the appearance of *Northidinium perforatum*, the disappearance of *Odontochitina operculata*, *Hystrichodinium pulchrum*, *Gillinia hymenophora*, *Odontochitina wetzeli*, and probably *Xenascus ceratioides*.

The Campanian-Maastrichtian boundary, such as it is defined in the third chapter, is not clearly indicated by the dinocysts. However, it is neces-

sary to notice in the Beutenaken Member the appearance of the following species: *Palaeoperidinium pyrophorum*, *Samlandia solida* and *Spongodinium delitiense*, which confirms WILSON's data for this area.

5.5.4. Remarks

The stratigraphical distribution of several species may not be accurate, reworking being always possible. The reappearance after a variable length of time of a species represented by rare and badly preserved specimens can be a sign of reworking. It might be so for *Odontochitina costata*, *Xenascus ceratioides*, *Heterosphaeridium* ? *heteracanthum*, *Florentinia* ? *truncigera*, *Callaiosphaeridium asymmetricum*, *Xiphophoridium alatum*, *Florentinia buspina*, *Oligosphaeridium prolaxispinosum*, etc.

The stratigraphical distribution of the 14 chosen dinocyst species (Fig. 35) is not exactly the same according to authors and countries. However, the comparison of the various data allows one to select some species in order to situate an approximate Campanian-Maastrichtian boundary for Western Europe. *Thalassiphora* ? *spinosa* disappears during the Upper Campanian; so does *Palaeohystrichophora infusorioides* generally, whereas *Spongodinium delitiense* appears in the uppermost Campanian or in the basal Maastrichtian. *Triblastula utinensis*, on the other hand, is a typical Maastrichtian species.

5.6. SPORES AND POLLEN GRAINS (O.L.)

5.6.1. Halembaye quarry (Fig. 22);

Although the samples from the Gulpen Formation in the Halembaye quarry (HAL. 82-3 to HAL. 82-12) contain a large number of dinoflagellate cysts, they are completely barren in Spores and pollen grains, apart from a few very rare elements of terrestrial origin which have been reworked from older horizons. Only the two samples from the Vaals Formation, at the base of the section, have yielded material of terrestrial origin, although relatively little compared to the material of marine origin. This material represents about 20% in HAL. 82-1 and 30% in HAL. 82-2 of the palynological content, Dinoflagellates accounting for almost all the remainder.

These Spores and pollen grains have been the subject of preliminary inventories by VANGUESTAINE (1966) and VANGUESTAINE & STREEL (*in* STREEL *et al.*,

LC	UPPER CAMP.	LOW. MAAST	UP. MAAST	LC	UPPER CAMPANIAN	LOWER MAASTRICHTIAN	STAGES
	A	B	C		A	B	
V.	ZEVEN WEGEN M.	BEUTENAK. M.	VIJLEN M.	V.	ZEVEN WEGEN Member	BEUTENAKEN Member	HOFKER's zones Formal lithotypes (FELDER, 1975) Metric scale LITHOLOGY
							SAMPLES
	85 m	75.95 to 80.00 81.00	75.90 to 77.00		BEUT-82-7	BEUT-82-6 BEUT-82-5 BEUT-82-4 BEUT-82-3 BEUT-82-2 BEUT-82-1	<i>Achomosphaera ramulifera</i> (DEFLANDRE) <i>Achomosphaera sagena</i> DAVEY & WILL in DAVEY et al. <i>Adnatosphaeridium</i> sp. cf. <i>A. aemulum</i> in WILSON <i>Areoligera coronata</i> (O. WETZEL) <i>Areoligera senonensis</i> LEJEUNE-CARPENTIER
			cf.				<i>Areoligera tenuicapillata</i> (O. WETZEL) <i>Cannosphaeropsis utinensis</i> O. WETZEL em. DUXBURY <i>Chalangiella</i> sp. <i>Cladopyxidium</i> spp. <i>Cleistosphaeridium armatum</i> and cf. (DEFLANDRE)
							<i>Coronifera striolata</i> (DEFLANDRE) <i>Deflandrea</i> spp. <i>Exochosphaeridium bifidum</i> (CLARKE & VERDIER) <i>Exochosphaeridium phragmites</i> DAVEY et al. in DAV. et al. <i>Exochosphaeridium? pseudhystrichodinium</i> (DEFLANDRE)
							<i>Florentinia buspina</i> (DAVEY & VERDIER) <i>Fromea</i> sp. <i>Gillinia hymenophora</i> COOKSON & EISENACK <i>Hystrichodinium pulchrum</i> DEFLANDRE <i>Hystrichosphaeridium salpingophorum</i> DEFLANDRE
							<i>Hystrichosphaeridium tubiferum</i> (EHRENBERG) <i>Hystr. tubiferum brevispinum</i> (D. & W. in D. et al.) <i>Isabelidinium cooksoniae</i> (ALBERTI) <i>Leberidocysta chlamydata</i> (COOKSON & EISENACK) <i>Microdinium</i> cf. <i>obscuriplicatum</i> in WILSON
							<i>Microdinium</i> spp. <i>Odontochitina operculata</i> (O. WETZEL) <i>Oligosphaeridium complex</i> (WHITE) <i>Oligosph. proluxispinosum</i> DAV. & WILL. in DAV. et al. <i>Palaeoperidinium pyrophorum</i> (EHRENBERG)
							<i>Spiniferites membranaceus</i> (ROSSIGNOL) <i>Spiniferites ramosus gracilis</i> (DAV. & WILL. in DAV. et al.) <i>Sp. ramosus granosus</i> (DAV. & WILL. in DAV. et al.) <i>Sp. ramosus multibrevis</i> (DAV. & WILL. in DAV. et al.) <i>Sp. ramosus ramosus</i> (EHRENBERG)
							<i>Sp. ramosus reticulatus</i> (DAV. & WILL. in DAV. et al.) <i>Surculosphaeridium? longifurcatum</i> (FIRTION) <i>Trichodinium castaneum</i> (DEFLANDRE) <i>Xenascus ceratioides</i> (DEFLANDRE) <i>Xenikoon</i> sp.
							<i>Xiphophoridium alatum</i> (COOKSON & EISENACK) <i>Canningia colliveri</i> COOKSON & EISENACK <i>Cyclonephelium distinctum</i> DEFLANDRE & COOKSON

CADIER EN KEER

BEUTENAKEN

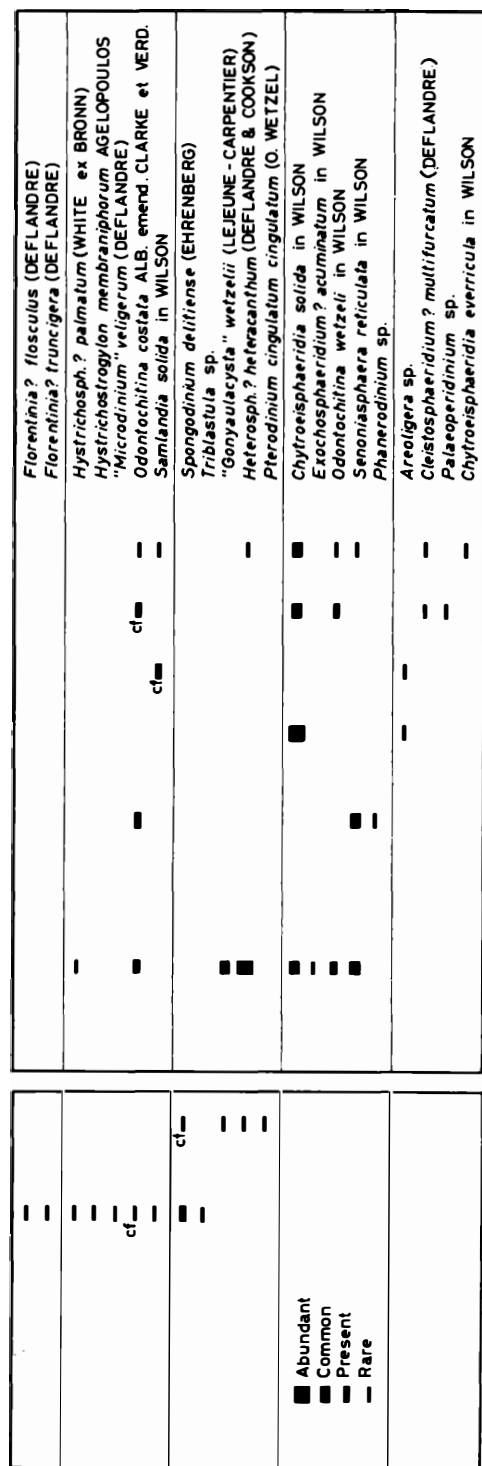


FIGURE 21
Vertical distribution of dinoflagellate cysts in the Beutenaken and Cadier en Keer sections

1977, p. 73]. This palynoflora consists of elements of different ages. A relatively large number of Spores and pollen grains from older horizons are, in fact, associated with the *in situ* palynoflora. The rest of the association comprises elements which are too difficult to attribute to either horizon because of their wide stratigraphic distribution. Moreover, the possible redistribution of older sediments had been pointed out by VANGUESTAINE & STRELL, *in STRELL et al.* (1977).

The Normapolles, which only account for about 1 % of the palynological content, represent the palynoflora which is obviously *in situ*. The most noticeable amongst them are the genera *Trudopollis* and *Semioculopollis* and the main species recognized are *Trudopollis nonperfectus*, *Trudopollis pflugii*, *Trudopollis artifex*, *Trudopollis* sp. 1, ?*Trudopollis* sp. 4, *Semioculopollis* cf. *verrucosa*, *Semioculopollis* cf. sp. A. TSCHUDY, 1975. Also present are *Interporipollenites turgidus*, *Interporipollenites* sp. 1, *Felderipollenites triangulus*, ?*Hofkeripollenites* sp., *Pompeckjoidaepollenites subhercynicus*, *Santonipollis* sp. 1, *Extrapollis* sp. 1, AZEMA *et al.*, 1981, *Vacuopollis munitus* and undetermined Normapolles : Normapollis A (Pl. 14, Fig. 4) and Normapollis B (Pl. 14, Fig. 1 a-b, 2).

Although this assemblage is very incomplete, the presence especially of the genera *Semioculopolis*, *Santonipollis* and *Extrapollis* is generally indicative of a Santonian to Lower Campanian age.

5.6.2. Beutenaken section

Spores and pollen grains are very rare in the Beutenaken samples, amongst them, a single Normapolle specimen in the Beut. 82-7 sample.

5.6.3. Cadier en Keer borehole (Fig. 23)

The two samples taken from the Beutenaken Member at 80-81 m and 78.95-80 m, together with the sample from the Vijlen Member at 75.9-77 m, have yielded material of terrestrial origin. This material represents 30 % of the palynological content at 80-81 m and around 40 % in the other two samples.

As in Halembaye, this palynoflora is made up of elements of different ages. The palynoflora which is evidently *in situ* is represented by a limited amount of Normapollens, accounting for only 1 % to 3 % of the palynological content : *Pseudotrudopollis pseudoalnus*, *Pompeckjoidaepollenites* sp. 1, *Extratropipollenites* sp. 1, ? *Trudopollis* sp. 3 and Normapollene C in the Beutenaken Member: *Trudo-*

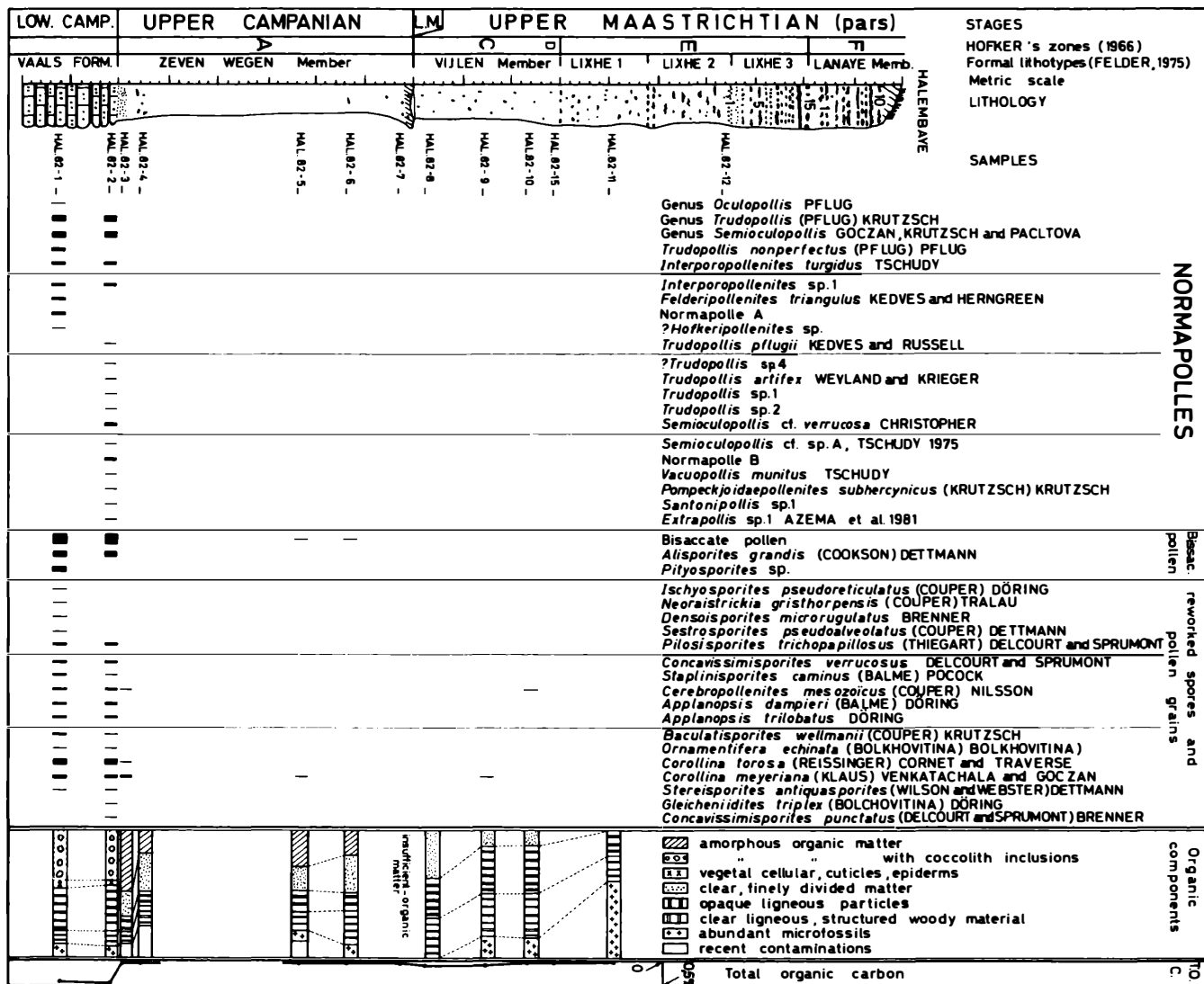


FIGURE 22

Vertical distribution of Spores and pollen grains in the Halembaye section

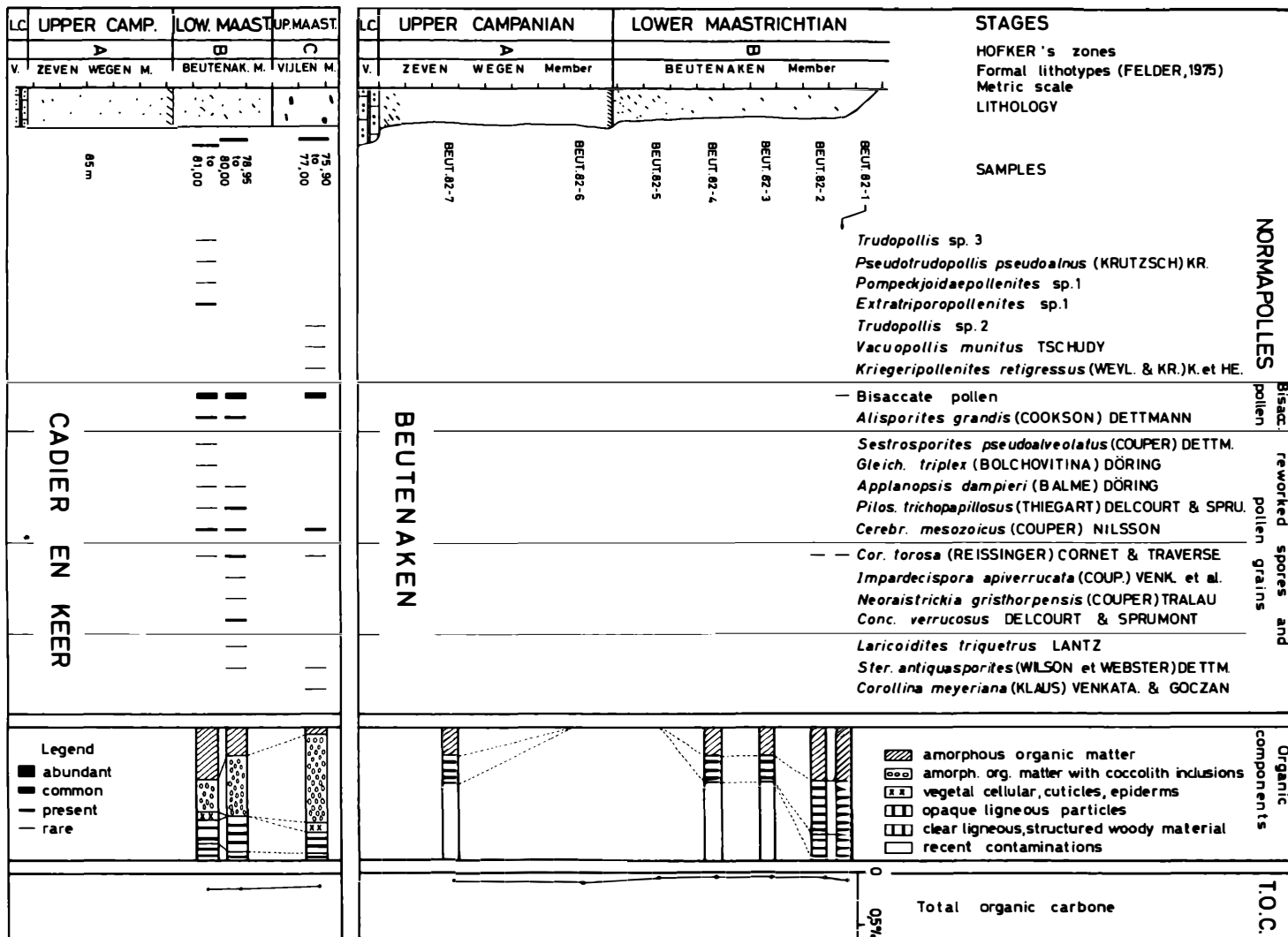


FIGURE 23

Vertical distribution of Spores and pollen grains in the Beutenaken and Cadier en Keer sections (Gleich = Gleicheniidites; Pilos = Pilosporites; Cerebr. = Cerebropollenites; Cor. = Corollina; Conc. = Concavissimisporites; Ster. = Stereisporites)

pollis sp. 2, *Vacuopollis munitus*, *Kriegeripollenites retigressus* and Normapollis D in the Vijlen Member (Pl. 14, fig. 3, 5-7, 9-11).

The presence of the genus *Pompeckjoidaepollenites* (which appears in the Coniacian) and of the genera *Trudopollis* and *Vacuopollis* as well as the absence of typical Paleocene genera which are generally very well represented, suggests a Coniacian to Maastrichtian age for this incomplete assemblage.

6. — PALAEOECOLOGY AND PALAEOENVIRONMENT

6.1. MACROFOSSILS : BELEMNITES (L.A. VDT.)

Belemnites were neritic Cephalopods, probably predating in groups, as recent squids do. In general, one can say that belemnite populations, composed of juvenile, adolescent, as well as adult specimens are found in nearshore, shallow-water sedimentary facies, and populations of only adult specimens are found in offshore deposits. Besides, Belemnites in offshore deposits are much rarer than in nearshore deposits (CHRISTENSEN, 1976). In Halembye and in the Beutenaken area, Belemnites occur commonly and all growth stages can be found. Regarding their functional morphology and their septal strength, Belemnites were neritic animals, inhabiting shallow waters (NAEF, 1922; WESTERMANN, 1973). According to JELETZKY (1951), representatives of the genus *Belemnitella* are generally associated with a warm-water environment (with e.g. Rudists) and representatives of the genus *Belemnella* with a colder-water environment, although the terms "warm" and "cold" are questionable and must not be exaggerated, as isotopic measurements suggest (NAIDIN *et al.*, 1966).

This could be an explanation for the disappearance of the genus *Belemnitella* and the appearance of *Belemnella* at the transition of Campanian-Maastrichtian and the reappearance of *Belemnitella* and the disappearance of *Belemnella* at the end of the Lower Maastrichtian. So one may conclude that the Campanian and Maastrichtian deposits in Limburg were laid down in a nearshore, shallow water depositional regime with changing temperature.

6.2. MESOFOSSILS (P.J.F.)

6.2.1. Introduction

The Late Cretaceous organoclastic deposits of South-Limburg contain a number of very fossiliferous bands, which are characterized by the predominance of a distinctive fossil or group of fossils. Since many of these beds serve as regional markers for correlation, they have been named after the dominant fossil in the same. Thus, names such as the "Belemnite Graveyard", "Coprolith Band", "Dentalium Band", "Echinocorys Level", "Bryozoan Beds", "Hemipneustes Band", and so on, have been established. The fact that these bands can be traced over relatively long distances of sometimes twenty to thirty kilometres suggests rather uniform environmental conditions within this part of the Late Cretaceous basin. However, in the course of the Campanian and Maastrichtian, these conditions appear to have varied considerably, as can be deduced from the quite different dominant fossil groups mentioned above.

These variations in the environment have been investigated systematically in a quantitative study of the mesofossil content of a large number of sections. Mesofossils are all the bioclasts between 1.0 and 2.5 mm which can be identified as belonging to one of the major taxa. These include both small fossils and fragments of large specimens.

In practice, five groups of mesofossils are distinguished, which can be subdivided into smaller groups for more refined correlation purposes:

- Foraminifera;
- Sponges, Bryozoans, Corals;
- Molluscs, Brachiopods;
- Echinoderms;
- a rest group, including a.o. Arthropods, Serpulids, Coproliths, fish remains.

Variations in the quantitative distribution of these groups allow very detailed correlations between the different sections in the Late Cretaceous and Early Tertiary of South-Limburg and surrounding areas, sometimes even over a distance of more than one hundred kilometres. The method has been applied successfully both for samples obtained from quarries and natural outcrops as well as for rollerbit samples from boreholes (FELDER, 1981, 1982, and *in* ROBASZYNSKI *et al.*, 1985).

For the preparation of the mesofossils, the samples are crushed (insofar as needed), washed

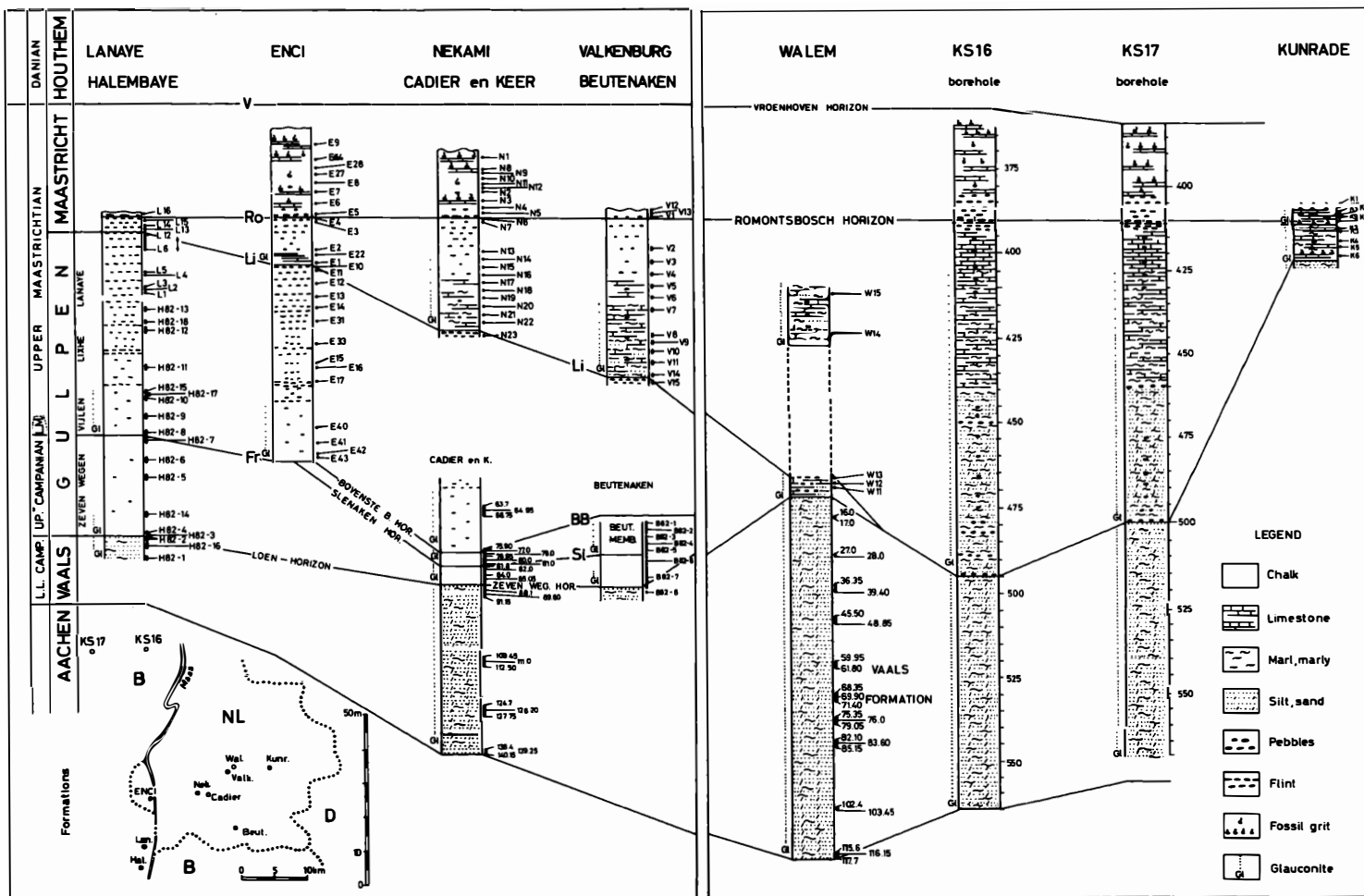


FIGURE 24

Sampling of Campanian-Maastrichtian sections in the South-Limburg for the study of mesofossils and Ostracods

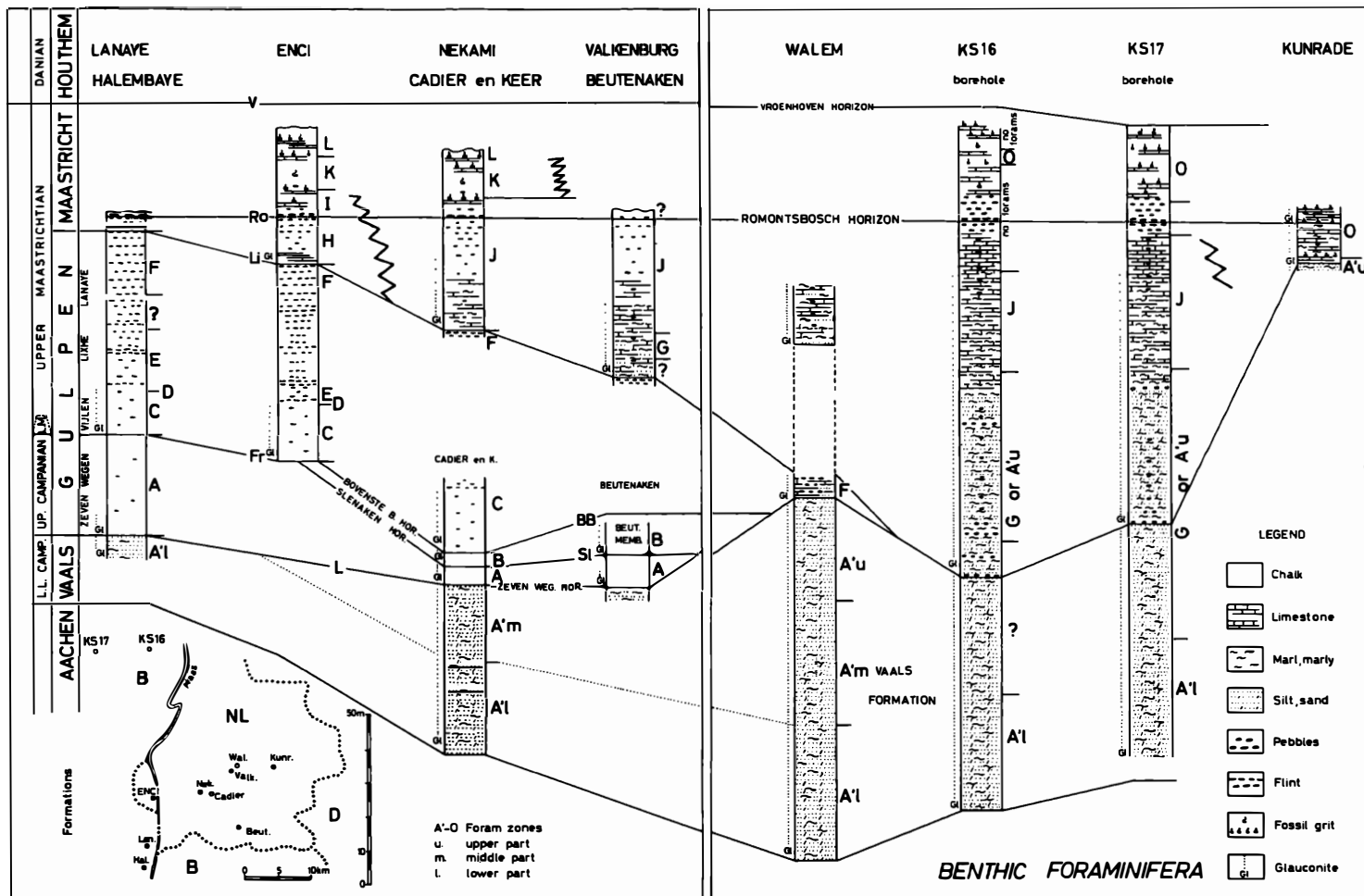


FIGURE 25
 Benthic Foraminifera zones in the Campanian-Maastrichtian of South-Limburg

and sieved (meshes used here are 1.0 mm and 2.4 mm). Subsequently, the bioclasts are picked out under a binocular microscope, separated into the above mentioned five major groups, and counted. Finally, the quantitative composition of the mesofossil assemblage in the sample is calculated.

6.2.2. Remarks on mesofossil groups

— *Foraminifera*. Only the large forms (> 1.0 mm) of this taxon are observed because of the size of the bioclasts considered. Two groups can be distinguished: agglutinated and non-agglutinated forms. The latter is composed mainly of Lagenidae, Rotaliidae and Orbitoididae.

— *Sponges, Bryozoans and Corals*. Sponge spicules are rare since these usually pass through the sieve. Coral remains are also very rare, since practically all the corals have been dissolved in the deposits. Therefore, in practice this group consists almost entirely of bryozoan remains.

— *Molluscs and Brachiopods*. These taxa have been taken together, since it is not always easy to distinguish between the fragments of Bivalves and Brachiopods. On the other hand, two subgroups are readily recognized: fragments of belemnite guards and fragments of the prismatic layer of pelecypod shells.

— *Echinoderms*. Frequently, a distinction may be made between Crinoids, Ophiuroids, Asteroids and Echinoids. However, this is not possible for all fragments.

— *Rest group*. This heterogeneous group includes a.o. arthropod remains, Coproliths, Serpulids and fish remains. Only Serpulids tend to be common to abundant in some intervals.

6.2.3. Quantitative distribution

Variations in the quantitative distribution of various mesofossil groups and subgroups are shown in Fig. 24 to 31. The correlation lines drawn on the basis of these quantitative variations match remarkably well the lithostratigraphical and biostratigraphical correlations. Therefore, within the area under consideration, these mesofossil correlations can be regarded as reliable.

Comparison of the data on the Fig. 24 to 31 has permitted one to establish a tentative mesofossil ecozonation for the area (Fig. 32). Six major ecozones may be distinguished, which can be subdivided into smaller units.

— *Mesofossil ecozone 1* (Vaals Formation). Characterized by the predominance of Foraminifera (Lagenidae), Pelecypods and/or Belemnites. Bryozoans and Serpulids are rare to absent. Echinoderms become locally abundant towards the top of this zone.

— *Mesofossil ecozone 2* (lower part of Gulpen Formation: Zeven Wegen Member to basal part of Vijlen Member). Rapid lateral and vertical changes in the quantitative distribution of practically all fossil groups, partly because of repeated reworking of material from Vaals Formation and basal part of Gulpen Formation.

— *Mesofossil ecozone 3* (upper part of Gulpen Formation: middle Vijlen Member to Lanaye Member). Characterized by usually high amounts of echinoderm fragments, among which Crinoids abound in the upper part of this zone. Frequently high numbers of Brachiopods. In the lower portion of this zone, mesofossils are very rare.

— *Mesofossil ecozone 4* (lowermost Maastricht Formation; "Foraminifera Zone G"). Characterized by predominance of Pelecypods and Belemnites, largely reworked from Vaals and/or Gulpen Formations.

— *Mesofossil ecozone 5* (middle portion of Maastricht Formation below Romontsbosch Horizon). Characterized by predominance of Echinoderms, especially Echinoids and Ophiuroids. Locally high numbers of Serpulids, Bryozoans and large non-agglutinated Foraminifera (in so-called Kunrade facies). Pelecypods and Belemnites are rare to absent. The lower portion of this zone bears very low numbers of mesofossils.

— *Mesofossil ecozone 6* (Maastricht Formation, above Romontsbosch Horizon). Characterized by predominance of Echinoderms (especially Echinoids). The lower portion of this zone yields high numbers of Serpulids, whereas non-agglutinated Foraminifera and Bryozoans tend to abound in the upper half of the zone.

6.3. OSTRACODS (M.J.M.B.)

6.3.1. Historical review

Ostracods have been studied from some 180 samples collected from the Vaals to Houthem Formations in ten sections in north-eastern Belgium and South-Limburg (The Netherlands). The location of these sections and the stratigraphical position of the studied samples is indicated in Figure 24.

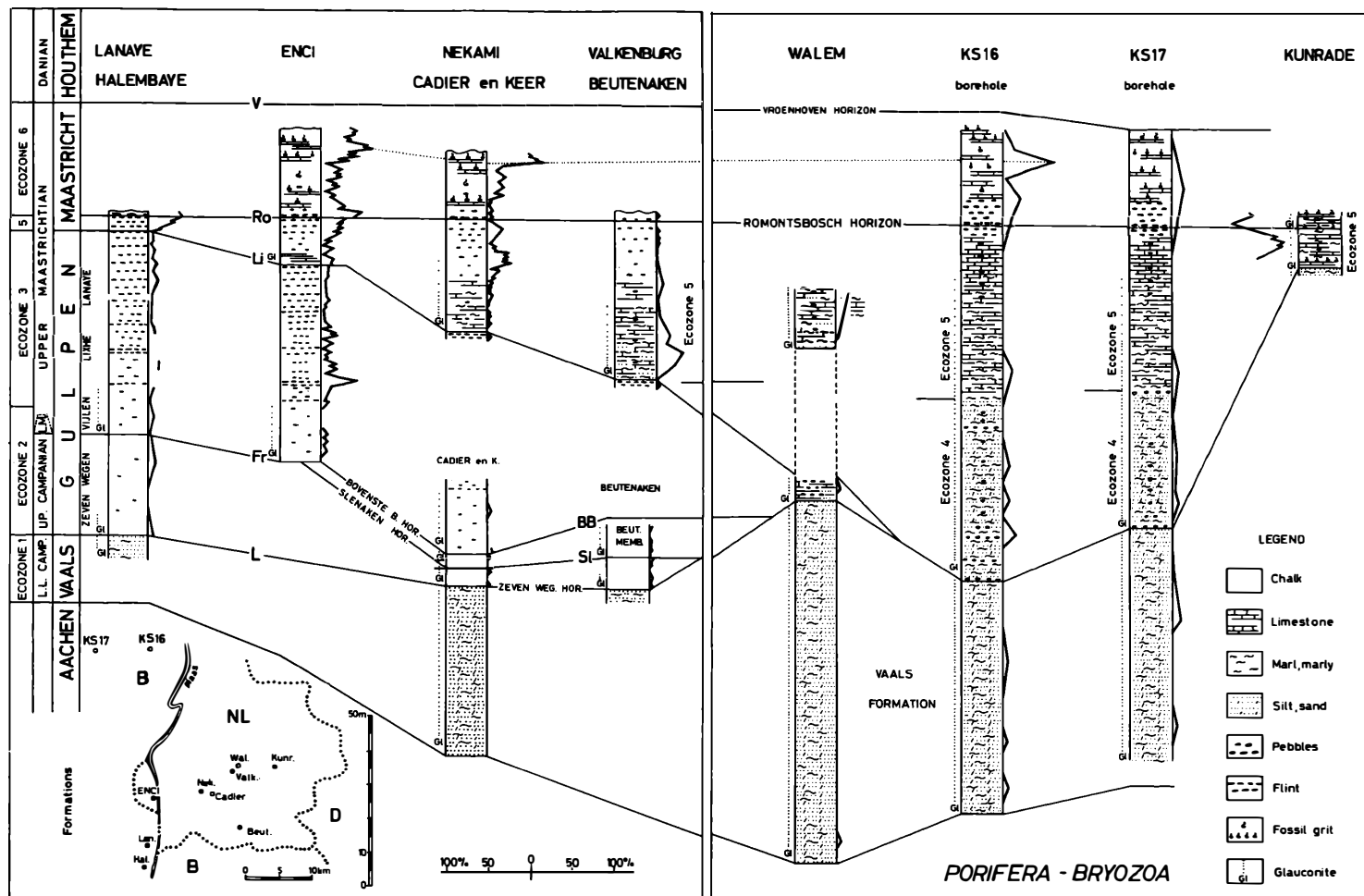


FIGURE 26

Quantitative distribution of Sponges and Bryozoans in the Campanian-Maastrichtian of South-Limburg

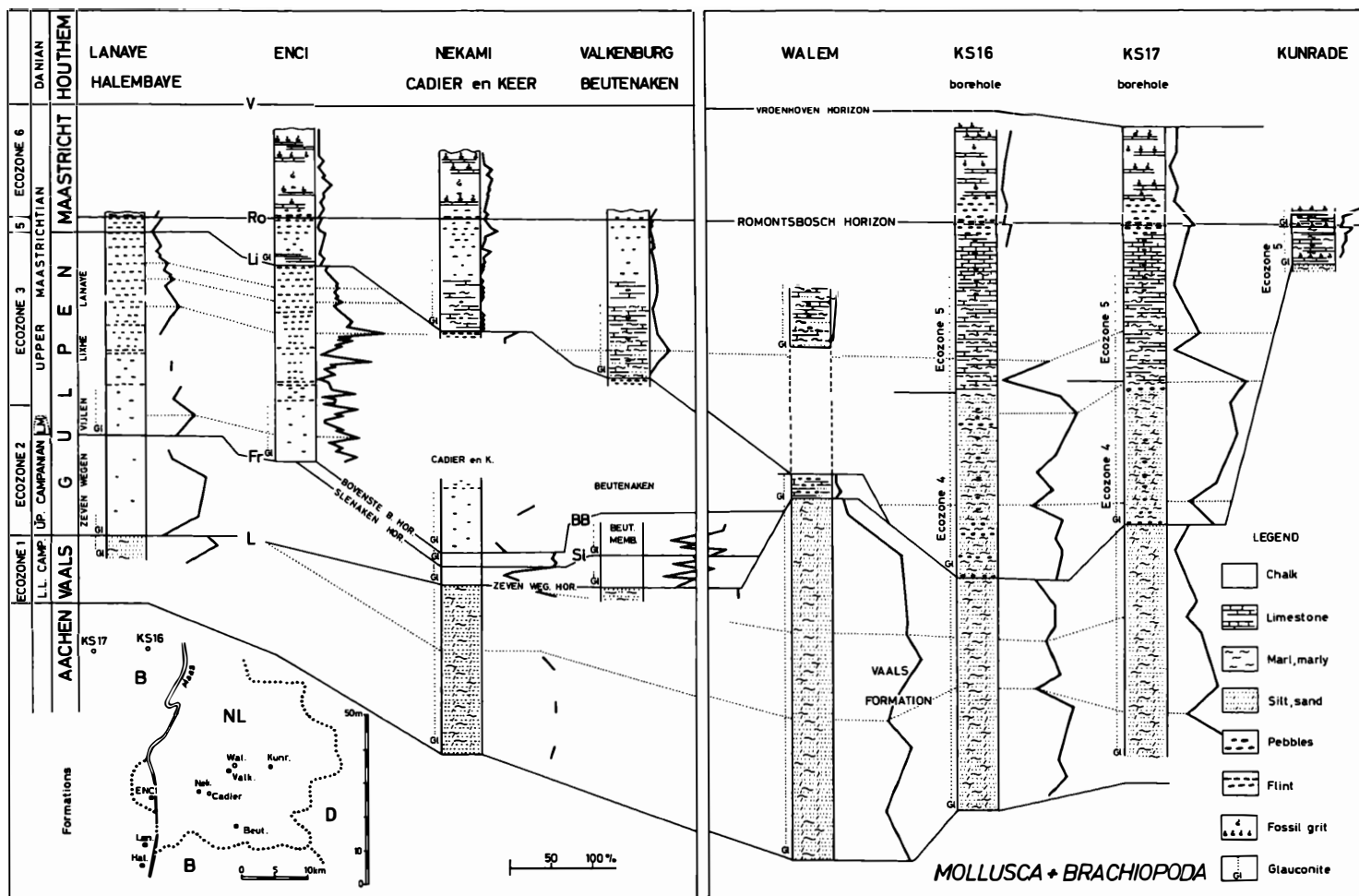


FIGURE 27

Quantitative distribution of Molluscs and Brachiopods in the Campanian-Maastrichtian of South-Limburg

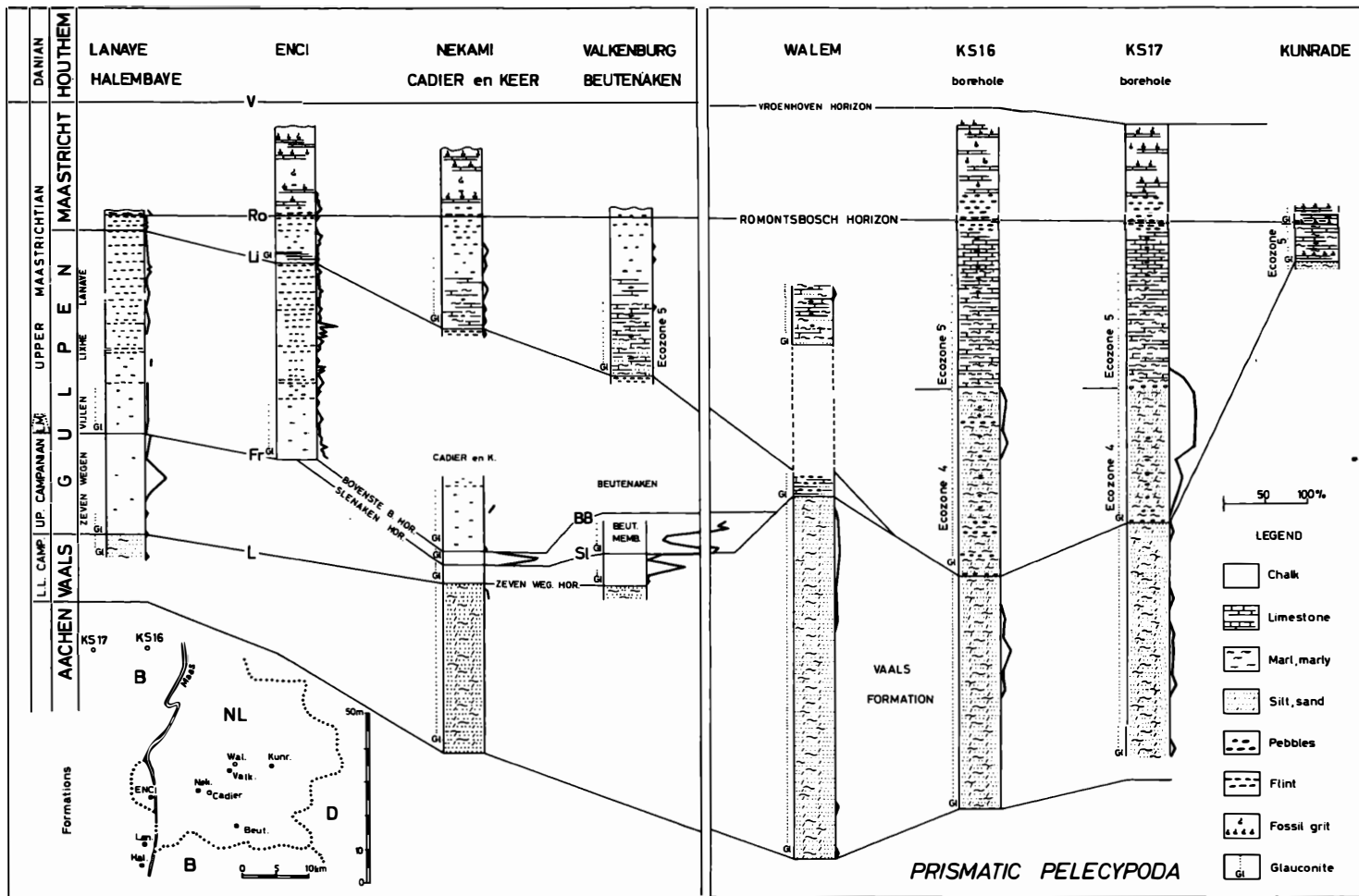


FIGURE 28

Quantitative distribution of Molluscs and Pelecypods in the Campanian-Maastrichtian of South-Limburg

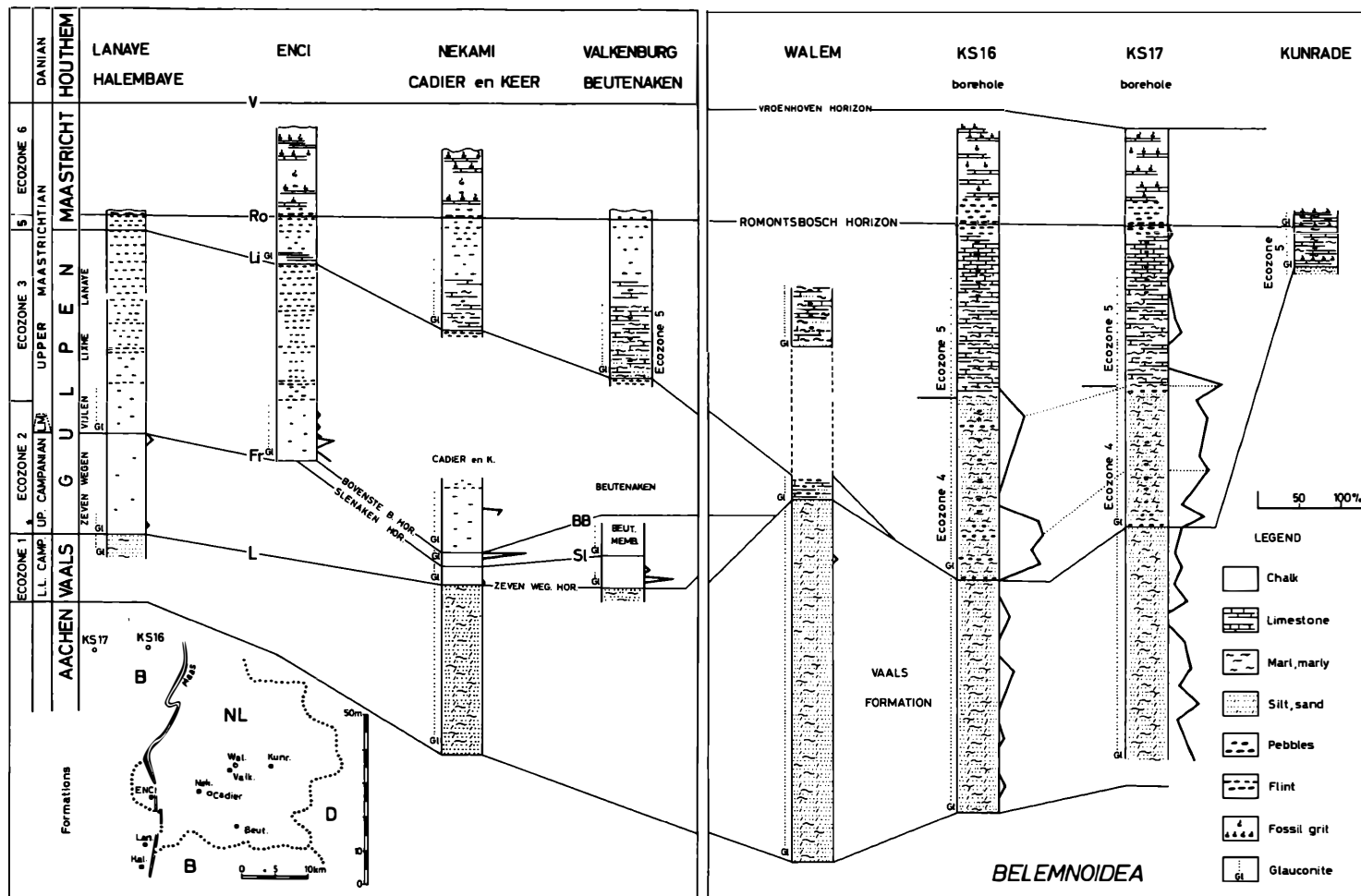


FIGURE 29

Quantitative distribution of belemnite guards in the Campanian-Maastrichtian of South-Limburg

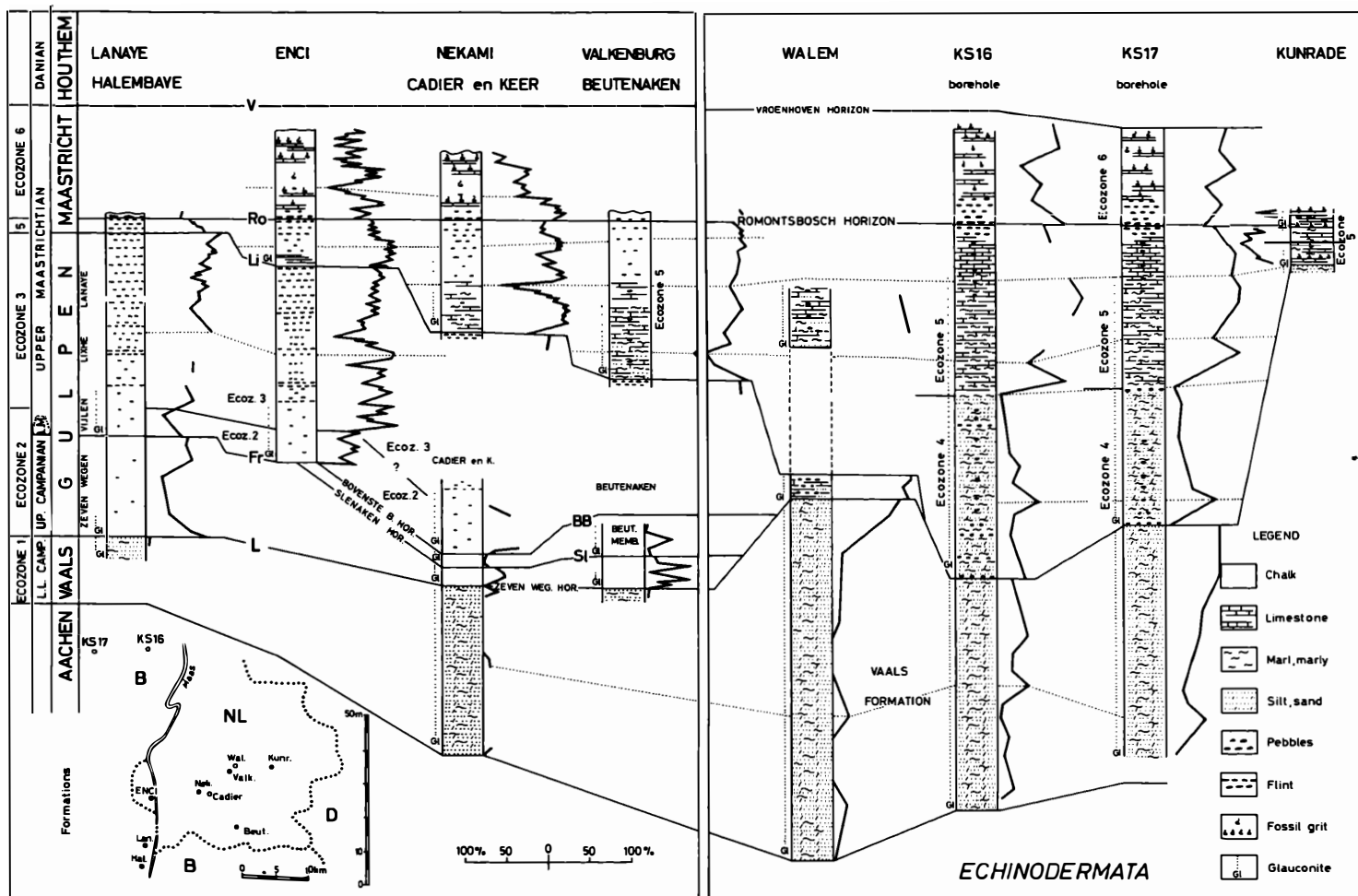


FIGURE 30

Quantitative distribution of Echinoderms in the Campanian-Maastrichtian of South-Limburg

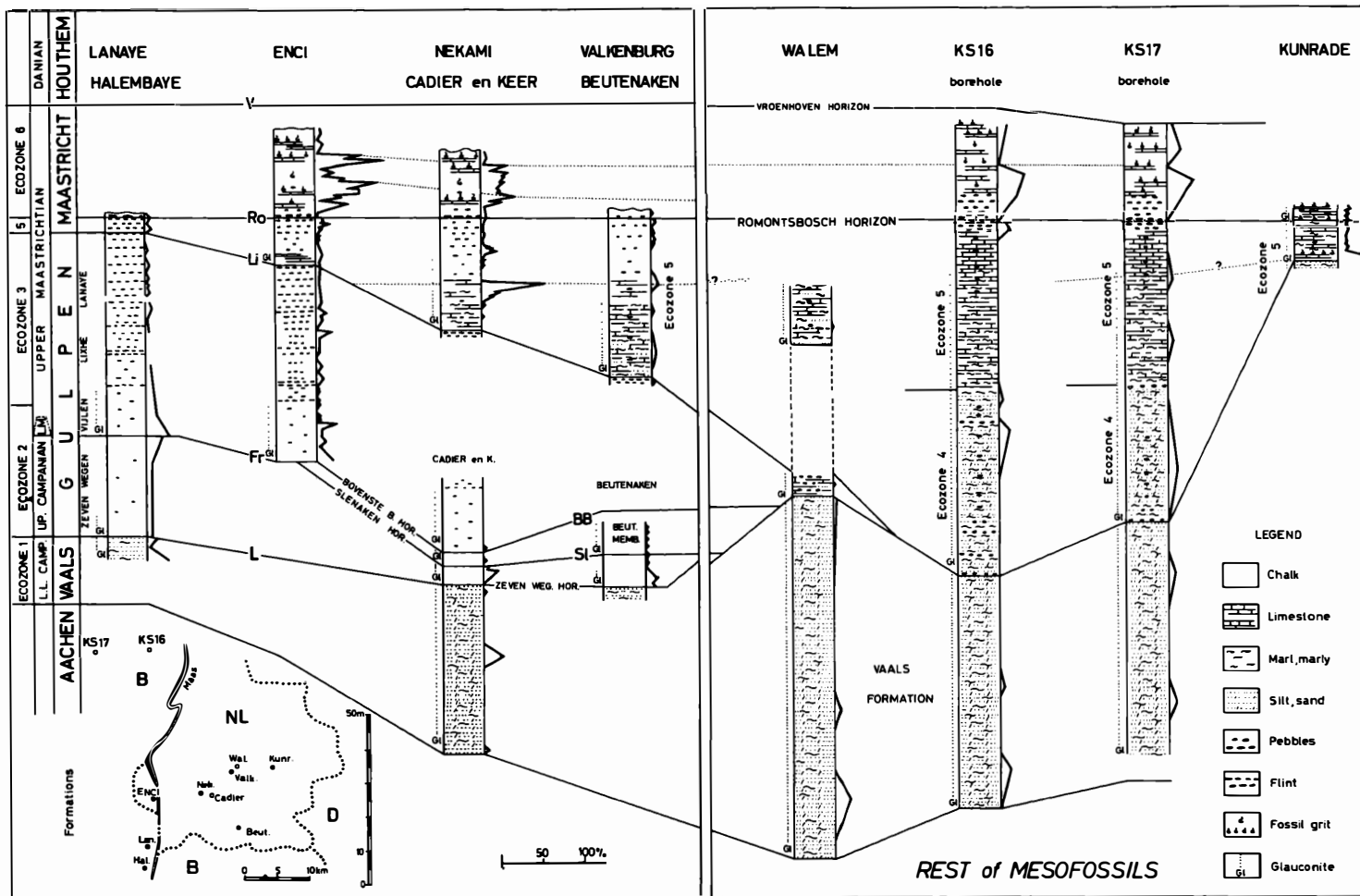


FIGURE 31

Quantitative distribution of the rest of the mesofossils in the Campanian-Maastrichtian of South-Limburg

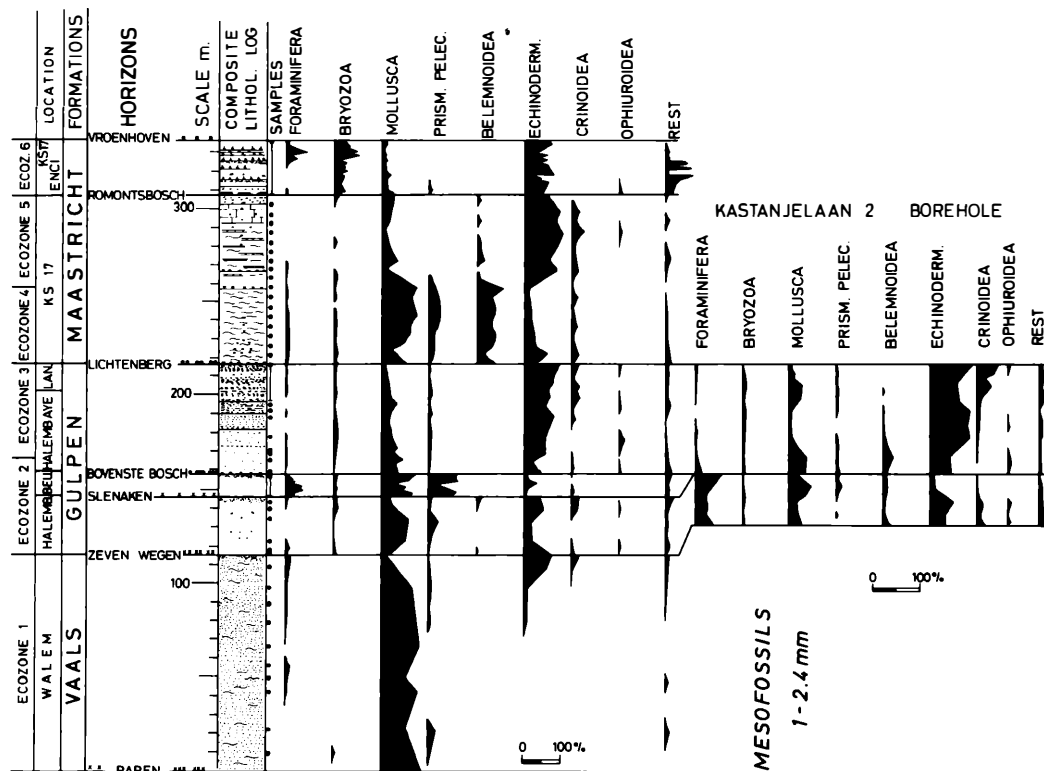


FIGURE 32

Synthetic quantitative distribution of mesofossils in Campanian-Maastrichtian of South-Limburg and definition of the six mesofossils ecozones

The study of Late Cretaceous and Early Tertiary Ostracods from this area started already halfway through the last century (BOSQUET, 1847, 1854). More detailed investigations have been carried out in this century (VAN VEEN : 23 publications between 1932 and 1937; DEROO, 1966; ROMEIN *et al.*, 1977). Almost 250 species have been described thus far. Practically all species had been obtained from the Gulpen, Maastricht or Houthem Formations. Only a few species from the Vaals Formation have been described by DEROO (1966). However, the latter data must be considered as incomplete since only very few samples had been studied. Finally, some remarks on the palaeoecology of the Ostracods have been published by BLESS *et al.* (1983) and in ROBASZYNSKI *et al.* (1985).

6.3.2. Palaeoecological value

A review of the species list published by DEROO (1966, table 6) readily learns that there is a marked

difference in the species diversity observed in the various stratigraphic intervals. Species diversity is low in the Gulpen Formation (between 20 and 36 species) and high in the Maastricht Formation (between 75 and 125 species). This suggests important changes in the palaeoenvironmental conditions.

These variations in the palaeoenvironment may also be deduced from a quantitative investigation on the assemblages, as carried out for this paper. For this purpose two purely artificial groups of Ostracods have been distinguished : more or less smooth-shelled forms (Plate 19) and ornamented (Plates 20 to 22) ones. This was done on the assumption that many smooth-shelled Ostracods have a rather fragile carapace compared to that of ornamented ones, and that smooth-shelled Ostracods might therefore be indicative for low-energy and/or relatively deep environments, whereas ornamented Ostracods might show a preference for high-energy and relatively shallow facies. Of

course, it was realized that this assumption is an oversimplification, and that the terms "low and high energy", "shallow" and "deep" have only a comparative meaning. For example, the term "deep" is used here in the sense of "less shallow" and reversely the term "shallow" is meant as "less deep", without fixing any exact figure to the boundary between shallow and deep and even accepting that this boundary may be flexible.

The group of smooth-shelled Ostracods as defined here comprises the genera *Cypridina*, *Cytherella*, *Bairdia*, *Macrocypris*, "*Paracypris*", *Xestoleberis*, *Asciocythere*, *Clithrocytheridea*, *Parataxodonta*, *Aequacytheridea*, *Veenidea*, *Kalyptovalva*, *Krithe*, *Globoleberis*, *Sphaeroleberis* and *Tumidoleberis*. The latter three genera frequently show a finely striated ornament, and an inflated, somewhat overhanging latero-ventral portion of the valves. Therefore, these might as well have been included in the group of ornamented Ostracods. All the other genera (*Cytherelloidea* and a large number of genera assigned to the Cytheracea by DEROO, 1966), have been considered as ornamented, even if their carapaces may be (practically) smooth (e.g. some species of *Kikliocythere* and *Mosaeleberis*).

Subsequently, the number of individuals belonging to one of these two groups has been counted. In each sample a minimum of 25 ostracod specimens were counted (no distinction was made between single valves and complete carapaces). But frequently up to 50, and occasionally over one hundred specimens were counted. If the number of specimens was below 25, the countings of two successive samples have been combined into one larger sample interval. It was observed that smooth-shelled individuals usually predominate over ornamented forms (except for the lower and middle Vaals Formation and occasionally in the Maastricht Formation, where ornamented Ostracods may be predominant). Therefore, a practical cut-off value of 80 % smooth-shelled individuals in a sample was accepted for the distinction between "smooth" and "ornamented" assemblages. This approach allowed the recognition of fifteen assemblage zones or ecozones which can be traced from one section into the other (Fig. 33). This suggests extremely uniform ecological conditions within the basin.

6.3.3. Definition of ostracod ecozones

For the scope of this report, short characteristics of the ecozones 1 to 6 are presented below,

whereas the ecozones 7 to 15 are commented in a more generalized way.

— Ecozone 1

Roughly corresponding to the lower and middle Vaals Formation. Ornamented Ostracods are predominant in many samples (up to 82 % ornamented forms in Beut. 82-8), but occasionally, there occurs a predominance of smooth-shelled specimens. Characteristic are *Veenia*, *Cythereis*, *Pterygocythere* whereas *Pterygocythereis*, *Curfsina* and *Cytherella* are common. Sometimes high numbers of *Bairdia* or *Asciocythere*.

— Ecozone 2

Roughly corresponding to the upper Vaals Formation. Predominance of smooth-shelled Ostracods (between 80 and 100 %), especially *Cytherella* and *Asciocythere*. Commonly some specimens of *Veenia*, *Pterygocythere* and *Cythereis*.

— Ecozone 3

Corresponding to the base of the Zeven Wegen Member. Predominance of smooth-shelled Ostracods (*Bairdia*, *Krithe*), but relatively high numbers of ornamented Ostracods (up to 30 %), notably *Cytherelloidea* and *Bythoceratina*.

— Ecozone 4

Corresponding to the middle and upper portion of Zeven Wegen Member and base of Beutenaken Member. Predominance of smooth-shelled *Cytherella* (in Halembaye samples) or *Bairdia* (in Beutenaken and Cadier en Keer samples). Regularly some specimens of *Cytherelloidea* and *Bythoceratina*, whereas *Mosaeleberis rutoti* occurs in several samples of the Zeven Wegen Member.

— Ecozone 5

Corresponding to the middle portion of Beutenaken Member. Predominance of smooth-shelled genera *Asciocythere* and *Bairdia*, and relatively high numbers (30 % to 37 %) of ornamented forms (notably *Cytherelloidea*, *Aversovalva*, *Bythoceratina*, *Schizocythere*, *Curfsina* and *Eucytherura dorsotuberculata*).

— Ecozone 6

Corresponding to the top of Beutenaken Member, Vijlen, Lixhe 1-2-3 Members, and the lower portion of Lanaye Member. A predominance of ornamented *Cytherella*. Regularly low numbers of *Krithe* and *Aversovalva*. Isolated specimens of *Bythoceratina* and *Eucytherura dorsotuberculata* in Vijlen Member.

The ecozones 7 to 11 show characteristic off-lap (zone 7) and on-lap (zones 8 to 11) phenomena.

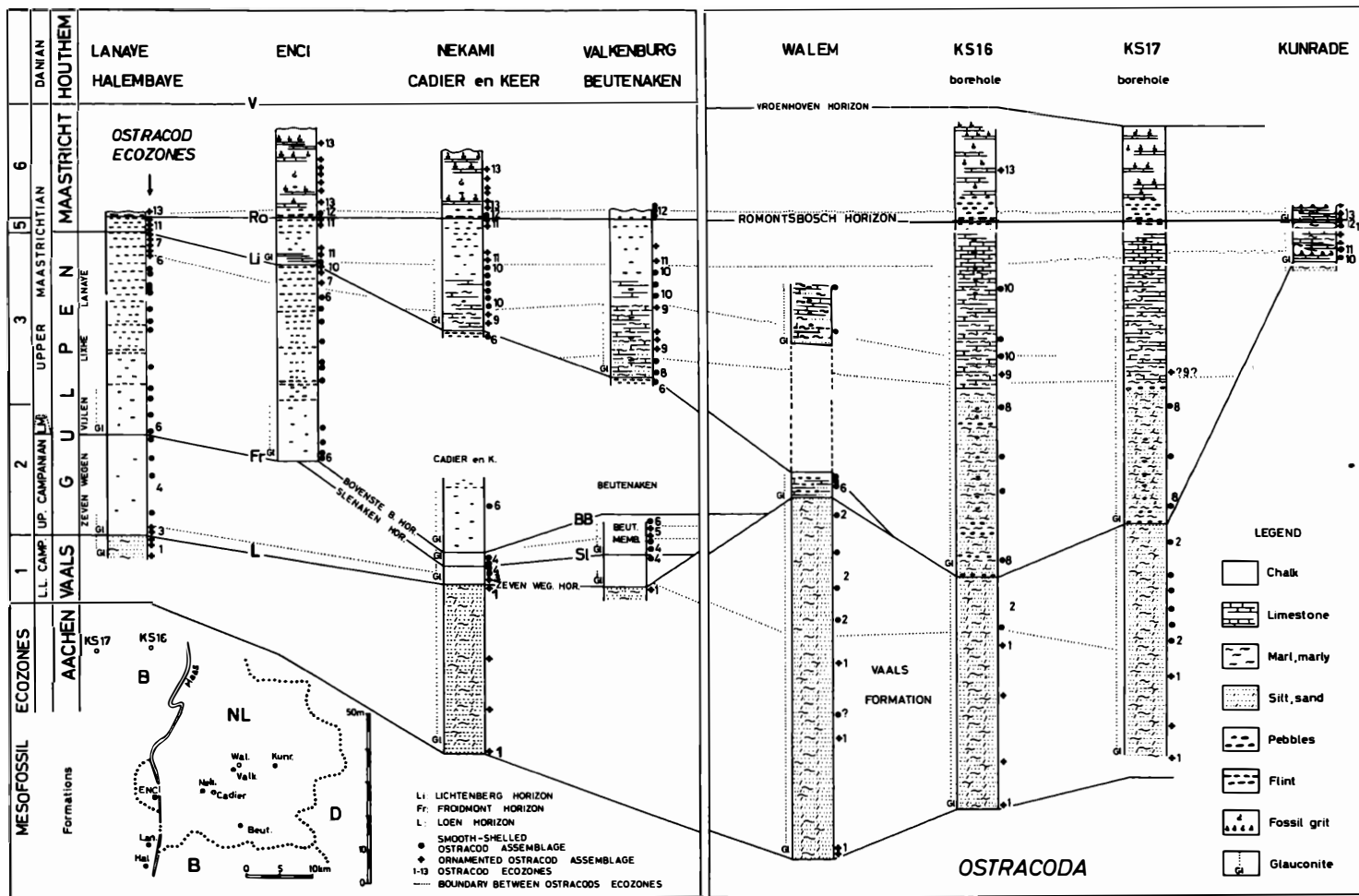


FIGURE 33

Distribution of the thirteen ostracod ecozones in the Campanian-Maastrichtian of South-Limburg

Of special importance is the succession of the assemblage zones 10 to 13, which has been recognized in the ENCI, Nekami and Kunrade sections, and partly also in the Valkenburg section (zones 10 to 12). This succession confirms the correlation of the "Koraalkalk van Kunraad" Horizon in the upper portion of the Kunrade section with the Romonstbosch Horizon in the ENCI and Nekami sections (FELDER, 1977), and is convincing evidence for the suggestion by FELDER (1977) that the Kunrade Chalk corresponds to the lower portion of the Maastricht Formation (Mb), insofar as exposed at the ENCI. However, this is a problem that deserves a more detailed discussion beyond this paper.

The Halembye section clearly shows the presence of important gaps at the position of the Loën Horizon and Froidmont Horizon, where marked environmental changes took place in other sections. Also it should be noticed that the ostracod content of the Halembye section is not necessarily a standard one for the basin. This may be deduced, for example, from the observation that lateral variations occur in e.g. the ecozone 4, where the genus *Cytherella* predominates at Halembye and the genus *Bairdia* at Cadier en Keer and Beutenaken.

6.3.4. Species diversity

Species diversity and the number of genera are highest in the ecozones 1, 3, 5 and 7, where the percentage of smooth-shelled Ostracods is less than 80%. The number of genera and species is lower within the ecozones 2, 4 and 6. Similar observations have been made for the Maastricht and Houthem Formations.

This suggests that ostracod species invaded the basin during periods of optimal ecological conditions, when the mega-environment was relatively shallow and the water energy level not too low (presumably above wave base and well-aerated). When the mega-environment became deeper in subsequent periods, the number of species decreased, apparently because of a less suited facies. Such a rhythmic variation in the composition of the ostracod assemblages suggests that the appearance and disappearance of the ostracod species is strongly facies-controlled. Therefore, the (eco-)stratigraphical ranges of the Ostracods in this area are not necessarily the same as in other regions.

The relatively low number of ostracod species in the Vaals and Gulpen Formations against the high species diversity in the Maastricht Formation

may be related to the fact that the Maastricht area was within the reach of the Boreal realm during the Campanian and large part of the Maastrichtian, and became a part of the Tethyan Province at the end of the Maastrichtian (deposition of the "type-Maastrichtian" of DUMONT, 1849).

6.3.5. Palaeoecological implications

CLARKE (1983) suggested an increased temperature for a.o. the Lower Maastrichtian of Hemmor (Federal Republic of Germany) because of a.o. the increased number of species and individuals of the "warm-water" genus *Cytherelloidea* in the uppermost Campanian and Lower Maastrichtian. However, this increase in the number of species is not spectacular (usually from two to incidentally four). Moreover, the high numbers of valves per 100 g sediment (between 50 and 170) correspond to low numbers of species (two). Therefore, this argument is considered as insufficient for accepting the hypothesis of an increased sea-water temperature during that period. On the other hand, CLARKE's suggestion that the minimum temperature of the sea-water in northwestern Europe was 10° C because of the presence of a.o. the "warm-water" genus *Cytherelloidea* seems valid. Such temperatures are not restricted however to the seas between 40° southern and northern latitudes. These may occur also further to the North than to the South because of warm oceanic currents, such as the recent Gulf Stream.

6.4. SPORES AND POLLEN GRAINS AND ORGANIC MATTER (O.L.)

Terrigenous organic supplies are negligible in the Gulpen Formation at Halembye and at Beutenaken: Spores and pollen grains are very rare and the organic carbon content very low, suggesting a greater distance from the shore. These supplies are significantly higher in the Vaals Formation at Halembye and in the Beutenaken Member and Vijlen Member at Cadier en Keer: Spores and pollen grains are much more numerous and the organic content higher. These observations are indicative of more near-shore conditions, underlined also by the presence of autochthonous amorphous organic matter with coccolith inclusions. The presence of autochthonous organic matter is evidence of an environment of deposition which favours its good preservation, i.e. poorly oxygenated conditions at depth.

As it was expressed in the biostratigraphic chapter, a redistribution of older sediments is emphasized by the occurrence of reworked Spores and pollen grains.

6.4.1. Reworked Spores and pollen grains

A reworking of deposits is revealed at Halem-baye quarry (Fig. 23) by the presence of quite a lot of Spores and pollen grains. Most of the reworked species have a limited stratigraphic extension which, for the most part, is common to them all. The longest of the stratigraphic interval stretches from the Kimmeridgian to the Cenomanian and the shortest one is from the Hauterivian to the Aptian: *Cerebropollenites mesozoicus*, *Pilosisorites trichopapillosus*, *Concavissimisorites verrucosus*, *Concavissimisorites punctatus*, *Applanopsis dampieri*, *Applanopsis trilobatus*, *Sestrosorites pseudoalveolatus*, *Baculatisorites wellmanii*, *Densisorites microrugulatus*, *Ornamentifera echinata*, *Gleicheniidites triplex*, *Ischyosorites pseudoreticulatus* (Pl. 15).

Some species such as *Corollina torosa* (Pl. 15) have a slightly longer stratigraphic extension, ranging from the Upper Trias to the Cretaceous.

Furthermore, the presence of *Neoraistrickia gristhorpensis* (Pl. 15) restricted to the Bajocian-Bathonian and *Corollina meyeriana* (Pl. 15) known from the Upper Trias to the Lias, indicates the resedimentation of even older Jurassic deposits.

The bisaccate pollen grains are relatively numerous, accounting for about half the material of terrestrial origin: these pollens include *Alisporites grandis* and *Pityosporites* sp. Their varying colouring suggests that they probably have been derived from different horizons and that some of the quite light ones are *in situ*.

The relatively dark colour of the Circumpolles pollen grains with *Corollina meyeriana* and *Corollina torosa* suggests that they have all been reworked from older levels.

The samples taken along Beutenaken section (Fig. 23) contain very few Spores and pollen grains. A few reworked elements including *Corollina torosa* in the Beut. 82-2 and Beut. 82-1 samples, can be noted.

Reworkings of the same type as those observed in the Vaals Formation at Halem-baye, are visible at Cadier en Keer (Fig. 23) in the Beutenaken Member and in the Vijlen Member: *Sestrosorites pseudoalveolatus*, *Gleicheniidites triplex*, *Applanopsis dampieri*, *Pilosisorites trichopapillo-*

sus, *Cerebropollenites mesozoicus*, *Impardecispora apiverrucata*, *Concavissimisorites verrucosus* (Pl. 15).

As in Halem-baye, the presence of *Neoraistrickia gristhorpensis* and of *Corollina meyeriana* indicates the resedimentation of deposits which are Bathonian-Bajocian and Upper Trias to Lias in age.

The bisaccate pollen grains represent 30 to 40 % of the material of terrestrial origin: amongst these, *Alisporites grandis*. Their varied colouring shows that, just like those in Halem-baye, they come from different horizons.

As in Halem-baye, the quite dark Circumpolles pollen are probably all reworked from older levels.

6.4.2. Organic matter

The highest organic carbon content has been found in the Vaals Formation at Halem-baye quarry (Fig. 22) although even here it remains low: TOC is in the order of 0.45 % (TOC: Total Organic Carbon). The terrigenous supplies are more numerous here than in the rest of the section; this is indicated by the presence of terrestrial microflora, even though in a relatively limited quantity. The organic matter comprises half amorphous and half ligneous matter. The amorphous matter contains many coccolith inclusions which attest to its algal origin (Pl. 14, fig. 12-13) and therefore to its autochthonous nature, whereas the ligneous material comes from the mainland. In the Gulpen Formation, the organic carbon content is very low: TOC < 0.1 %. The organic deposits are, therefore, negligible and the palynofacies are not very representative: they consist of ligneous material associated with a small amount of amorphous matter below the Froidmont Horizon. In the Lixhe Member, most of the palynofacies are made up of dinoflagellate cysts.

Organic carbon content is very low in all the samples of the Beutenaken section: TOC < 0.1 %. The organic deposits are negligible and the palynofacies are not very representative. They show mixed amorphous-humic facies that are generally highly contaminated by subactual pollutions.

At Cadier en Keer, organic carbon content is low in the three samples: the TOC varies from 0.15 to 0.12 %. The presence of terrestrial microflora reflects the terrigenous supplies which, however, remain limited. The organic matter consists mainly of amorphous material combined with a small quantity of opaque ligneous material. All of the amorphous matter in the Vijlen Member and a part of it in the Beutenaken Member contains coccolith

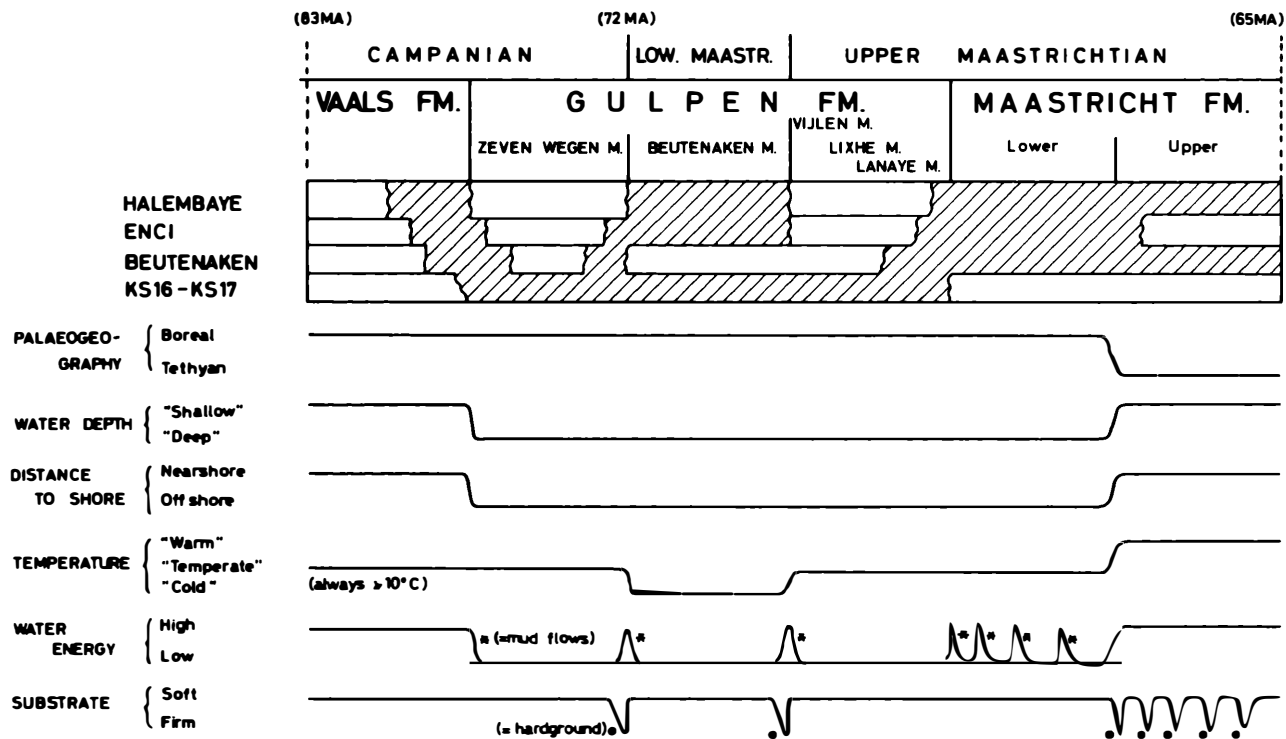


FIGURE 34

Main variations of palaeoecological conditions in the Campanian-Maastrichtian of South-Limburg

inclusions and is, therefore, of algal origin (Pl. 14, fig. 12-13).

6.5. FORAMINIFERA

6.5.2. Benthic Foraminifera (J.P.M.Th.M.)

A comparison at the family level of benthic Foraminifera from the Campanian and Maastrichtian deposits in the Maastricht area with those of modern seas suggests that the water depth varied between 40 and 150 m during the sedimentation of the Gulpen Formation and between 0 and 40 m during the sedimentation of the upper Maastricht Formation (VILLAIN, 1977).

A similar comparison suggests a relatively "cold" water temperature during the deposition of the calcilutites of the Gulpen Formation, whereas the water was warm (20-25°C) during the sedimentation of the highest ("Md") Maastricht Formation (VILLAIN, 1977).

Important differences exist in the qualitative and quantitative composition of the Foraminifera assemblages from the Zeven Wegen Member in the Halembaye and Beutenaken sections. These may be due to selective preservation, to the fact that only a few spot samples have been compared, or to local differences in the palaeoenvironment.

The qualitative composition of the Foraminifera assemblages from the Beutenaken Member in the Cadier en Keer and Beutenaken sections is very similar. However, there are differences in the quantitative distribution of species. For example, *Gavelinopsis voltziana* and *Eponides beisseli* are common in the Beutenaken section, whereas *Cibicides subbosqueti* and *Gaudryina cretacea* are amongst the most frequent forms in Cadier en Keer.

Therefore, it seems premature to use the quantitative distribution of benthic Foraminifera for a palaeoecological interpretation.

6.5.2. Planktonic Foraminifera and sea-depth (F.R.)

In the Vaals Formation, only some globular and slightly double-keeled forms were recorded as, for example, specimens belonging to the genus *Archaeoglobigerina* and one specimen of *Globotruncana* cf. *bulloides*. According to HART (1980) and CARON (1983), the speciation of Globotruncanids has been controlled partly by the sea-depth. As the sea-depth increases, globular forms become

double-keeled and single-keeled more below. If we follow this interpretation, the occurrence of only globular or slightly double-keeled forms in the Vaals Formation involves a shallow marine environment.

In the basal glauconious white chalk of the Zeven Wegen Member, rare *Archaeoglobigerina* are accompanied by some *Globotruncana* of the double-keeled "arca group" which indicate a less shallow marine environment.

In the calcilutites and calcarenites of the Beutenaken, Vijlen and Lixhe Members, Globotruncanids are more diversified, but small and globular forms are dominant. In addition to *Archaeoglobigerina* and *Globigerinelloides*, specimens of double-keeled forms as *Globotruncana arca* and intermediate forms of *Globotruncana arca-rosetta* were found with very rare single-keeled forms such as *Globotruncanita stuartiformis*. Should the latter keeled species be abundant, they would suggest a deep water environment, but their scarcity suggests that their presence is more probably the result of marine currents which transported them into a relatively shallow marine environment.

6.6. NANNOPLANKTON AND DINOFLAGELLATES (H.M., J.-C.F.)

A great part of the nannoflora from Limburg calcilutites and calcarenites belongs to the Boreal province characterized by the scarcity or the absence of index species known in Tethyan province as in Tunisia or Charentes, as *Quadrum gothicum*, *Quadrum trifidum* and *Ceratolithoides aculeus*. On the other hand, the rarity of these species is compensated by the abundance of *Arkhangelskiella*, *Reinhardtites anthophorus* which then evolves into *Reinhardtites levis* and also the increasing of *Eiffellithus turriseiffeli*, *E. gorkae*, *Lithraphidites carniolensis* and *Prediscosphaera cretacea*. All these nannofossils are generally predominant in the high latitudes (> 35-40°) as noticed by THIERSTEIN (1976). Moreover, this author considered that *Lucianorhabdus cayeuxi* and *Phanulites obscurus* were two "hemipelagic" species of high latitudes and that the presence of *Kamptnerius magnificus* could be interpreted as an indicator of nearshore environment.

The good preservation and the clean aspect of all Coccoliths observed in the samples studied give no evidence for a reworking of the nannoflora.

Thus, the presence of numerous Nannoplankton and Dinoflagellates indicates that calcilutites and calcarenites from Limburg were deposited in an open marine environment.

6.7. PALAEOECOLOGICAL SYNTHESIS (M.J.M.B., P.J.F., J.P.M.Th.M.)

The terminology used for describing depositional environments is not quite uniform. For example, an ecological niche at 150 m below sea-level remains a problem, because the exact depth of the deposition of many marine shelf sediments is virtually unknown. Therefore, one should keep in mind that terms as deep and shallow, cold and warm, of offshore and nearshore are used here in a comparative way, and not in an absolute one.

6.7.1. Palaeogeographical influences

The Campanian and Maastrichtian deposits of the Maastricht area reflect influences of the Boreal and the Tethyan realms.

Boreal conditions prevailed during deposition of the Vaals, Gulpen and the lower part of the Maastricht Formations. These are characterized by relatively low numbers of macrofossils, showing a comparatively low diversity. Bivalves and Cephalopods frequently dominate.

During the Upper Maastrichtian the number of fossils and of taxa increases rather rapidly in the upper portion of deposits characterized by benthic Foraminifera belonging to HOFKER's zones H-I and J. Presumably, many of these taxa are conspecific or closely related to those considered characteristic of the Tethyan realm.

VILLAIN (1977) argued that a migration of Mediterranean Foraminifera from the Aquitaine into the Maastricht area (as suggested by DEROO, 1966) at the end of the "Mb" (in upper part of foraminifera zones H-I and J) is not very likely. However, it cannot be denied that a number of characteristic Tethyan Foraminifera (a.o. *Siderolites* and Orbitolidae), the "warm-water" Serpulid *Sclerostyla mosae* (BRONN) as well as the first Rudists (which are common in many shallow-marine Tethyan deposits) appear in this region at the end of the Mb.

This means that the deposits of Halembaye, Beutenaken, Cadier en Keer and Bovenste Bosch have been laid down under prevailing Boreal conditions.

6.7.2. Relative water depth

It is suggested that all the Late Cretaceous deposits in the Maastricht area have been laid down on the marine shelf. This points to a maximum water depth of 200 to 400 m. In practice, however, the water depth in this area will have been considerably less than these maximum figures, probably with an average of 40 to 100 m.

According to ALBERS (1976), the deposits of the Vaals Formation suggest sedimentation in a shallow sea, partly within the reach of wave action. This means within a depth of say 40 to 50 m.

VILLAIN (1977) suggested a water depth of some 80-100 m for the Zeven Wegen, Vijlen and Lixhe Members of the Gulpen Formation. This interpretation was based on the association of benthic Foraminifera occurring in the calcilutites, calcisiltites and calcarenites of this Formation.

Relatively high numbers of ornamented Ostracods are frequent in the deposits of the Vaals Formation and in the upper portion of the Maastricht Formation. These are relatively rare in the Gulpen Formation and lower portion of the Maastricht Formation. Presumably, high numbers of ornamented Ostracods are characteristic for relatively shallow environments, whereas assemblages characterized by more than 80 % smooth-shelled specimens are indicative comparably for more deep marine facies (BLESS, 1983; BLESS *et al.*, 1983).

The frequent occurrence of the ostracod genus *Cytherelloidea* in the Zeven Wegen Member and in the lower portion of the Vijlen Member may be considered as an argument for a maximum water depth of 200 m. The optimal distribution of these Ostracods is in seas with a maximum depth of 100 m (KOZUR, 1972; LIEBAU, 1976).

Therefore, it seems reasonable to accept that the Gulpen Formation has been deposited in a shelf sea of some 80 to 100 m depth.

The abundance of broken fossils, and of a.o. Corals, Bryozoans, Serpulids and calcareous Algae in the upper portion of the Maastricht Formation is considered as an indication for a very shallow marine shelf with a maximum depth of less than say 50 m.

6.7.3. Relative distance to the shore line

The regular occurrence of silicified wood and other land-derived macrofloral remains in the Vaals Formation and in the upper portion of the Maastricht Formation suggests that these sedi-

ments have been deposited in a more nearshore environment than those of the Gulpen Formation and lower part of the Maastricht Formation, where macrofloral fossils are practically absent.

The significantly higher quantity of organic terrigenous supplies in the Vaals Formation as compared with the Gulpen Formation at Halem-baye and Beutenaken is indicative of a more nearshore environment. Similar conditions are observed at Cadier en Keer, in the Beutenaken Member and in the Vijlen Member.

In contrast, the very slight terrigenous influences observed in the Gulpen Formation at Halem-baye and at Beutenaken suggests a greater distance from the shore line.

The presence of washed-in glauconite and reworked Spores and Pollen grains in some levels at the very base of a.o. the Zeven Wegen, Beutenaken and Vijlen Members of the Gulpen Formation might be interpreted by accepting mud flows from the very shallow nearshore into the some what deeper offshore shelf.

6.7.4. Relative temperature

Accepting the hypothesis that Tethyan currents reached the Maastricht area somewhere during the Upper Maastrichtian (in the upper portion of HOFKER's Foraminifera zones H-I and J) we may believe that the sea water temperature was higher during the deposition of the upper portion of the Maastricht Formation than in the period before when this area was predominated by Boreal conditions.

This does not mean that the sea in the Boreal realm was (everywhere) a cold one. Living species of the ostracod genus *Cytherelloidea* (frequently occurring in the Vaals and lower half of the Gulpen Formations) prefer a minimum bottom temperature of the sea water of 10°C (CLARKE, 1982). This genus is also common in the Lower Maastrichtian of Rügen and Hemmoor (HERRIG, 1966; CLARKE, 1983). This suggests that the sea water temperature of the Boreal realm in northwestern Europe may have been relatively warm or temperate rather than cold.

A transitory drop of the sea water temperature in the Maastricht area may have occurred during the Lower Maastrichtian (Beutenaken Member). The fossil assemblages of the Beutenaken Member are distinguished from those of the underlying Zeven Wegen and overlying Vijlen deposits by the presence of the Cephalopods *Belemnella* and the absence of *Belemnitella*, the abundance of frag-

ments of prismatic Bivalves possibly belonging to some *Inoceramid*, the relatively low diversity in the Dinoflagellates, and the practical absence of Bryozoans and Crinoids. Moreover, the occurrence of the ostracod genus *Cytherelloidea* in the Beutenaken Member suggests that the temperature was not lower than about 10°C. This supposition should be corroborated by oxygen isotope analyses in the future.

6.7.5. Water energy

The water energy level must have been relatively high during the deposition of the Vaals and Maastricht Formations and relatively low during the deposition of the Gulpen Formation. The latter is characterized by very fine-grained sediments (calclutites, calcisiltites to calcarenites), whereas the former mainly consist of medium- to coarse-grained sediments (sands of the Vaals Formation and calcisiltites to calcarenites of the Maastricht Formation).

The medium- to coarse-grained glauconitic chalk bands at the base of a.o. the Zeven Wegen, Beutenaken and Vijlen Members of the Gulpen Formation are here interpreted as mud flows from a very shallow into a somewhat deeper environment (thickness less than 10-20 cm).

6.7.6. Substrate

The substrate of the Campanian and Maastrichtian seas in the Maastricht area has been usually soft and/or muddy. This is suggested by the large number of burrowing organisms (e.g. irregular Echinoids, Ostracods such as *Cytherella* and *Cytherelloidea*, Bivalves such as *Pinna*, Lobsters of *Calianassa*-type). A more firm substrate developed from time to time during the Upper Maastrichtian (hardgrounds), possibly during intervals of (practically) no sedimentation and sometimes with erosive marine currents. Such hardgrounds are characterised by the frequent occurrence of vertical burrows and a very fossiliferous layer on top. The erosion horizons at the base of a.o. the Zeven Wegen, Beutenaken and Vijlen Members of the Gulpen Formation may be explained as a result of turbidity currents and mud flows. These might also have transported the medium- to coarse-grained chalk and glauconite into the area.

6.7.7. Conclusions

The mean palaeoenvironmental conditions in the Maastricht area during the Campanian and

Maastrichtian are summarized in Fig. 34. Apparently, many ecological factors controlling the faunal assemblages at the Campanian-Maastrichtian boundary did not change so much. The water depth (80 - 100 m), distance to the shore line (offshore) and water energy (low) remained the same. But there seems to have been a critical change in the temperature, although the overall boreal conditions remained constant. These result a.o. in the transitory disappearance of the belemnite genus *Belemnitella* (that returned at the base of the Vijlen Member) and the temporary appearance of the genus *Belemnella*.

A turbidity current of mud flow at the base of the Beutenaken Member has faded out the original boundary between the Campanian and the Maastrichtian. This current eroded the top of the underlying Zeven Wegen Member and deposited a layer of varying thickness (some cm to 1 or 2 dm) with a mixture of reworked sediments and fossils of the Vaals Formation and the Zeven Wegen Member and (equally reworked) sediments and fossils of the basal Beutenaken Member.

7. — CONCLUSIONS

The type-Maastrichtian of DUMONT (1849) is exposed in Limburg, especially in the ENCI quarry located south of Maastricht. It is represented by the calcarenitic Maastricht Formation lying on a glauconious bed named Ma by UHLENBROEK (1905, 1912).

But, since ARKHANGELSKY (1912) and JELETZKY (1951), an agreement came to lower the base of the Maastrichtian. A Maastrichtian stage beginning, in the Boreal realm, with the appearance of *Belemnella lanceolata* was officially proposed by BIRKELUND *et al.* (1984) during the tenure of the International Geological Congress of Moscow, 1984. This proposal is followed herein.

Taking into account the definition of this boundary between Campanian and Maastrichtian stages, the intention of this work was to know what were the vertical distributions of various palaeontological groups on both sides of this boundary in the type-Maastrichtian region. In this way, a series of samples were studied from the Vaals Formation and mainly from the Gulpen Formation where this Campanian-Maastrichtian boundary is present.

We should recall that both these two Formations were deposited in a Boreal environment.

Only the type-Maastrichtian presents some Tethyan characteristics, for example the presence of Rudists (rare) and of large benthic Foraminifera (rare levels but with numerous *Orbitoides*, *Lepidodorboides*, *Omphalocyclus*, *Hellenocyclina*, *Siderolites*; cf. VILLAIN, 1977).

In each palaeontological group, several species seem to be particularly significant, whether by their extinction or by their appearance. The vertical distribution of the main species is given in Fig. 35 (Remark: with regard to the preliminary results presented at the "Senonian" Colloquium in Marseille — cf. ROBASZYNSKI *et al.*, 1985 — the study of new samples and of new sections allowed one to explain or to modify the distribution of some taxa).

• Belemnites

The species *Belemnella lanceolata inflata* appears in the Beutenaken Member and is present *in situ* only in this member. The Beutenaken Member is also capped with a level containing reworked *Belemnella "occidentalis"*. Thus, the Beutenaken chalk Member, of some metres thick, represents a part of the Lower Maastrichtian (as this substage is defined in the Boreal realm, cf. SCHULZ *et al.*, 1984). The Upper Maastrichtian begins in the Vijlen Member with the appearance of *Belemnitella junior*.

• Foraminifera

In the Lower Maastrichtian Beutenaken Member appears the small benthic Foraminifera species *Bolivinoidea australis* which is characterized by a number of pustules on the last chamber between 4 and 5. Several other benthic species also appear in the Lower Maastrichtian as *Neoflabellina praereticulata* and *Eponides beisseli*. The incoming of these species seems to be useful in the chalky facies of the whole Boreal realm. Very rare planktonic Foraminifera are represented especially by specimens of *Globotruncana gr. arca*, but they are not so numerous and their morphology is not so characteristic enough to be used as stratigraphical markers.

• Nannoplankton

In the Beutenaken Member appear *Lithraphidites praequadratus* and *Reinhardtites levis* whereas, above, *Reinhardtites anthophorus*, *Broinsonia parca constricta* and *Eiffellithus eximius* are still present and extinct in the Upper Maastrichtian Vijlen Member.

Lucianorhabdus cayeuxi linked with *Phanulites obscurus* extinct higher in the Lixhe 1 Member and

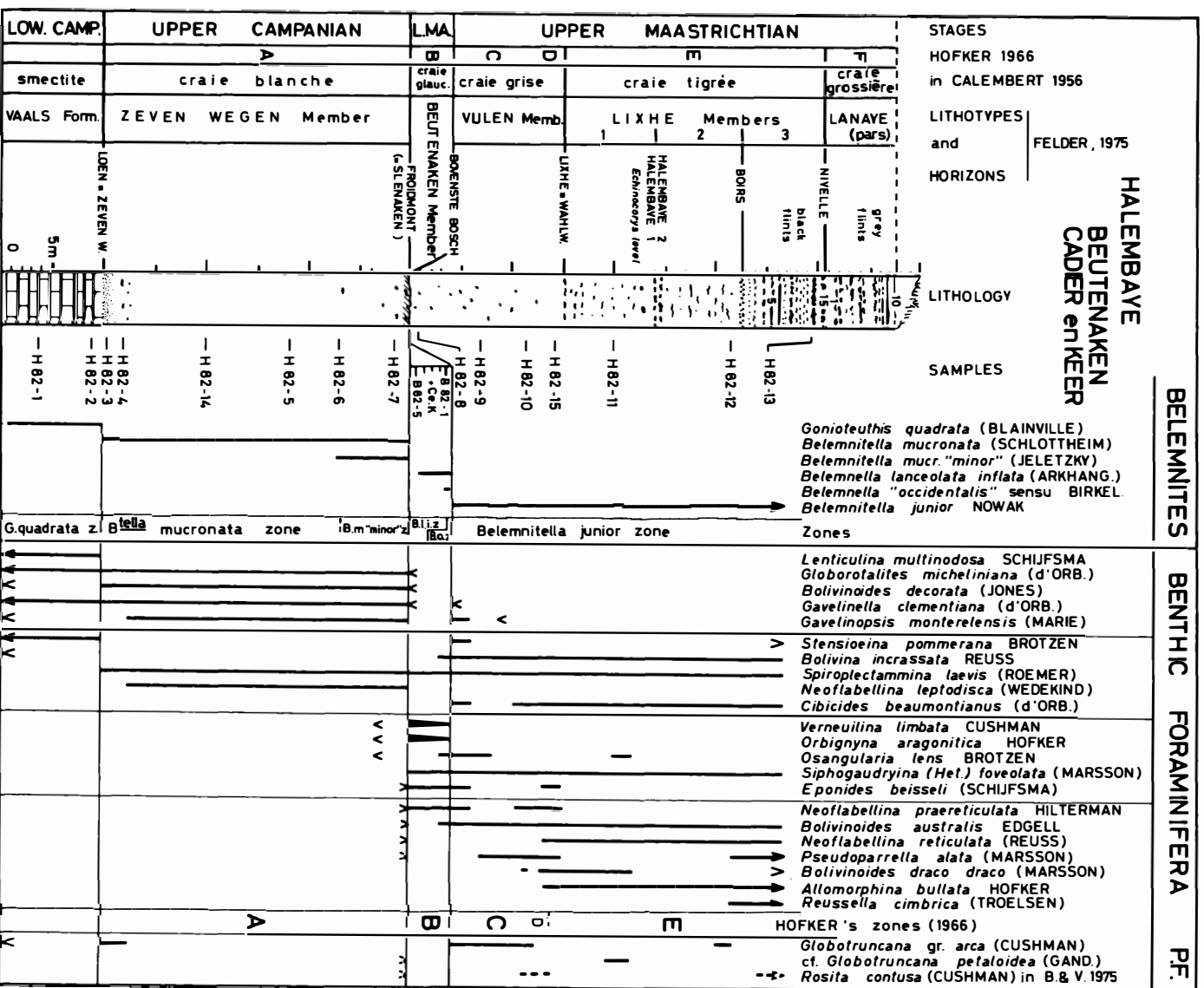


FIGURE 35

Synthetic chart with vertical distribution of index macro- and microfossils on both sides of the Campanian-Maastrichtian boundary for Halembye and Beutenaken areas

OSTRA- MESO- -CODS FOSSILS		NORMAPOLLES		DINOFLAGELLATES		NANOPLANKTON	
ECO- -ZONES	ECO- -ZONES	6 (smooth)	5 (seram.)	4 (smooth)	3 (ornam.)	1 (ornam.)	1
Extrapollis sp.1 AZEMA et al.							
Santonipollis sp.1							
Pompeckjoidaepollen subhercynicus (KR.)KR.							
Vacuopollis munitus TSCHUDY							
Normapollis B							
Semioculopollis cf. verrucosa CHRIST.							
Trudopollis artifex WEYL. & KRIEGER							
Interporopollenites turgidus TSCH. sp.1							
Felderipollenites triangulus KEDV. & HERN.							
Trudopollis nonperfectus (PFLUG) PFLUG							
Triblastula utinensis O. WETZEL							
Northidinium perforatum in WILSON							
Spongodinium delitiense (EHRENBERG)							
Samlandia solida in WILSON							
Areoligera senonensis LEJ.-CARP.							
Gillinia hymenophora COOKS & EISEN.							
Odontochitina wetzeli in WILSON							
Senoniasphaera reticulata in WILSON							
Xenascus ceratioides (DEFLANDRE)							
Odontochitina operculata (O. WETZ.)							
Hystriochodinium pulchrum DEFL.							
Aldorfia deflandrei (CLARKE & VERD.)							
Thalassiphora? spinosa (CLARKE & VERD.)							
Palaeohystrichophora infusorioides DEFL.							
Lithraphidites quadratus BR. & MART.							
Lithraphidites praequadratus ROTH							
Reinhardtites levis PRINS. & SISSINGH.							
Quadrum trifidum (STRADNER)							
Quadrum gothicum (DEFL.)							
Arkhangelskiella cymbiformis VEKSHINA							
Prediscosphaera stoveri (PERCH. NIELSEN)							
Eiffellithus turriseiffeli DEFL. & FERT.							
Lucianorhabdus cayeuxi DEFLANDRE							
Phanulites obscurus (DEFLANDRE)							
Eiffellithus eximius (STOVER)							
Amphizygus minimus BUKRY							
Broinsonia parca constricta HATTN. et al.							
Reinhardtites anthophorus DEFLANDRE							

Lithraphidites quadratus appears only at the top of the Lixhe 3 Member. It seems that the entries of *Lithraphidites praequadratus*, *Prediscosphaera stoveri* and *Arkhangelskiella cymbiformis* might occur earlier in the Tethyan type-Campanian area than in the Boreal Maastrichtian area (cf. NEUMANN *et al.*, 1984; NEUMANN & ROBASZYNSKI, 1985).

• Dinoflagellates

The species *Samlandia solida* appears in the Beutenaken Member whereas *Areoligera senonensis* comes a little before in the Upper Campanian Zeven Wegen Member.

• Spores and pollen grains

The Zeven Wegen Member has not yielded material of terrestrial origin. The palynoflora *in situ* observed in the Vaals Formation, Beutenaken Member and Vijlen Member is not in a sufficient quantity and the assemblages are incomplete.

From a biostratigraphical point of view, some obstacles preclude to correlate irrefutably the Campanian-Maastrichtian boundary between Boreal and Tethyan realms. These difficulties are of various nature.

First, the palaeontological groups in the two realms are different: Belemnites are numerous and vertically well distributed in the Boreal realm and practically absent in the Tethyan realm, planktonic Foraminifera are very well diversified in pelagic Tethyan environment and very rare in the Boreal realm, small benthic forms occur in the Boreal against large benthic forms in the Tethyan realm.

Furthermore, the entries of several species of Nannoplankton seem to be diachronous between the two realms. Besides, the data for the distribution of Dinoflagellates in the Tethyan realm are not sufficiently numerous to be compared to that of the Boreal realm.

From a palaeoecological point of view, the presence of numerous reworked Spores and pollen grains from the Jurassic to the Lower Cretaceous in the Vaals Formation points out the existence of rather important currents during the deposition of this unit. Moreover, the characteristics of the sea seem to be the same during the deposition of about the whole of the Gulpen Formation.

That suggests an open marine environment, relatively quiet and rather far from the shore.

That is to say that, during the Upper Campanian and a great part of the Maastrichtian (except the

uppermost part represented by the Maastricht Formation), the Maastricht area was under the influence of Boreal conditions with a relatively deep sea. Only the Maastricht Formation was deposited in shallow water under conditions affected by some Tethyan influences.

The lateral and vertical variations of thicknesses in the diverse members such as the preservation of sedimentary units in well delimited areas can be interpreted as a recording of vertical movements of tectonic blocks whose existence is linked to the Rur Graben.

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LIST OF PLATES

- 1-2-3 : Belemnites
 4-5-6 : Benthic Foraminifera
 7-8 : Nannoplankton
 9-10-11-12 : Dinoflagellates
 13-14 : Normapollens
 15 : Reworked Spores and pollen grains
 16-17-18 : Mesofossils
 19-20-21-22 : Ostracods *

PLATE 1
BELEMNITES

- Fig. 1 — *Gonoteuthis quadrata* (BLAINVILLE, 1827)
Length = 67 mm
Vaals Formation, C.P.L. Halembaye
Collection Teylers Museum, Haarlem, no. 25053
a. ventral view, b. lateral view
2. — *Belemnitella mucronata* (LINK, 1807)
Length = 98 mm
Zeven Wegen Member, lower part, C.P.L. Halembaye
Collection W.M. FELDER, Vijlen, no. GK1914
a. ventral view, b. lateral view
3. — *Belemnitella mucronata* (LINK, 1807)
Length = 104 mm
Zeven Wegen Member, upper part, Malensbosch
Collection W.M. FELDER, Vijlen, no. GK1485A3
a. ventral view, b. lateral view

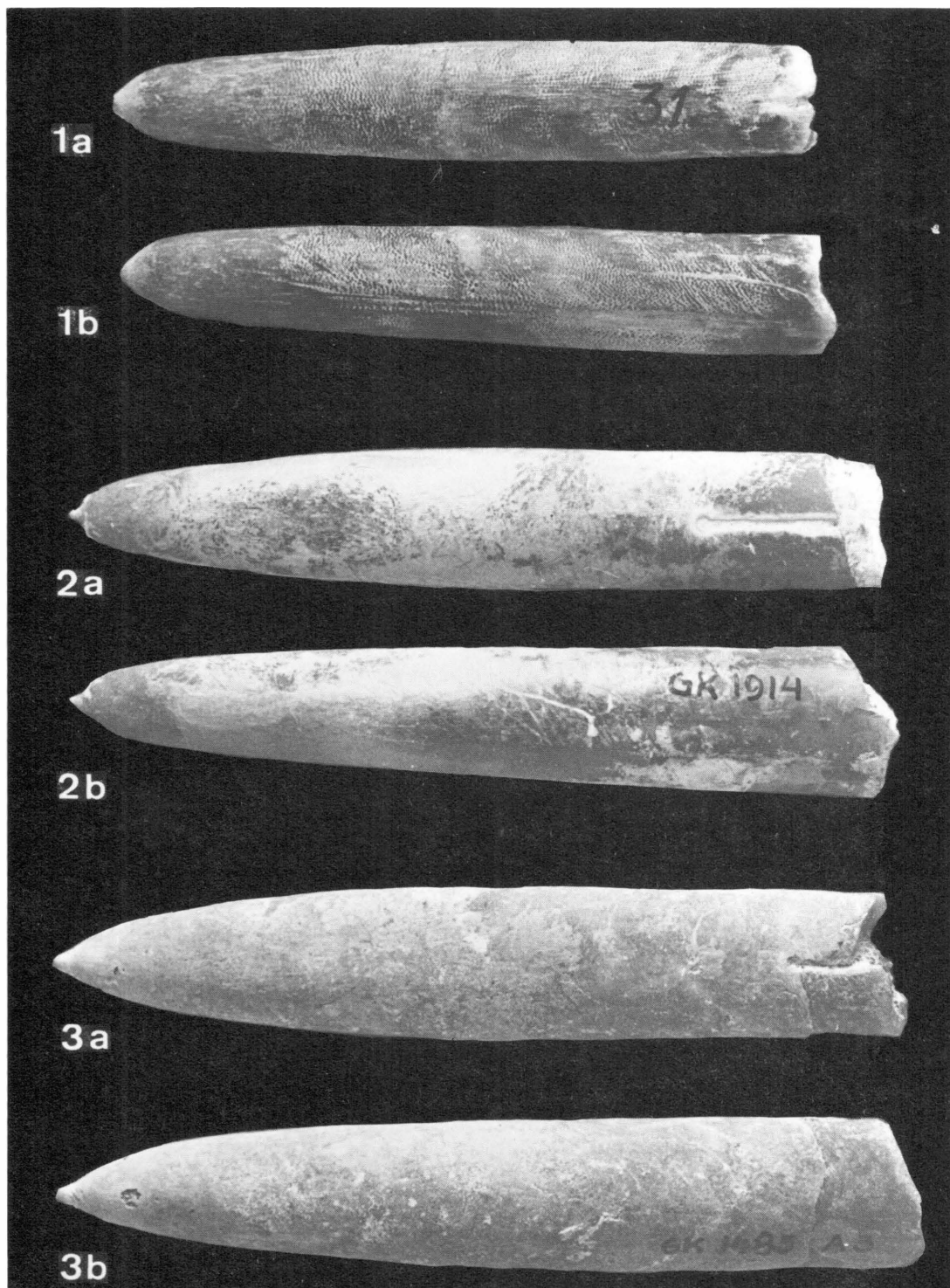
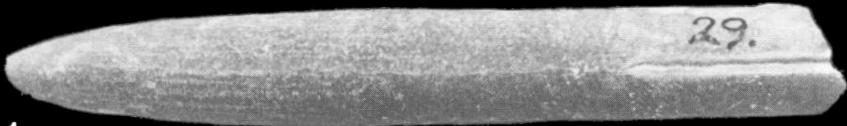
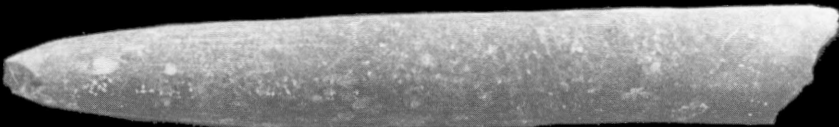


PLATE 2
BELEMNITES

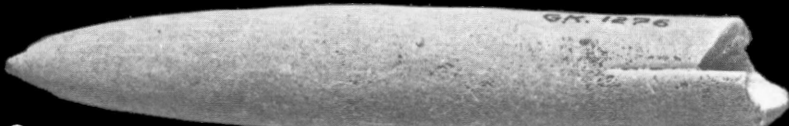
- Fig. 1 — *Belemnitella mucronata* "minor" sensu JELETZKY, 1949
Length = 88 mm
Zeven Wegen Member, upper part, C.P.L. Halembaye
Collection Teylers Museum, Haarlem, no. 25057
a. ventral view, b. lateral view
2. — *Belemnitella mucronata* "minor" sensu JELETZKY, 1949
Length = 84 mm
Zeven Wegen Member, upper part, Plattebosch
Collection W.M. FELDER, Vijlen, no. GK1267
a. ventral view, b. lateral view
3. — *Belemnitella lanceolata inflata* (ARKHANGELSKY, 1912)
Length = 72 mm
Beutenaken Member, upper part, Bovenste Bosch, Epen
Collection Teylers Museum, Haarlem, no. 25058
a. ventral view, b. lateral view



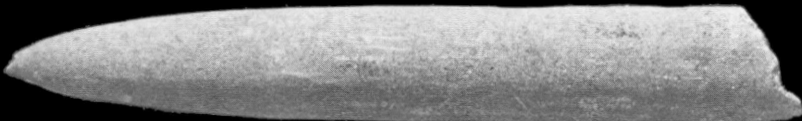
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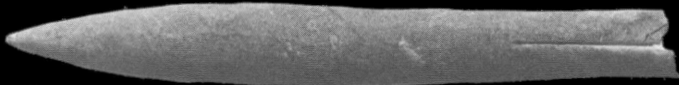
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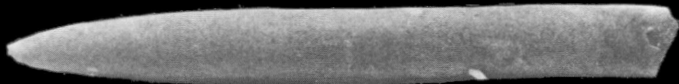
2a



2b



3a



3b

PLATE 3
BELEMNITES

- Fig. 1 — *Belemnella « occidentalis »* sensu BIRKELUND, 1957
Length = 94 mm
Beutenaken Member, upper part, Bovenste Bosch, Epen
Collection Teylers Museum, Haarlem, no. 25063
a. ventral view, b. lateral view
2. — *Belemnitella junior* NOWAK, 1913
Length = 90 mm
Lixhe Member, C.P.L. Halembaye
Collection Teylers Museum, Haarlem, no. 25067
a. ventral view, b. lateral view
3. — *Belemnitella junior* NOWAK, 1913
Length = 103 mm
Vijlen Member, lower part, Kosberg, Epen
Collection W.M. FELDER, Vijlen, no. GK2020
a. ventral view, b. lateral view

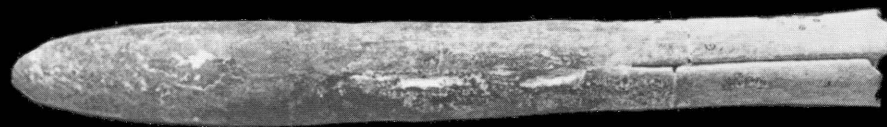
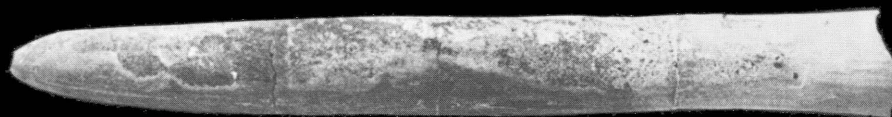
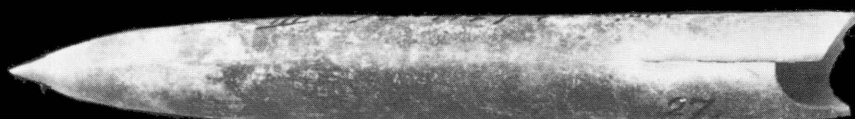
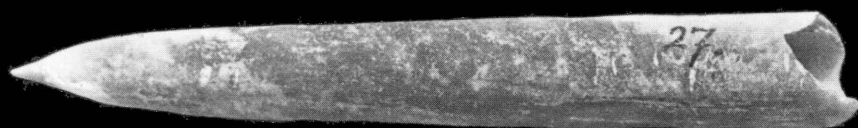
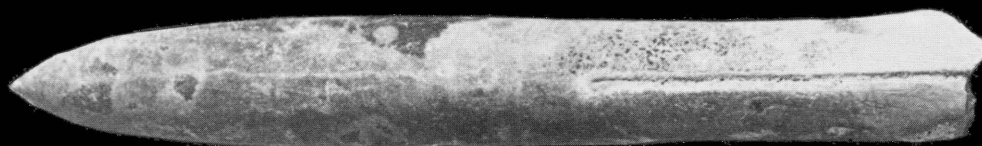
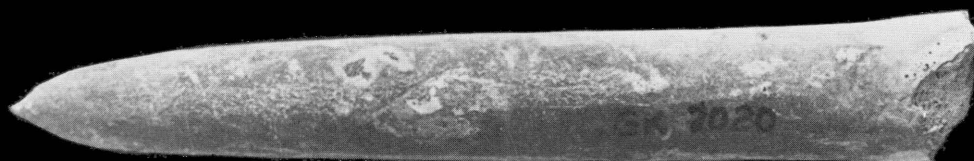
**1a****1b****2a****2b****3a****3b**

PLATE 4
BENTHIC FORAMINIFERA

The bar on each photograph represents 100 micrometres; a = spiral side; b = umbilical side

- Fig. 1. — *Gavelinella clementiana* (D'ORBIGNY)
Sample H 82-1
2. — *Gavelinella clementiana* (D'ORBIGNY)
Sample H 82-5
3. — *Stensioeina pommerana* (BROTZEN)
Sample H 82-8
4. — *Pseudoparrella alata* (MARSSON) sensu HOFKER, 1966
Sample H 82-12

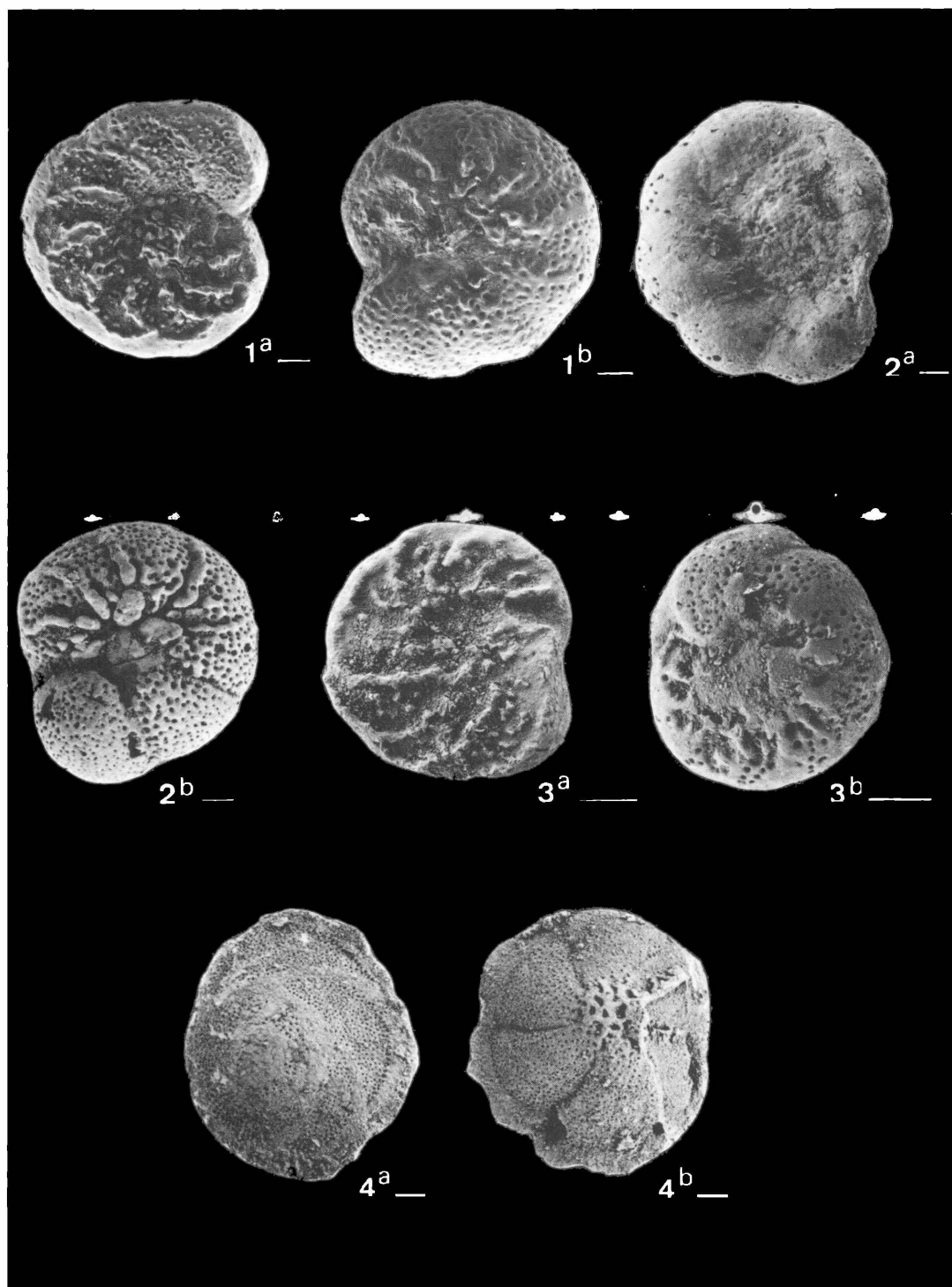


PLATE 5
BENTHIC FORAMINIFERA

The bar on each photograph represents 100 micrometres; a = spiral side; b = umbilical side

- Fig. 1. — *Neoflabellina leptodisca* (WEDEKIND)
Sample H 82-7
2. — *Neoflabellina praereticulata* HILTERMANN
Sample H 82-3
3. — *Neoflabellina reticulata* (REUSS)
Sample H 82-11
4. — *Bolivinooides draco* (MARSSON)
Sample H 82-15
5. — *Gavelinopsis monterelensis* (MARIE)
Sample H 82-6
6. — *Eponides beisseli* SCHIJFSMA
Sample B 82-2
7. — *Bolivina incrassata* REUSS
Sample H 82-10

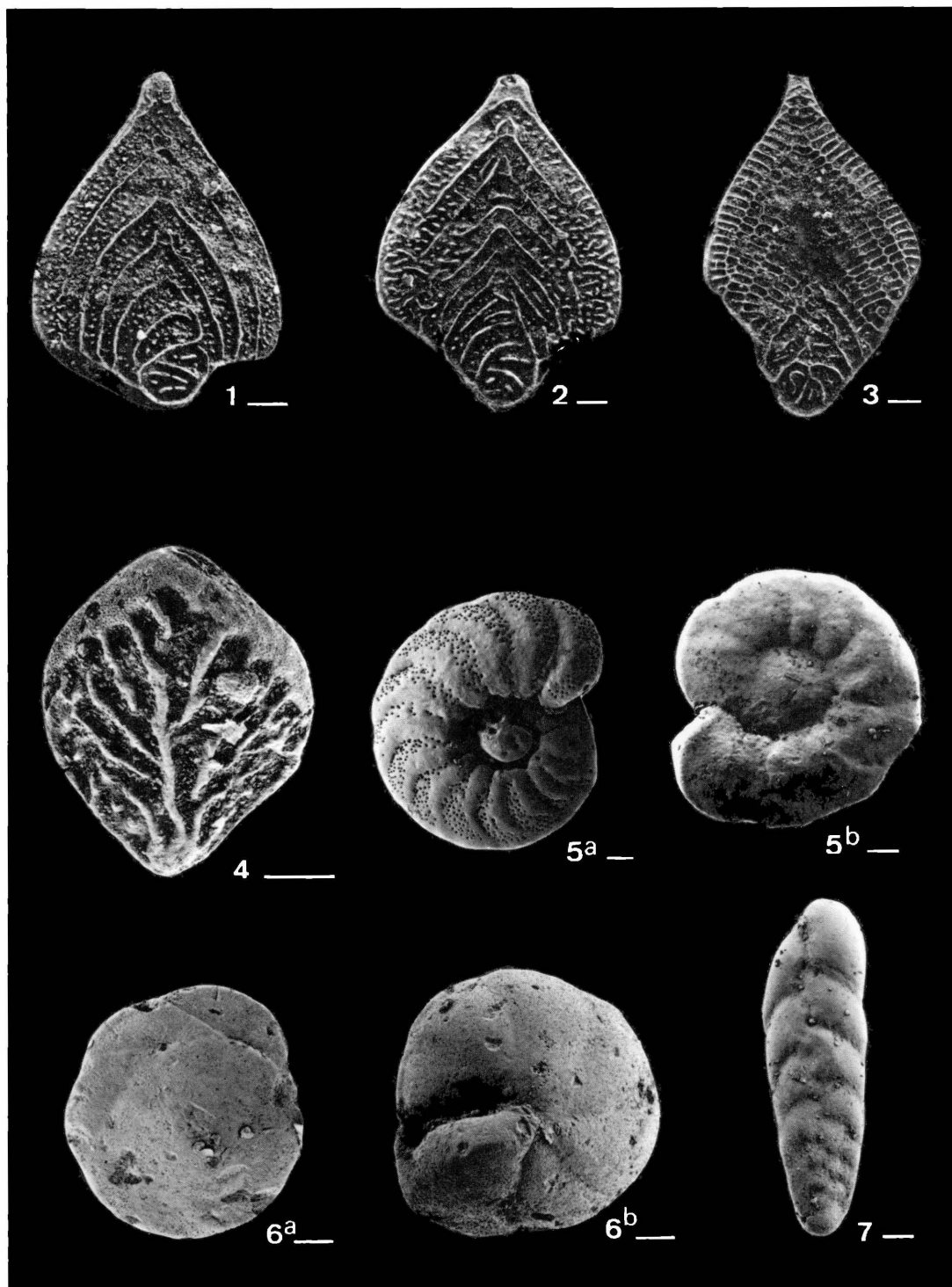


PLATE 6
BENTHIC FORAMINIFERA
THE *BOLIVINOIDES DECORATA-AUSTRALIS* LINEAGE

The bar on each photograph represents 100 micrometres

- Fig. 1. — *Bolivinoides decorata* (JONES)
Sample H 82-3, with 3 pustules on the last formed chamber
2. — *Bolivinoides decorata* (JONES)
Sample H 82-4, with 4 pustules on the last formed chamber
3. — *Bolivinoides australis* EDGELL
Sample H 82-2, with 5 pustules on the last formed chamber
4. — *Bolivinoides australis* EDGELL
Sample H 82-11, with 5 pustules on the last formed chamber
5. — *Bolivinoides australis* EDGELL
Sample H 82-11, with 6 pustules on the last formed chamber
6. — *Bolivinoides australis* EDGELL
Sample H 82-11, with 7 pustules on the last formed chamber

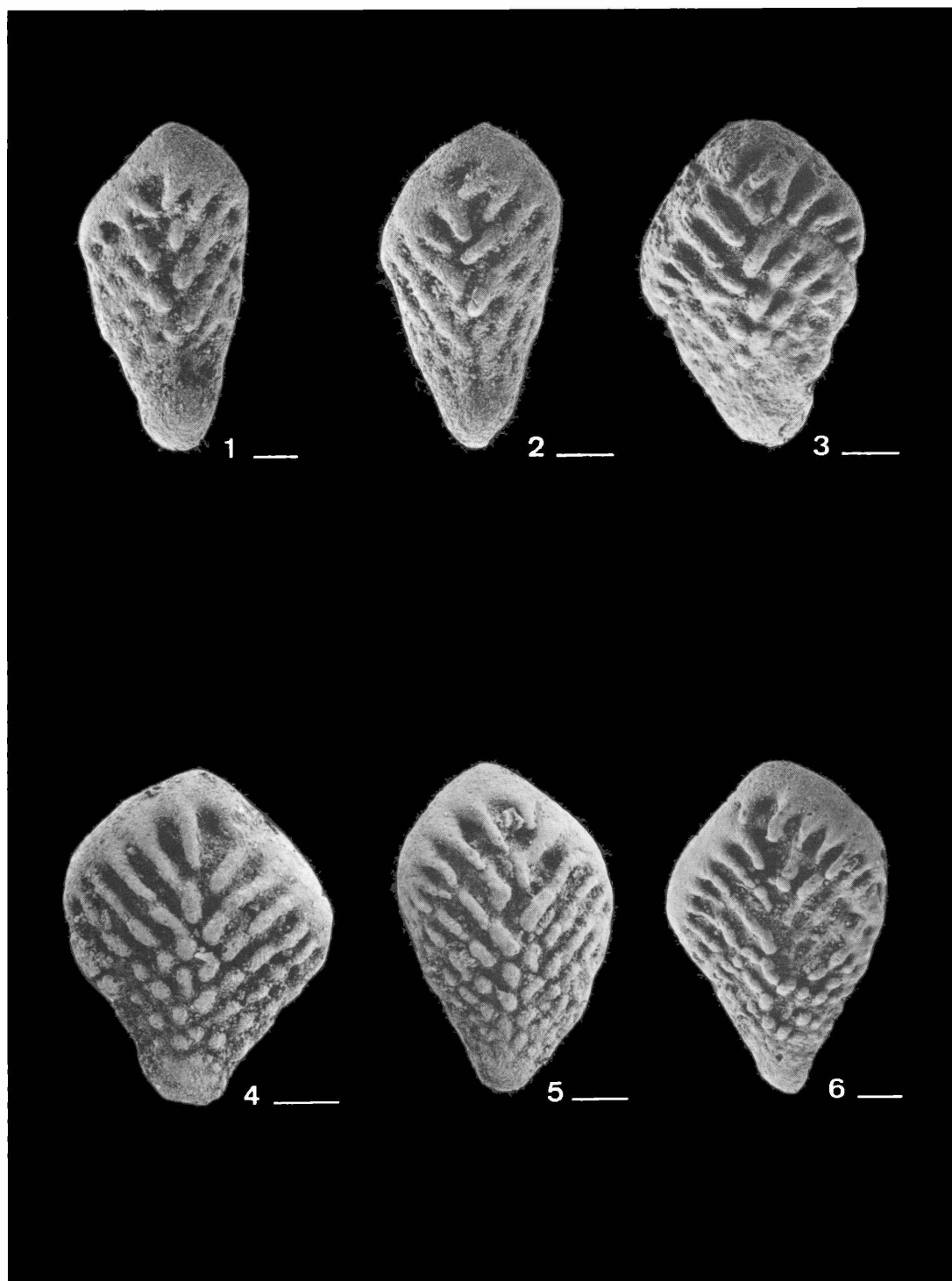


PLATE 7
NANNOPLANKTON

The bar on each figure represents 1 micrometre

- Fig. 1 — *Broinsonia parca* (STRADNER)
Distal view
2. — *Eiffellithus eximius* (STOVER)
Distal view
3. — *Broinsonia enormis* (SHUMENKO)
Proximal view
4. — *Ahmuellerella regularis* (GORKA)
Distal view
5. — *Ahmuellerella octoradiata* (GORKA)
Distal view
6. — *Kamptnerius magnificus* DEFLANDRE
Distal view
- 7 — *Reinhardtites anthophorus* DEFLANDRE
Side view
8. — *Gartnerago obliquum* (STRADNER)
Distal view
- 9 — *Tranolithus orionatus* STOVER
Side view
10. — *Prediscosphaera stoveri* (PERCH-NIELSEN)
Distal view
- 11 — *Lucianorhabdus cayeuxi* DEFLANDRE
12. — *Amphizygus brooksi* BUKRY
Distal view

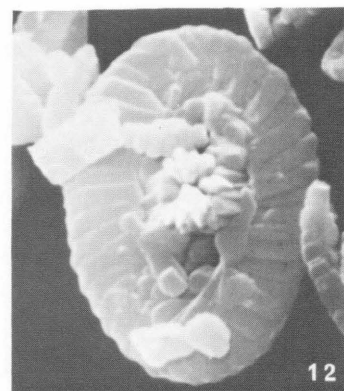
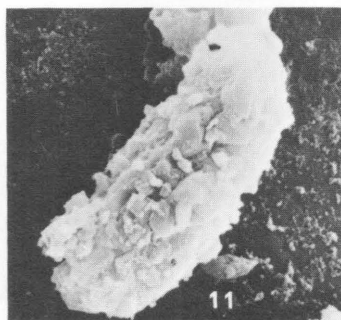
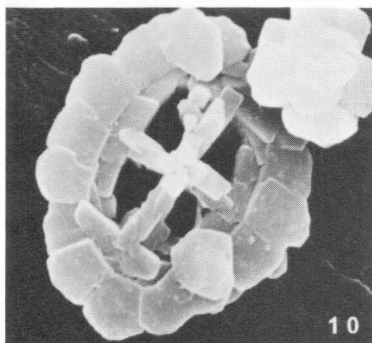
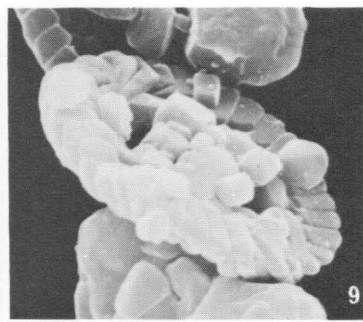
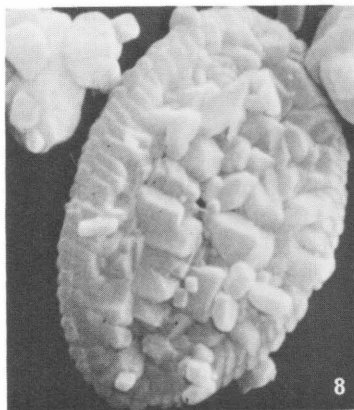
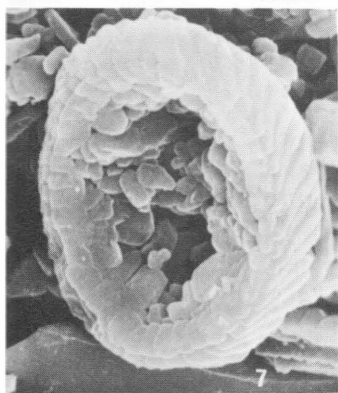
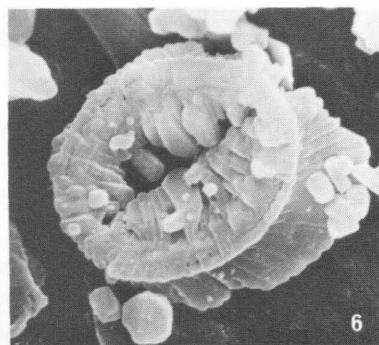
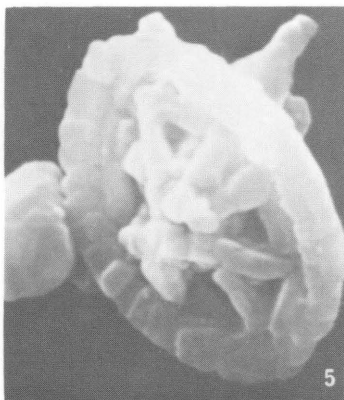
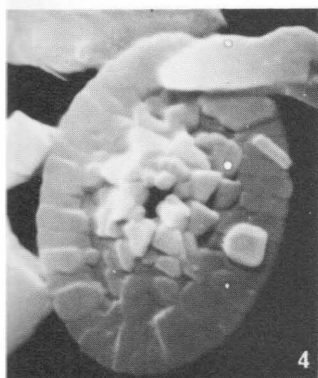
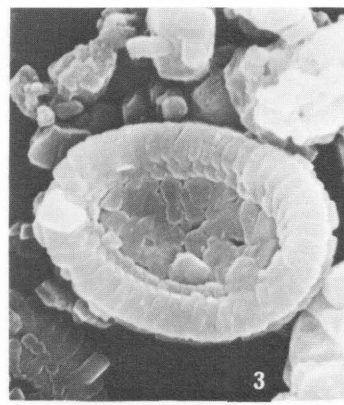
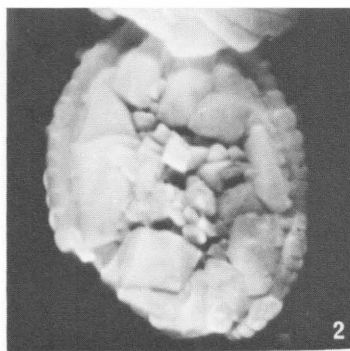
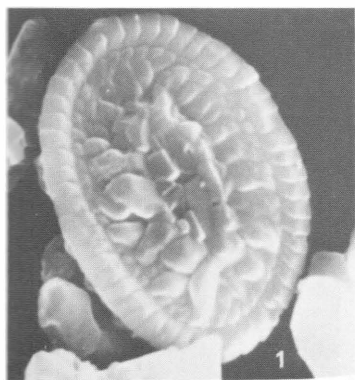


PLATE 8
NANNOPLANKTON

The bar on each figure represents 1 micrometre

- Fig. 1 — *Quadrum gothicum* (STRADNER)
2. — *Microrhabdulus decoratus* DEFLANDRE
3. — *Micula staurophora* (GARDET)
Proximal view
4. — *Reinhardtites anthophorus* DEFLANDRE
Proximal view
5. — *Arkhangelskiella cymbiformis* VEKSHINA
Proximal view
6. — *Amphizygus brooksi* BUKRY
Distal view
7 — *Prediscosphaera cretacea* (ARKHANGELSKY)
Distal view
8. — *Markalius circumradiatus* (STOVER)
Proximal view
9. — *Reinhardtites levis* PRINS & SISSINGH
Distal view
10. — *Lithraphidites* cf. *praequadratus* ROTH
Proximal view
11 — *Lithraphidites* cf. *praequadratus* ROTH
Distal view
12. — *Lithraphidites quadratus* BRAMLETTE & MARTINI
Side view

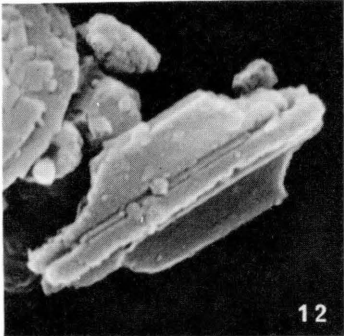
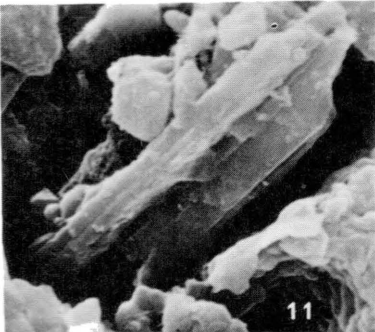
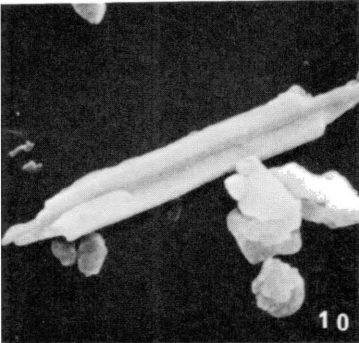
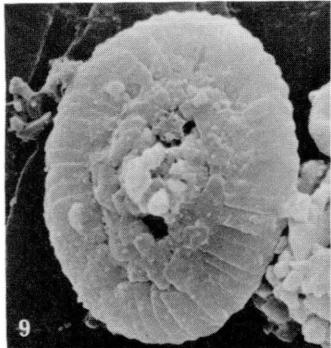
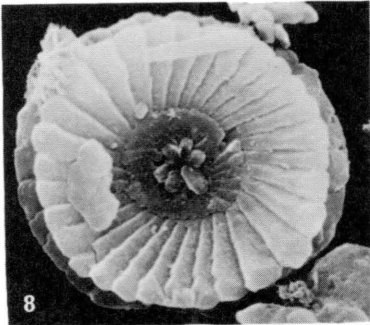
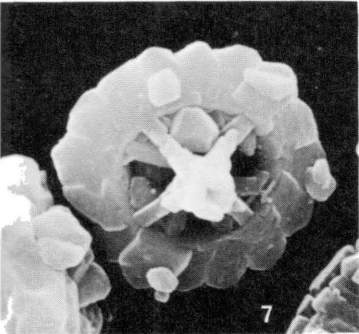
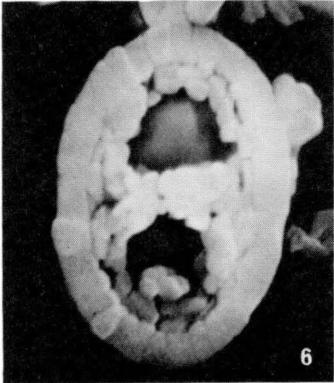
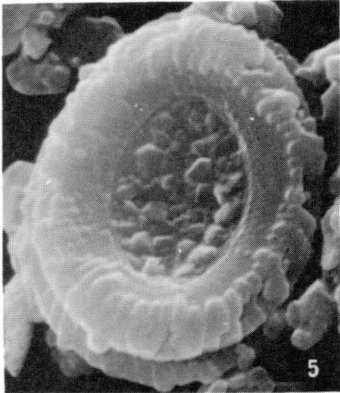
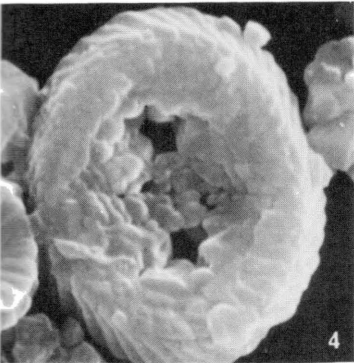
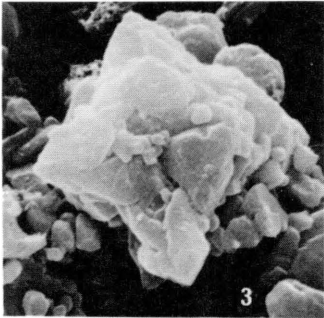
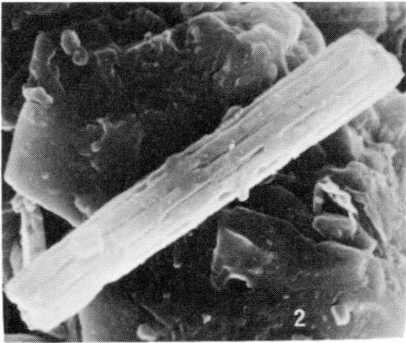
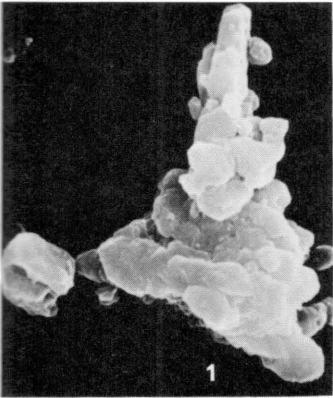


PLATE 9
DINOFLAGELLATES

The bar on each figure represents 10 micrometres

- Fig. 1. — *Kleithriasphaeridium* cf. *truncatum* (BENSON) STOVER & EVITT
Lixhe Member, Upper Maastrichtian
Sample HAL. 82-11, Preparation 54732-1, N31. Precingular archeopyle*
2. — *Kleithriasphaeridium* cf. *truncatum* (BENSON) STOVER & EVITT
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, G46.1
3. — *Laticavodinium gracilispinosum* in WILSON and *Fromea* sp.
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-6, Preparation 54715-1, F38.4
4. — *Heterosphaeridium?* *heretacanthum* (DEFLANDRE & COOKSON) EISENACK & KJELLSTRÖM
Vaals Formation, Lower Campanian
Sample HAL. 82-1, Preparation 54710-1, V28.1 Apical archeopyle
5. — *Hystriochodinium pulchrum* DEFLANDRE
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-3, Preparation 54712-1, K39.1
6. — *Cyclonephelium distinctum* DEFLANDRE & COOKSON
Vaals Formation, Lower Campanian
Sample HAL. 82-1, Preparation 54710-1, G23.3. Apical archeopyle
7. — *Pterodinium cingulatum cingulatum* (O. WETZEL) BELOW
Vaals Formation, Lower Campanian
Sample HAL. 82-1, Preparation 54710-1, L28.2. Precingular archeopyle
- 8, 9. — *Thalassiphora?* *spinosa* (CLARKE & VERDIER) FOUCHER
Vaals Formation, Lower Campanian
Sample HAL. 82-1, Preparation 54710-1, U48.1
- 10, 11. — *Senoniasphaera reticulata* in WILSON
Vaals Formation, Lower Campanian
Sample HAL. 82-2, Preparation 54711-1, J45. Apical archeopyle
12. — *Gillinia hymenophora* COOKSON & EISENACK
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-5, Preparation 54714-1, K21.3

* The following data have been added for each specimen

(1) The number of the sample HAL. 82-11.

(2) The number of the preparation 54732-1 (slides are deposited at the Laboratoire de Palyno-Planctologie de la Société Nationale Elf Aquitaine, in Boussens, 31360 Saint-Martory).

(3) Co-ordinates with England Finder N31.

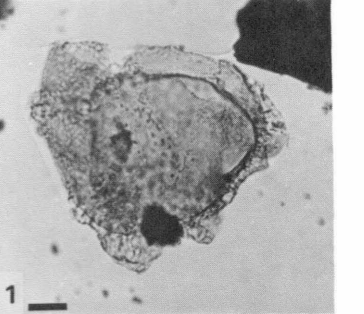
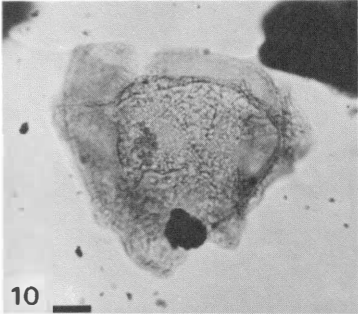
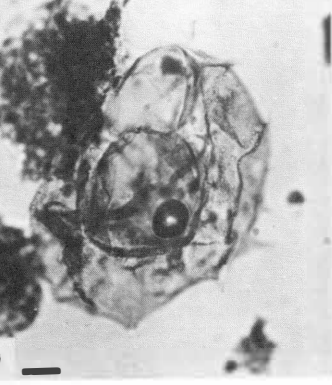
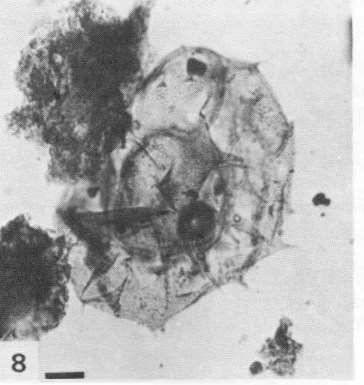
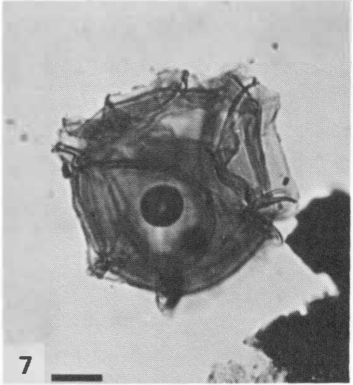
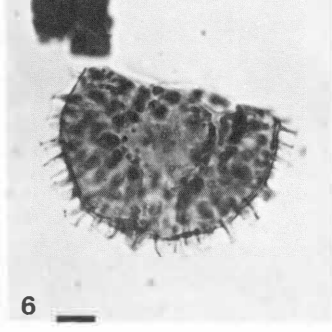
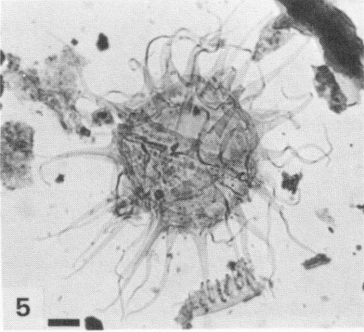
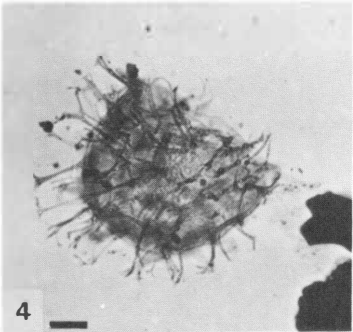
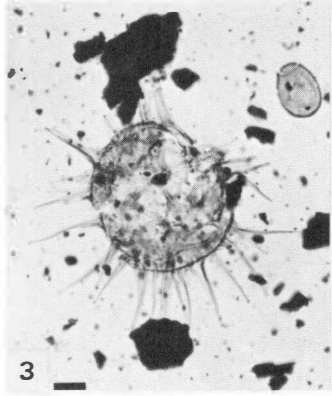
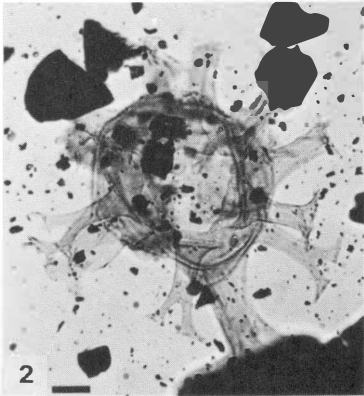


PLATE 10
DINOFLAGELLATES

The bar on each photograph represents 10 micrometres

- Fig. 1 — *Odontochitina costata* ALBERTI emend. CLARKE & VERDIER
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-6, Preparation 54715-1, E19. Apical archeopyle
2. — *Odontochitina costata* ALBERTI emend. CLARKE & VERDIER
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-3, Preparation 54712-1, M28.4. Apical archeopyle
3. — *Odontochitina costata* ALBERTI emend. CLARKE & VERDIER
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-3, Preparation 54712-1, N41.4. Operculum
4. — *Xenascus ceratioides* (DEFLANDRE) LENTIN & WILLIAMS
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-6, Preparation 54715-1, U27.4. Apical archeopyle
5. — *Xenascus ceratioides* (DEFLANDRE) LENTIN & WILLIAMS
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-6, Preparation 54715-1, H31. Apical archeopyle
6. — *Xenascus ceratioides* (DEFLANDRE) LENTIN & WILLIAMS
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-6, Preparation 54715-1, U26.4. Operculum
- 7-8. — *Odontochitina operculata* (O. WETZEL) DEFLANDRE in DEFLANDRE & COOKSON
Beutenaken Member, Lower Maastrichtian
Sample BEUT 82-2, Preparation 55162-1, J34. A. specimen showing traces of a tabulation, paracingulum and apical archeopyle
- 9-10. — *Odontochitina wetzeli* in WILSON
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-4, Preparation 54713-1, M36.1. Apical archeopyle
- 11-12. — *Odontochitina wetzeli* in WILSON
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-7, Preparation 54716, Q41.2. Apical archeopyle

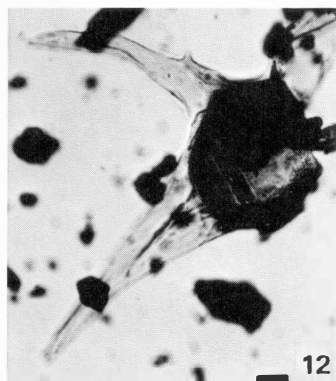
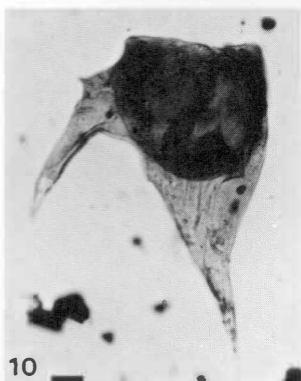
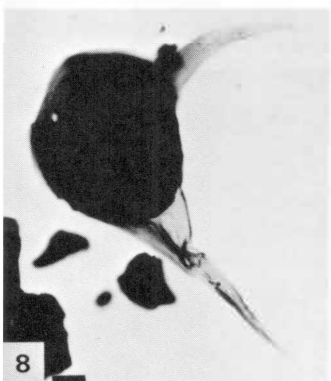
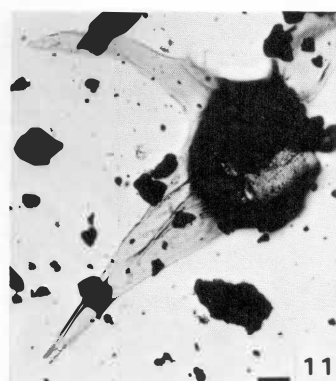
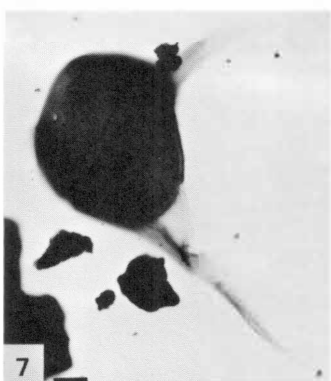
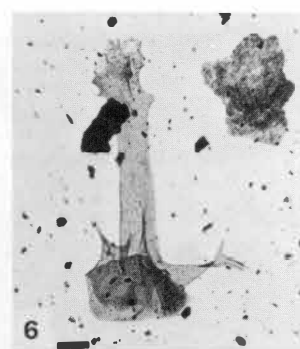
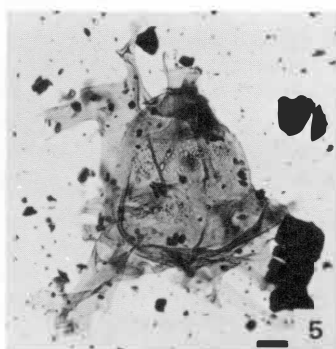
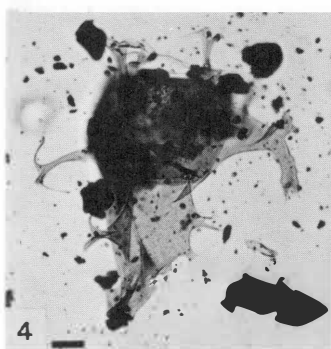
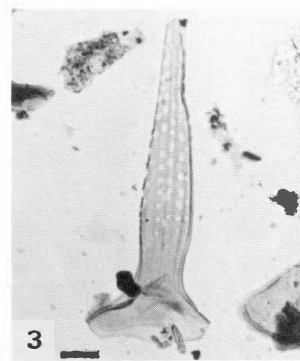
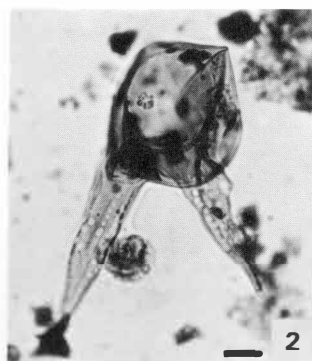
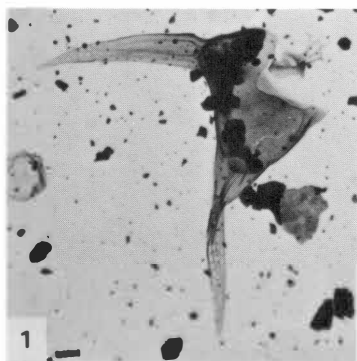


PLATE 11
DINOFLAGELLATES

The bar on each photograph represents 10 micrometres

- Fig. 1 — *Areoligera senonensis* LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, E43.4. Apical archeopyle
2. — *Areoligera senonensis* LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, O47.3. Apical archeopyle
3. — *Areoligera senonensis* LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, F45.4. Apical archeopyle
4. — *Areoligera senonensis* LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-10, Preparation 54731-1, M27 1 Apical archeopyle
5. — *Areoligera* cf. *senonensis* LEJEUNE-CARPENTIER
Lixhe Member, Upper Maastrichtian
Sample HAL. 82-12, Preparation 54733-1, J27 1 Operculum
- 6-7 — *Areoligera coronata* (O. WETZEL) LEJEUNE-CARPENTIER
Lixhe Member, Upper Maastrichtian
Sample HAL. 82-12, Preparation 54733-1, E27 1 Apical archeopyle
8. — *Areoligera coronata* (O. WETZEL) LEJEUNE-CARPENTIER (= f. *medusettiiformis* O. WETZEL)
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, Q43.2. Apical archeopyle
9. — *Areoligera coronata* (O. WETZEL) LEJEUNE-CARPENTIER (= f. *medusettiiformis* O. WETZEL)
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, U39.4. Apical archeopyle
10. — *Areoligera coronata* (O. WETZEL) LEJEUNE-CARPENTIER (= f. *medusettiiformis* O. WETZEL)
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, P40. Apical archeopyle
- 11 — *Areoligera tenuicapillata* (O. WETZEL) LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-9, Preparation 54730-1, O20.4. Apical archeopyle
12. — *Areoligera tenuicapillata* (O. WETZEL) LEJEUNE-CARPENTIER
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-10, Preparation 54731-1, F32.3. Apical archeopyle

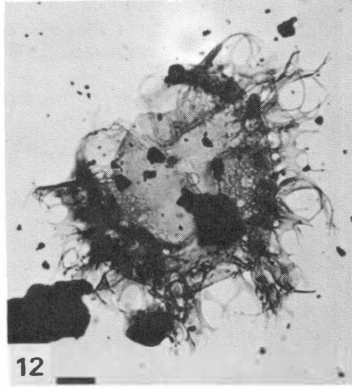
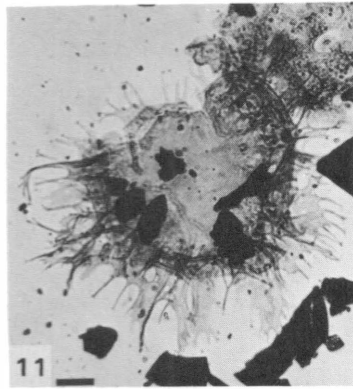
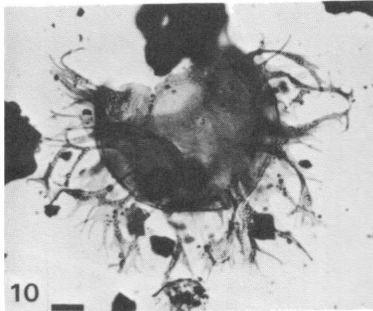
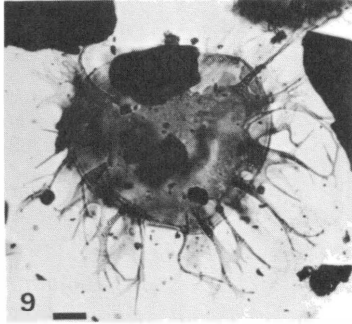
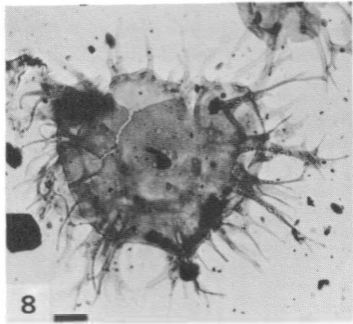
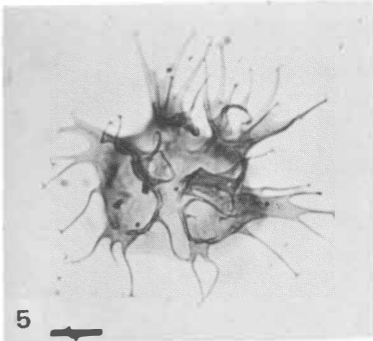
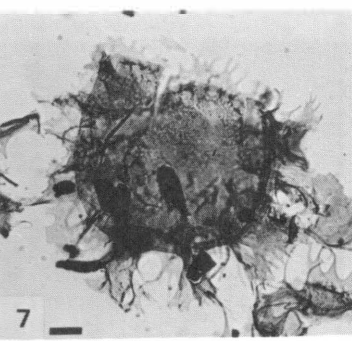
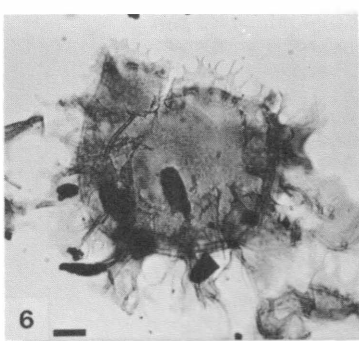
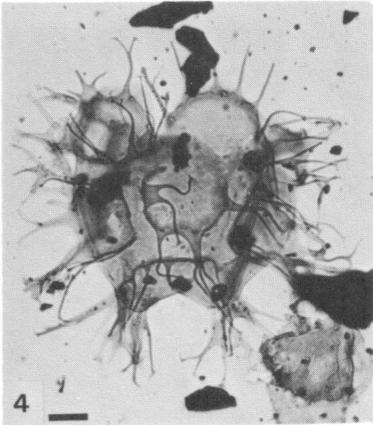
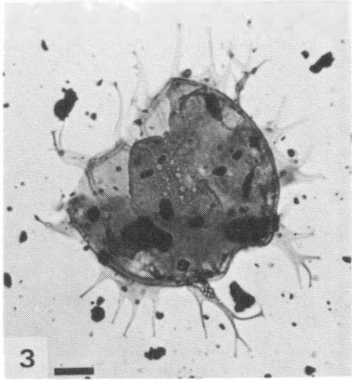
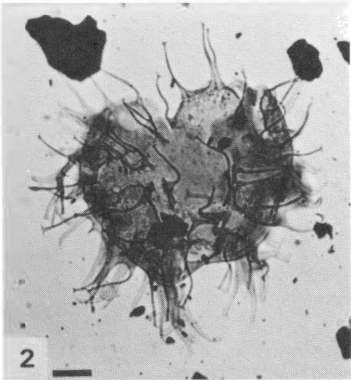
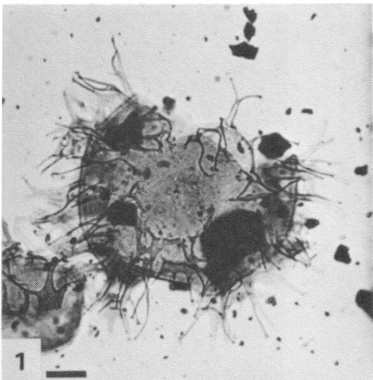


PLATE 12
DINOFLAGELLATES

The bar on each photograph represents 10 micrometres

- Fig. 1-2. — *Aldorfia deflandrei* (CLARKE & VERDIER) STOVER & EVITT
Vaals Formation, Lower Campanian
Sample HAL. 82-1, Preparation 54710-1, Q20
3. — *Spinidinium angustispinum* in WILSON
Vaals Formation, Lower Campanian
Sample HAL. 82-2, Preparation 54711-1, L23.3
4. — *Spinidinium angustispinum* in WILSON
Vaals Formation, Lower Campanian
Sample HAL. 82-2, Preparation 54711-1, G35
5. — *Northidinium perforatum* in WILSON
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-8, Preparation 54717-1, S34.4
6. — *Northidinium perforatum* in WILSON
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-8, Preparation 54717-1, S43.1 Apical archeopyle and operculum
7. — *Chytroeisphaeridia everricula* in WILSON
Vijlen Member, Upper Maastrichtian
Sample HAL. 82-10, Preparation 54731-1, O36.3. Apical archeopyle
8. — *Chytroeisphaeridia everricula* in WILSON
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-4, Preparation 54713-1, F29.3. Apical archeopyle
- 9-10. — *Chytroeisphaeridia solida* in WILSON
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-4, Preparation 54713-1, T23. Apical archeopyle
- 11-12. — *Cladopyxidium* sp.
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-7, Preparation 54716, M15. Apical archeopyle
13. — *Dinogymnium euclaense* COOKSON & EISENACK
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-3, Preparation 54712-1, S29.3
14. — *Gillinia hymenophora* COOKSON & EISENACK
Zeven Wegen Member, Upper Campanian
Sample HAL. 82-3, Preparation 54712-1, F27.2

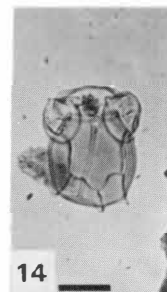
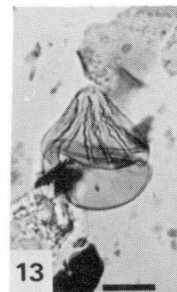
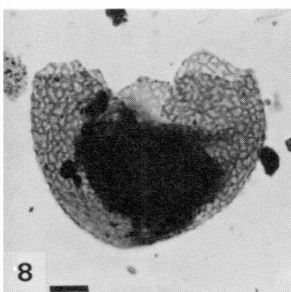
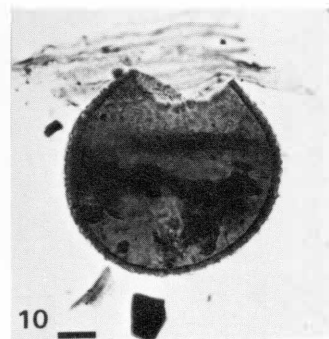
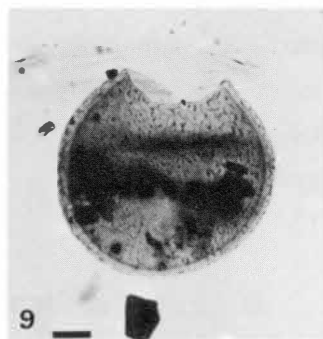
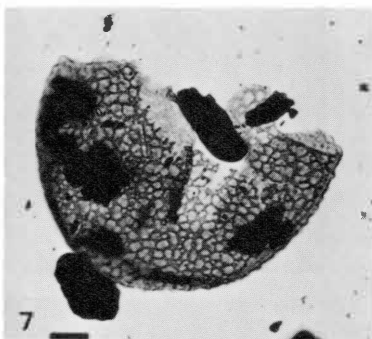
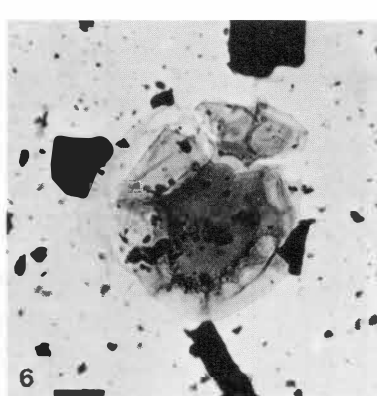
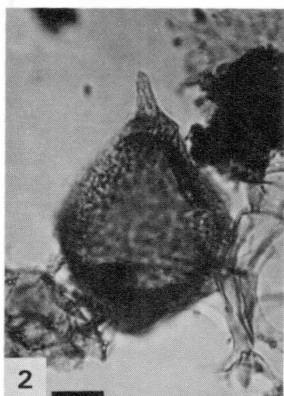
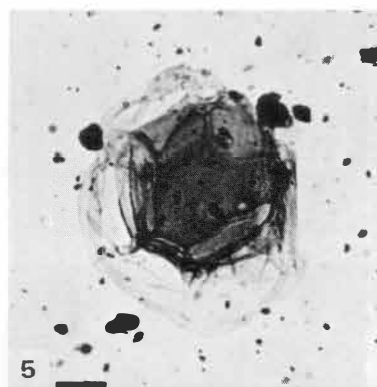
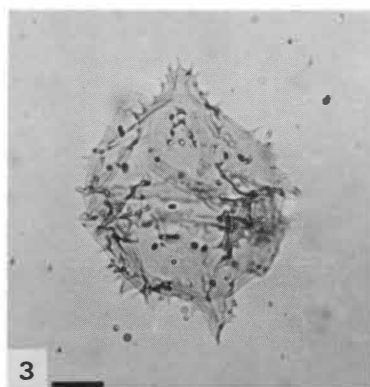


PLATE 13

NORMAPOLLESAll figures $\times 1000$

- Fig. 1 a, b. — *Trudopollis non perfectus* (PFLUG) PFLUG, 1953
2. — *Trudopollis* sp. 1
 3. — *Trudopollis* sp. 2
 4. — *Trudopollis* sp. 2
 5. — ? *Trudopollis* sp. 4
 6. — *Interporopollenites turgidus* TSCHUDY, 1975
 7. — *Semioculopollis* cf. sp. A TSCHUDY, 1975
 8. — *Semioculopollis* cf. *verrucosa* CHRISTOPHER, 1979
 9. — *Interporopollenites* sp. 1
 10. — *Trudopollis artifex* WEYLAND & KRIEGER 1953
 11. — ? *Hofkeripollenites* sp.
 12. — *Felderipollenites triangulus* KEDVES & HERNGREEN, 1980
 13. — *Extrapollis* sp. 1 AZEMA *et al.*, 1981
 14. — *Vacuopollis munitus* TSCHUDY, 1975
 15. — *Santonipollis* sp. 1

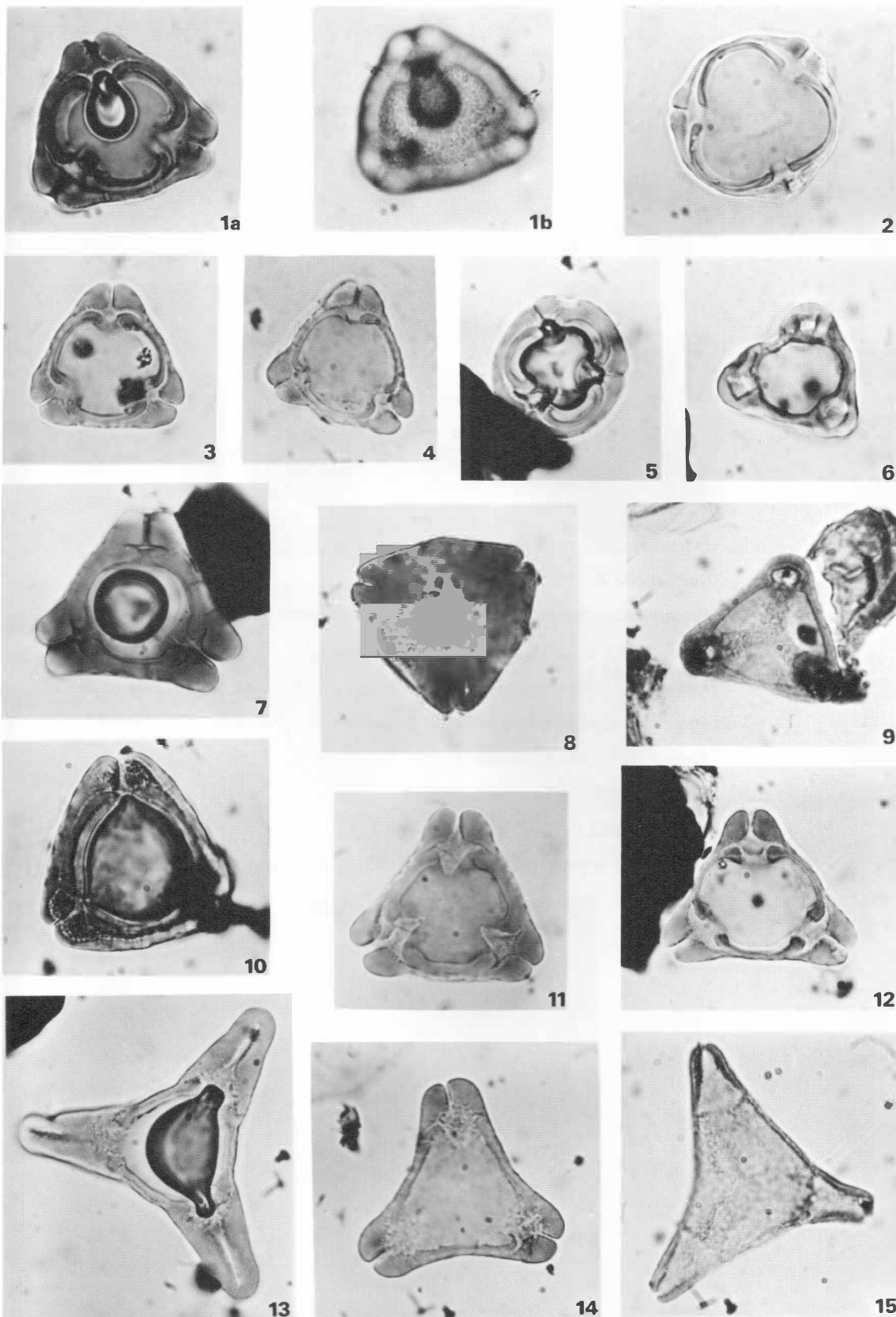


PLATE 14

NORMAPOLLESAll figures $\times 1000$

Fig. 1 a, b. - 2. — Normapolle B

3 a, b. — *Extratropopollenites* sp. 1

4. — Normapolle A.

5. — *Pseudotrudopollis pseudoalnus* (KRUTZSCH) KRUTZSCH, 1967

6. — ? *Trudopollis* sp. 3

7. — *Kriegeripollenites retigressus* (WEYLAND & KRIEGER) KEDVES & HERNGREEN, 1980

8. — *Pompeckjoidaepollenites subhercynicus* (KRUTZSCH) KRUTZSCH, 1967

9. — *Pompeckjoidaepollenites* sp. 1

10. — Normapolle C.

11. — Normapolle D.

12-13. — Amorphous organic matter with coccolith inclusions

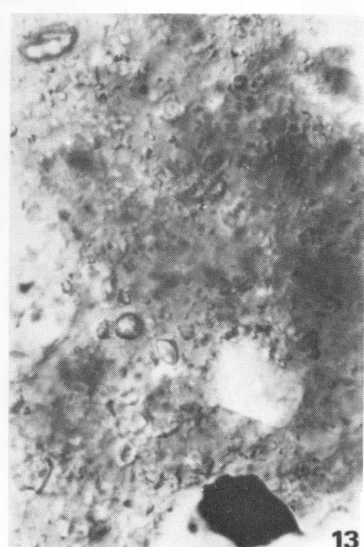
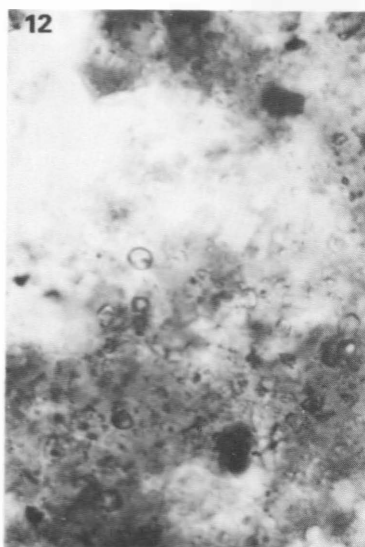
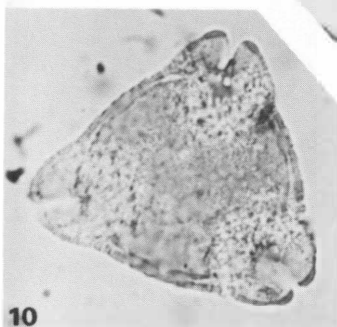
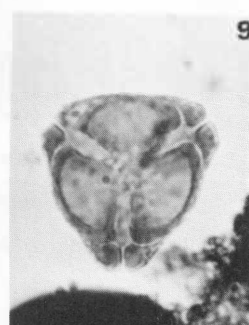
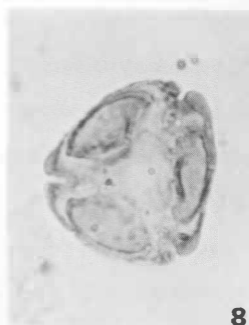
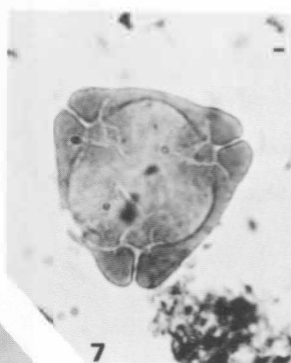
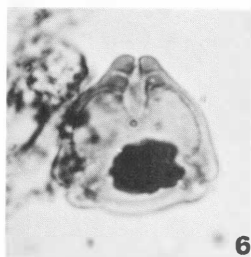
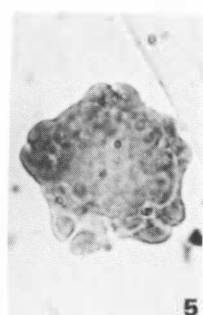
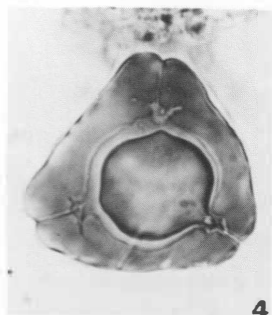
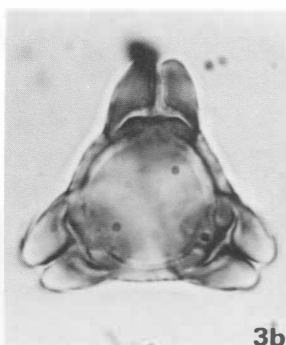
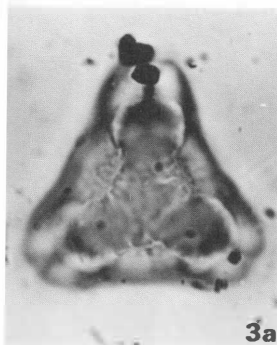
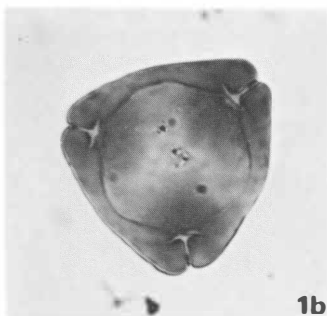
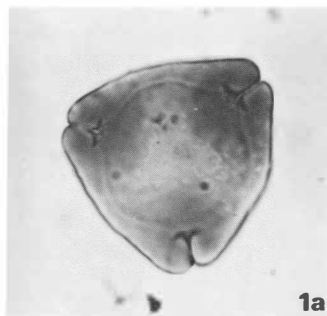


PLATE 15

REWORKED SPORES AND POLLEN GRAINS

All figures $\times 500$

- Fig. 1 — *Impardecispora apiverrucata* (COUPER) VENKATACHALA *et al.*, 1968
2. — *Pilosisorites trichopapillosus* (THIEGART) DELCOURT & SPRUMONT, 1955
3. — *Concavissimisorites verrucosus* DELCOURT & SPRUMONT, 1955
4. — *Neoraistrickia gristhorpensis* (COUPER) TRALAU, 1968
5. — *Sestrosorites pseudoalveolatus* (COUPER) DETTMANN, 1963
6. — *Gleicheniidites triplex* (BOLCHOVITINA) DÖRING, 1965
7. — *Cerebropollenites mesozoicus* (COUPER) NILSSON, 1958
8. — *Applanopsis trilobatus* DÖRING, 1961
9. — *Laricoidites triquetrus* LANTZ, 1958
10. — *Corollina meyeriana* (KLAUS) VENKATACHALA & GOCZAN, 1964
- 11-12. — *Corollina torosa* (REISSINGER) CORNET & TRAVERSE, 1975; fig. 11 well preserved specimens; fig. 12 slightly altered specimens

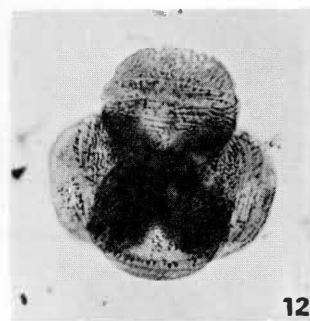
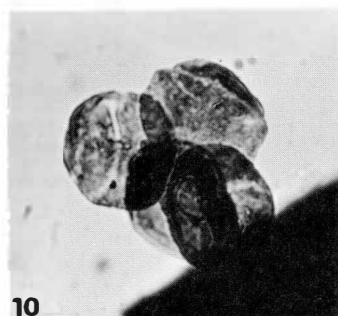
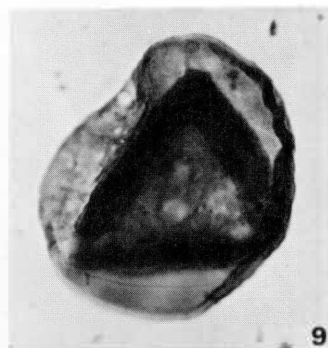
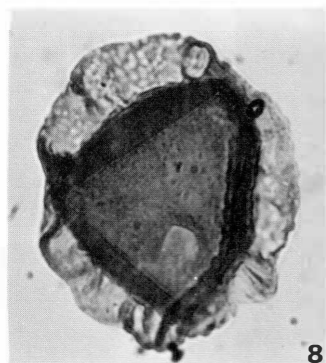
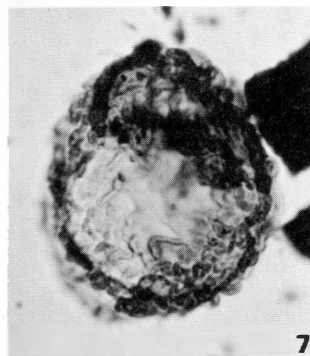
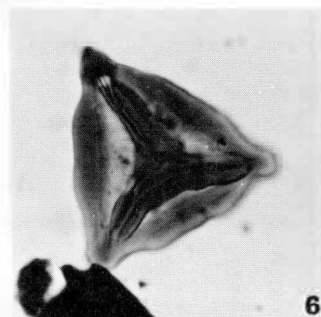
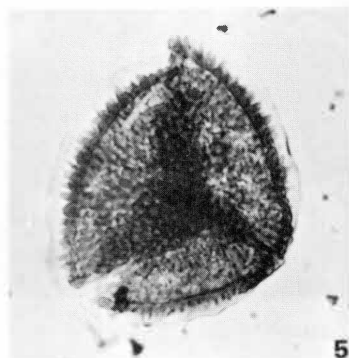
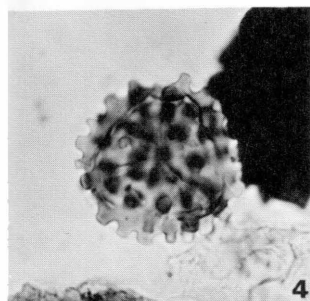


PLATE 16
MESOFOSSILS

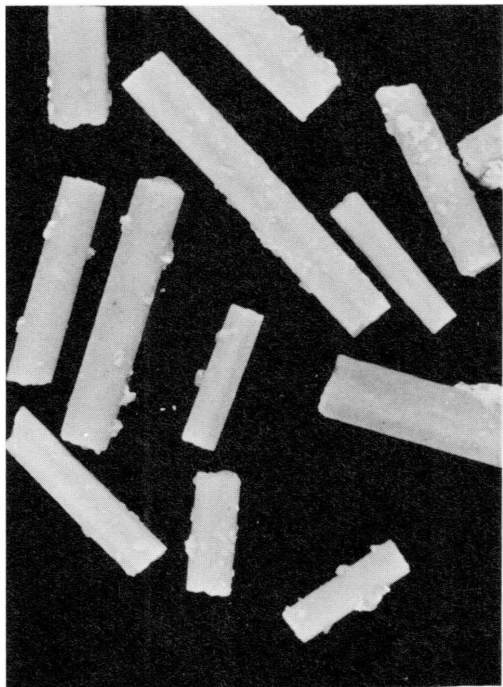
Characteristic mesofossils from the ecozone 3, ENCI quarry, Maastricht

Fig. 1. — Group Porifera, Bryozoa, Octocorallia, Grafularia

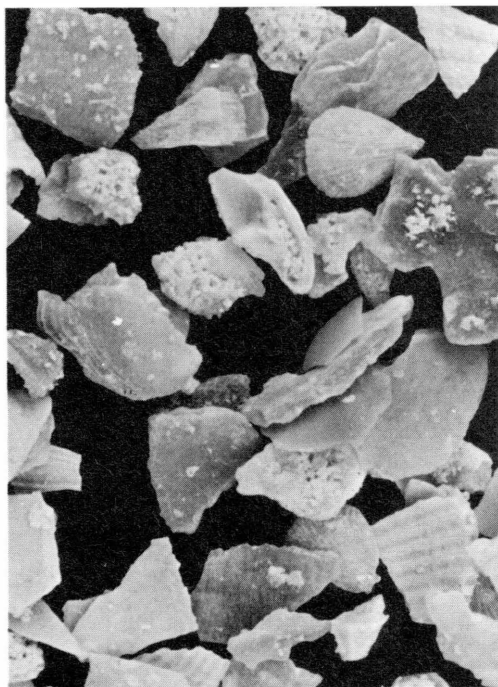
2. — Group Mollusca, Brachiopoda

3. — Group Crustacea, Cirripedia

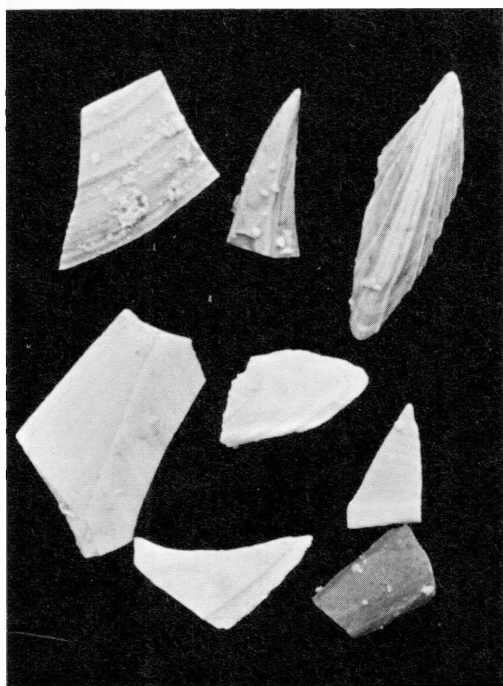
4. — Group Echinodermata, Crinoidea



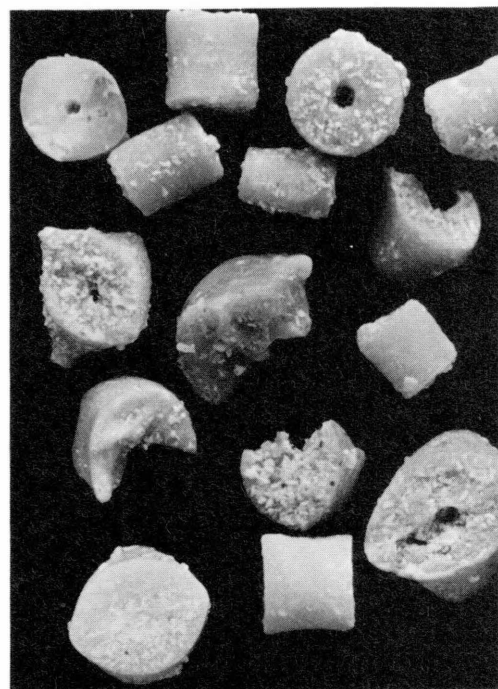
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2



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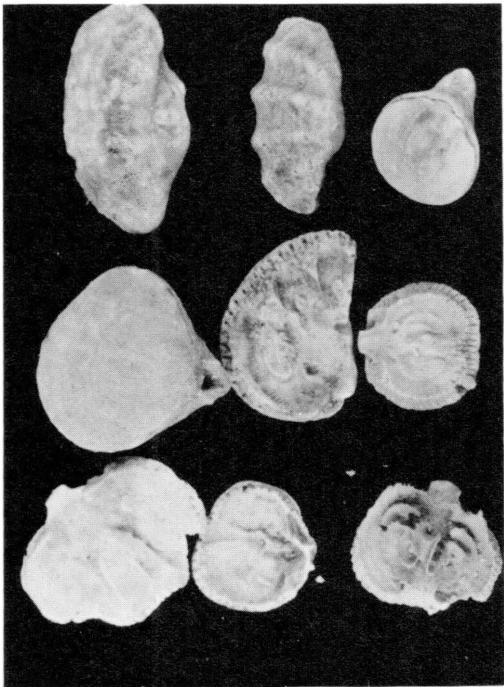
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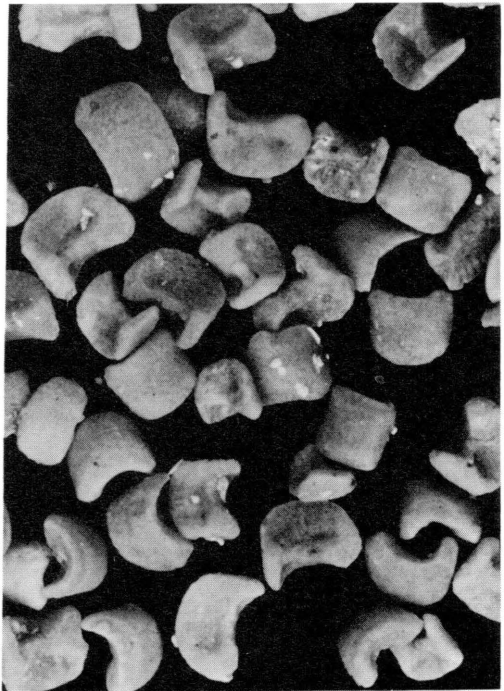
PLATE 17
MESOFOSSILS

Characteristic mesofossils from the ecozone 5, ENCI quarry, Maastricht

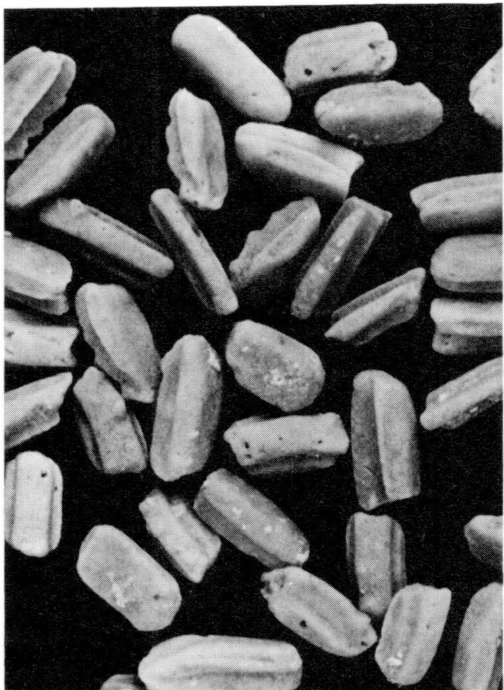
- Fig. 1. — Group Mollusca, Brachiopoda
2. — Group Echinodermata, Ophiuroidea
3. — Group Echinodermata, Asteroidea
4. — Group Echinodermata, Echinoidea



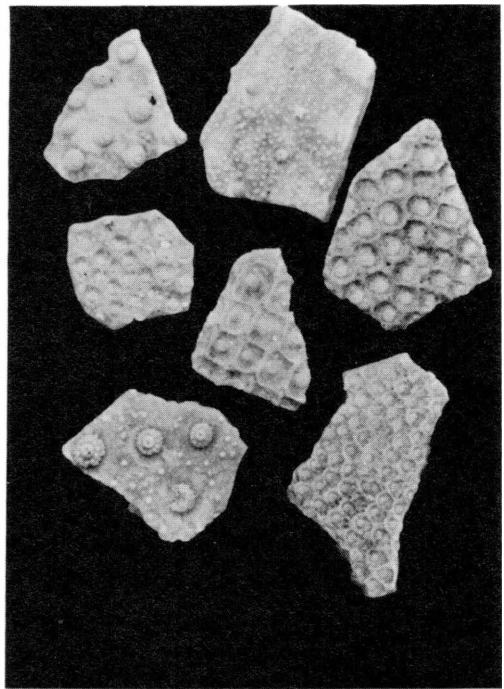
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2



3



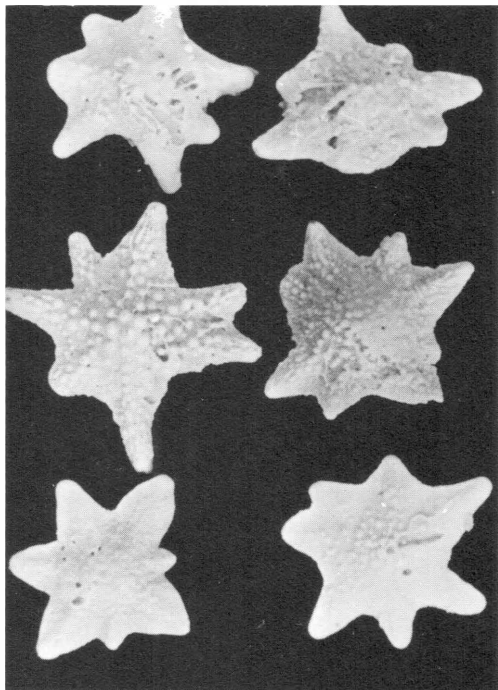
4

0 mm 5

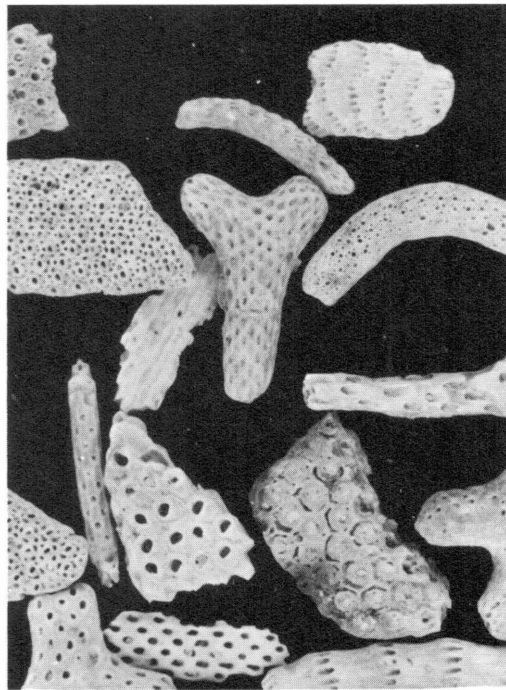
PLATE 18
MESOFOSSILS

Characteristic mesofossils from the ecozone 6, ENCI quarry, Maastricht

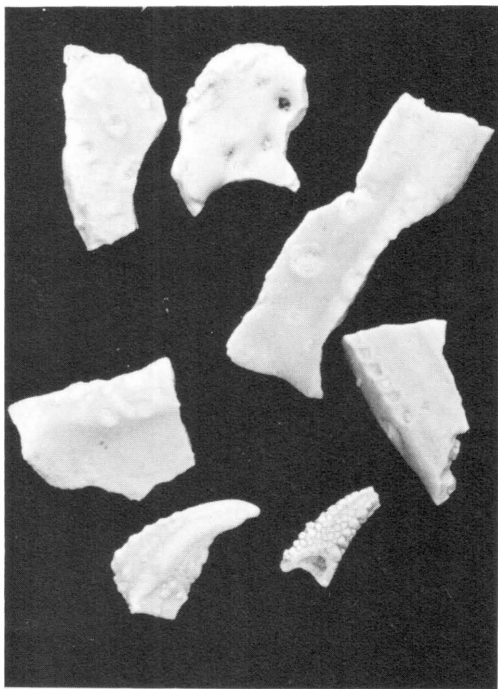
- Fig. 1 — Group Foraminifera, *Siderolites*
2. — Group Porifera, Bryozoa
3. — Group Crustacea, Decapoda
4. — Group rest, Serpulidae



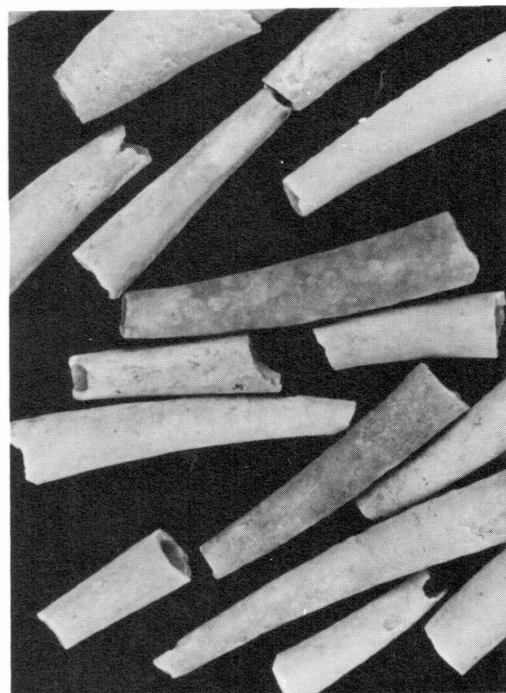
1



2



3



4

0 mm 5

PLATE 19
OSTRACODS

Smooth-shelled Ostracods from Vaals and Gulpen Formations at Halembaye (H) and Beutenaken (B)

- Fig. 1-2. — *Cytherella* ex gr. *ovata* (ROEMER, 1841)
1 B 82-1 (1 a = dorsal, 1 b = left view)
2 H 82-1 (left view)
- 3-4. — *Cytherella* ex gr. *contracta* VAN VEEN, 1932
3 B 82-1 (right view)
4 B 82-2 (left view)
- 5-7 — *Bairdia* spp.
5 B 82-2 (right view)
6-7 H 82-1 (right view)
8. — *Sphaeroleberis* sp.
H 82-1 (8 a = left view, 8 b = interior)
9. — *Sphaeroleberis saccata* (MARSSON, 1880)
B 82-2 (9 a = dorsal, 9 b = right view)
10. — *Krithe vanveenae* DEROO, 1966
B 82-2 (10 a = dorsal, 10 b = left view)
- 11-12. — *Asciocythere bonnemaï* DEROO, 1966
B 82-2 (11 a = left view, 11 b = interior, 12 a = dorsal, 12 b = right view)

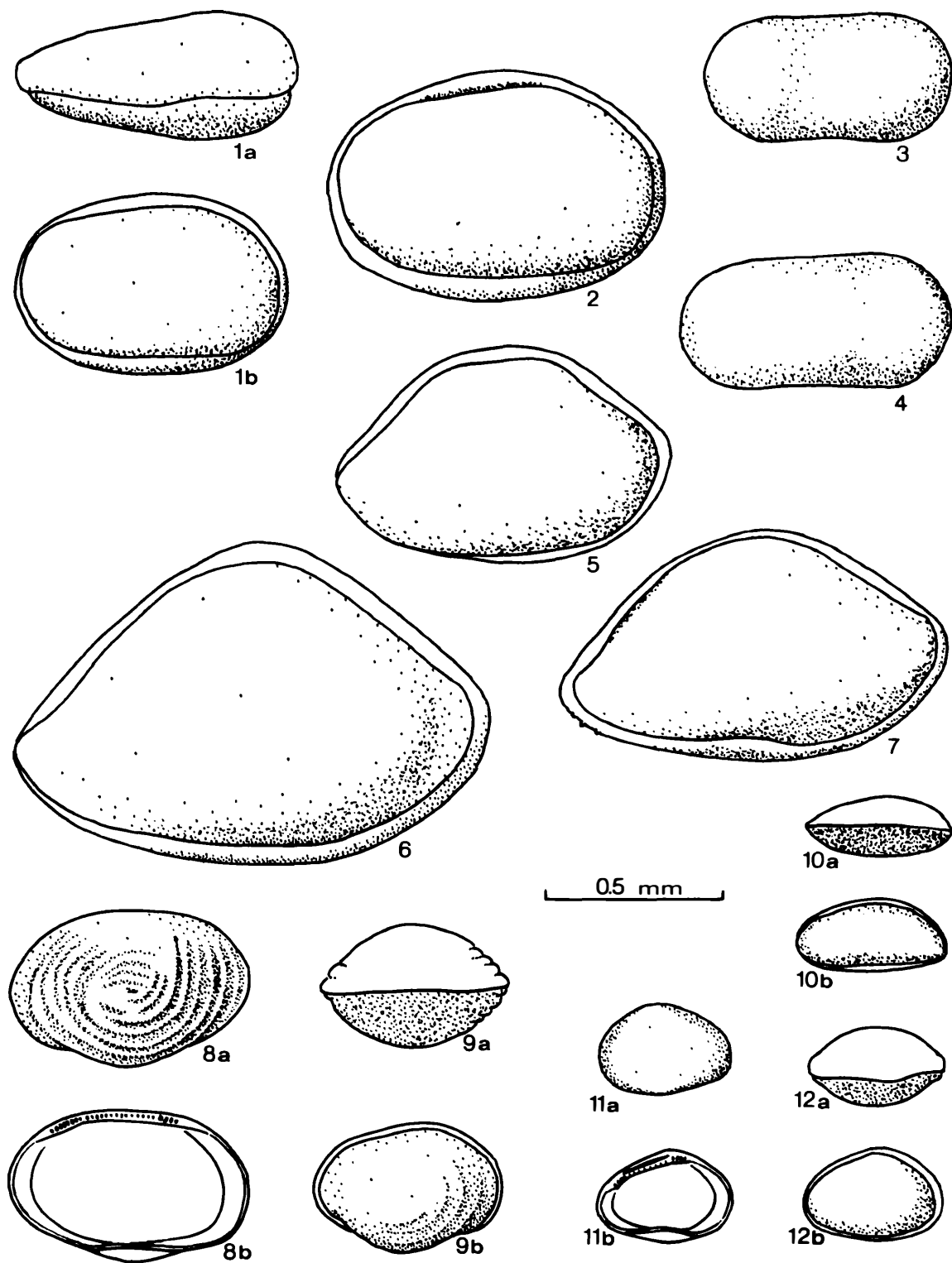


PLATE 20
OSTRACODS

Ornamented Ostracods from Vaals and Gulpen Formations at Halembaye (H) and Beutenaken (B)

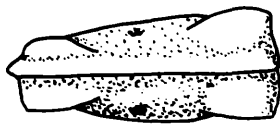
Fig. 1. — *Cytherelloidea* cf. *obliquirugata* (JONES & HINDE, 1890)
H 82-1 (1 a = dorsal, 1 b = left view)

2-3 - 5-6. — *Cytherelloidea levigata* HERRIG, 1963
B 82-2 (left views)

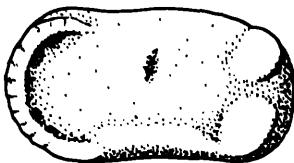
4. — *Cytherelloidea* sp.
B 82-2 (4 a = dorsal, 4 b = left view, 4 c = right view)

7-9. — *Pterygocythere laticristata* (BOSQUET, 1854)
H 82-1 (7 a = left view, 7 b = interior, 8 a = dorsal, 8 b = right view, 9 a = right view,
9 b = interior)

10. — *Aversovalva v-scriptum* VAN VEEN, 1936
B 82-2 (10 a = dorsal, 10 b = right view)



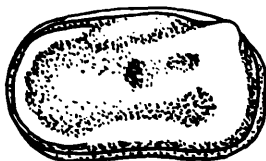
1a



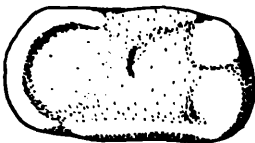
2



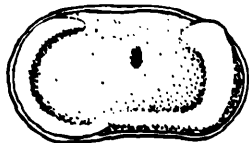
4a



1b



3



4b



5

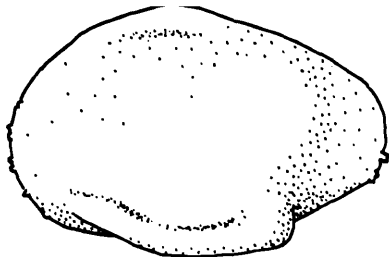


6

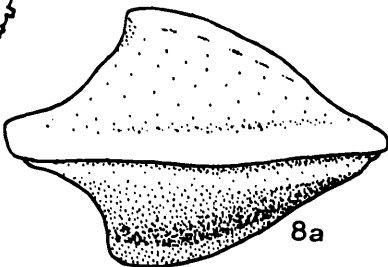


4c

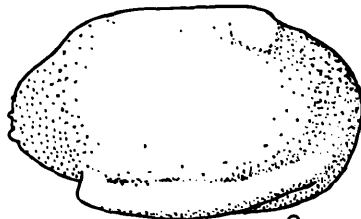
0.5 mm



7a



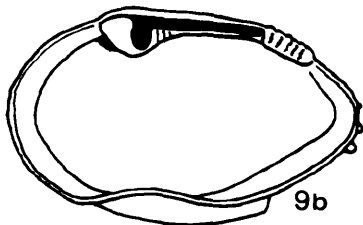
8a



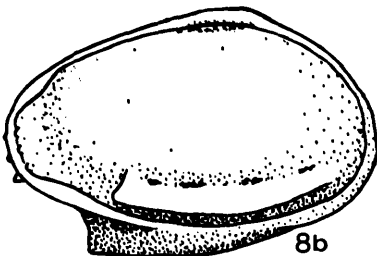
9a



7b



9b



8b



10a

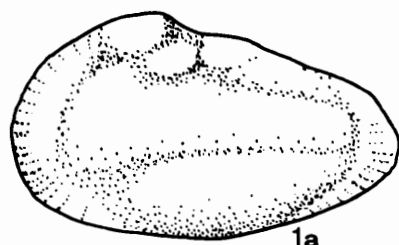


10b

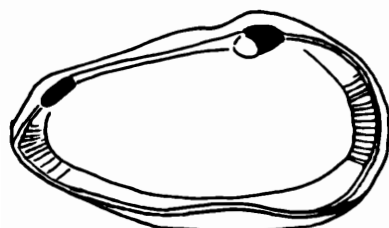
PLATE 21
OSTRACODS

Ornamented Ostracods from Vaals and Gulpen Formations at Halembaye (H) and Beutenaken (B)

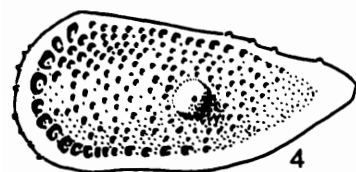
- Fig. 1-3. — *Veenia foersteriana* (BOSQUET, 1847)
 1 H 82-1 (1a = left view, 1b = interior)
 2 H 82-16 (2a = dorsal, 2b = right view)
 3 H 82-1 (3a = right view, 3b = interior)
4. — *Bythoceratina pedata* (MARSSON, 1880)
 H 82-4 (left view)
5. — *Bythoceratina* cf. *longispina* (BOSQUET, 1854)
 B 82-3 (left view)
6. — *Schizocythere* aff. *chelodon* (MARSSON, 1880)
 H 82-8 (left view)
- 7-9. — *Amphicytherura?* *slenakensis* DEROO, 1966
 7 H 82-1 (7a = dorsal, 7b = left view)
 8 B 82-3 (right view)
 9 B 82-2 (left view)
10. — *Schizocythere aculeata* (BONNEMA, 1941)
 B 82-2 (right view)
11. — *Hemicytherura* sp.
 B 82-3 (right view)
- 12-13. — *Mosaeleberis rutoti* DEROO, 1966
 12 H 82-6 (12a = right view, 12b = interior)
 13 H 82-5 (left view)



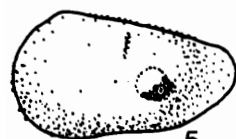
1a



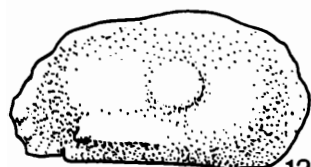
1b



4



5



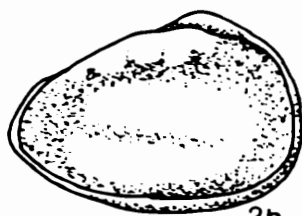
12a



12b



2a



2b



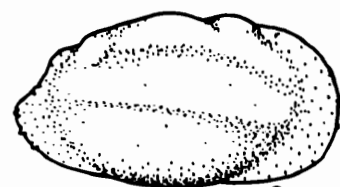
7a



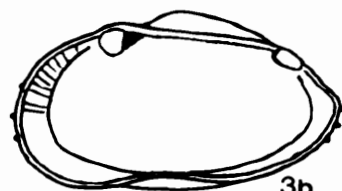
7b



13



3a



3b



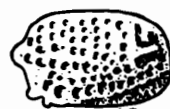
6



8



9



10



11

0.5 mm

PLATE 22
OSTRACODS

Ornamented Ostracods from Vaals and Gulpen Formations at Halembye (H) and Beutenaken (B)

- Fig. 1. — *Pterygocythereis phylloptera* (BOSQUET, 1854)
B 82-2 (1a = dorsal, 1 b = left view)
2. — *Pterygocythereis* aff. *tuberculata* (VAN VEEN, 1936)
H 82-1 (2 a = dorsal, 2 b = right view, 2 c = interior)
3. — *Planileberis parva* (BONNEMA, 1941)
H 82-7 (right view)
4. — *Spinoleberis* cf. *pseudoeximia* DEROO, 1966
H 82-12 (right view)
5. — *Phacorhabdotus batavus* DEROO, 1966
H 82-1 (left view)
6. — *Imhotepia marssoni* (BONNEMA, 1941)
H 82-12 (left view)
- 7-8. — *Curfsina* cf. *alseni* CLARKE, 1983
7 B 82-2 (left view)
8 H 82-1 (8 a = left view, 8 b = interior)
9. — *Curfsina anorchidea* (VAN VEEN, 1932)
B 82-8 (left view)
- 10-11. — *Eucytherura dorsotuberculata* VAN VEEN, 1938
10 B 82-2 (right view)
11 H 82-9 (right view)
- 12-13. — *Cythereis* spp.
12 H 82-2 (12 a = right view, 12 b = interior)
13 B 82-8 (left view)
14. — *Cythereis hallembayensis* DEROO, 1966
B 82-8 (left view)

