

Lithology and biostratigraphy of Upper Cretaceous-Paleocene carbonates in the Molenbeersel borehole (NE Belgium)

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Abstract

The Molenbeersel well was drilled by the Belgian Geological Survey as a reconnaissance well in the Rur (=Roer) Valley Graben (NE Belgium). Paleocene and Upper Cretaceous (Upper Maastrichtian) carbonates were traversed between 1223–1283.17 m of which interval the major part was cored.

A sedimentological and biostratigraphical analysis allows the recognition of three megasequences which correlate with thicker successions on the adjoining Brabant Massif, including the Maastrichtian type area. These megasequences testify to repeated flooding events on the inverted Rur Valley Block. Each of these is characterized by a basal conglomerate overlain by glauconite-rich deposits. In the upper two megasequences these deposits pass into pure calcareous strata. All deposits indicate shallow nearshore environments above storm wave base. Occasional emergence occurred as indicated by karstified horizons.

Fossil assemblages belong to the boreal province with the exception of an immigration of mediterranean organisms in the middle megasequence. This may be related to a period of tectonic relaxation of the Rur Valley Block during the Late Maastrichtian.

Introduction and geological setting

In an attempt further to explore the Rur (=Roer) Valley Graben in NE Belgium in 1987, the Belgian Geological Survey drilled the Molenbeersel well (classified as well KB 198, Belg. Geol. Survey files 49W226; Fig. 1). The well was located on a Cretaceous upwarping which could be observed on seismic line 8412 of the 1984 hydraulic hammer 'Poppel-Lommel-Maaseik' survey. In Fig. 1 the different strata penetrated by the well are indicated (Demyttenaere & Laga 1988).

All depths in this well refer to ground level

(33.22 m above mean sea level) as zero level. The cored limestone interval (diameter: 85 mm) forms part of a carbonate sequence starting at 1223 m. Cuttings from the upper interval (1223–1232.19 m) consist of yellow, coarsely bioclastic grainstones and finer wackestones, similar to the underlying cored sequence.

This subhorizontal (structural dip 2° N) carbonate sequence unconformably overlies Lower Jurassic Aalburg Shales. It is succeeded by Lower Paleocene continental deposits, informally assigned to the Maasmechelen Formation (1163–1223 m), which in their turn are succeeded by the marine Heers (1130–1163 m) and Upper Paleocene Landen (1107–1130 m) formations. Thick Oligocene (base at

Molenbeersel

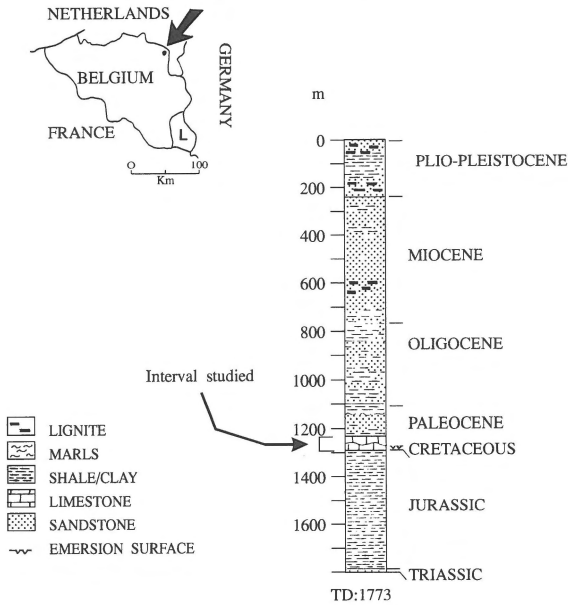


Fig. 1. Geographical situation and summary log of the Molenbeersel borehole.

1107m), Miocene (base at 774m) and Plio-Pleistocene deposits (base at 236m) testify to the important downward of the Rur Valley Graben during the Middle and Late Tertiary and Quaternary.

The general lithostratigraphical subdivision with lateral facies variations of the Campanian to Paleocene in the Netherlands' South Limburg (henceforth called: S-Limburg) is given in Fig. 2. Also the chrono- and biostratigraphical subdivision are given. The latter, which will be used throughout this paper, is based on benthic foraminifera zones (foram zones) defined by Hofker (1966). For a detailed overview of the stratigraphy of the Campanian-Maastrichtian in S-Limburg and the Belgian part of the Campine-Brabant Basin (henceforth called: Belgian Campine) the reader is referred to Felder et al. (1985).

The aim of the present paper is to unravel the stratigraphy, the sedimentology and depositional history of the cored limestone interval (1232.19–1283.17m). This interval is of special importance in reconstructing the Rur Valley Graben tectonic activity during the Late Cretaceous and Early Tertiary. Several studies have documented facies-vari-

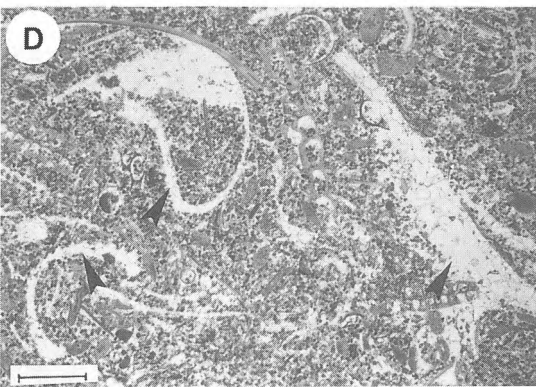
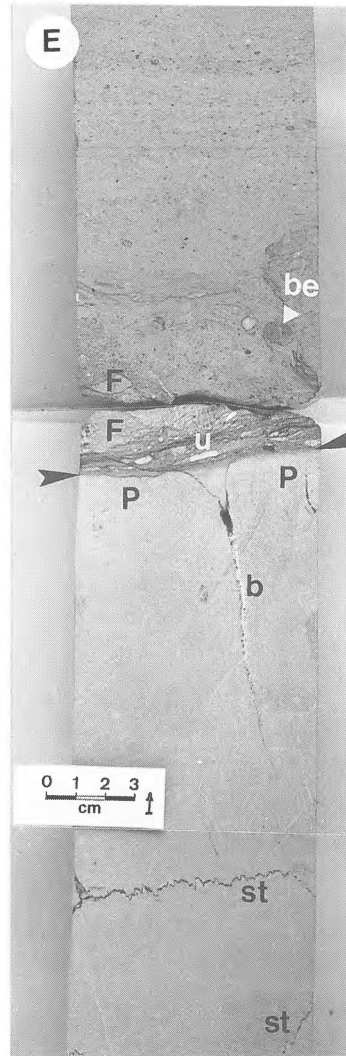
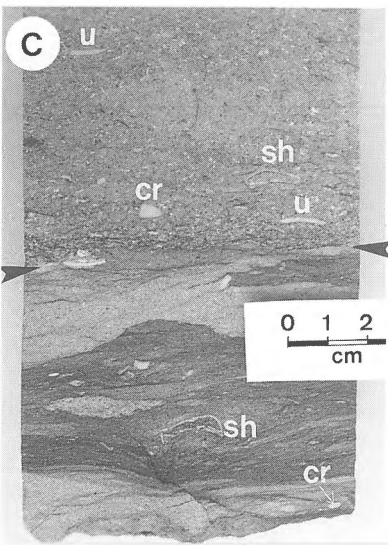
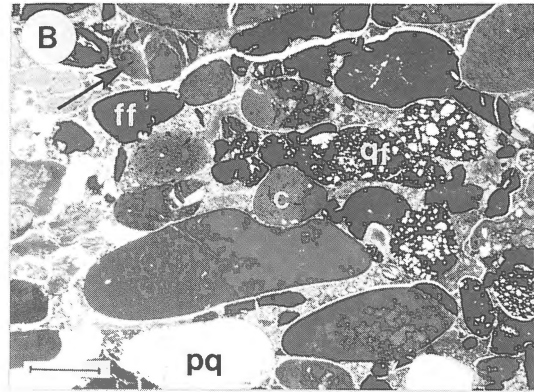
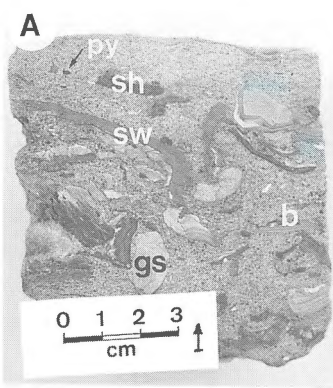
BIO/ECO	LITHO	CHRONO
R	HOUTHEM Geleen* Bunde* Geulhem*	PALEOCENE MONTIAN
Q		DANIAN
P		
M	MAASTRICHT Maas-tricht* Kun-rade* Valkenburg* Lanaye* Pre-Valkenburg* Zeven Wegen* VAALS	MAASTRICHTIAN Upper UPPER
L		
K ?		Middle UPPER
I J		
H O		
G		
F		
E		Lower UPPER
C		
B		LOWER
A / A'-upp	CAMPANIAN UPPER	
A' mid.		
A' low.		

Fig. 2. General bio/eco-, litho- and chrono-stratigraphical subdivision of the Campanian to Paleocene in the Netherlands' South Limburg and the Belgian part of the Campine Basin. The bio/ecostratigraphical subdivisions are based on benthic foraminifera zones (Felder et al. 1985). Formation names are given in capitals in litho-column. The other names in this column refer to members, to facies or to lithological units (*) which were not yet formally established as formations or members. Question marks have been used there where the boundaries are less well-defined.

tions in this time-interval in the Maastricht type area and the Belgian Campine Basin (e.g. Felder et al.

Table 1. Quantitative distribution of selected bioclasts (1–2.4 mm sieve fraction) in the Late Cretaceous and Paleocene of Molenbeersel borehole (in percentages: highest percentage per sample in italics). Bioclasts interpreted to characterize specific intervals are in bold and indicated by an asterisk.

Unit	Depth (in m)	large forams	bryozoans, sponges, octocorals	molluscs brachiopods	echinoderms	serpulids	
7	1232.49			37	63		
	1232.99		15*	28	57		
	1233.17		13*	10	77		
	1233.77		2	3	95		
	1234.12	1*	1		98		
	1234.68	1*	1		98		
	1235.18	4*	2		94		
	1236.05	3*	3	5	89		
	1236.70	2*	3	3	88	5	
	1236.97	2*	3	5	90		
	1237.61		3	11	86		
	1237.83		12*	13	75		
	1238.30		<i>40</i>	24	36		
	1239.20		<i>80</i>	6	13		
	1240.23		13*	42	42	2	
	1240.95		8*	4	88		
	1241.43				100		
	1242.13	2	43*	9	46		
	1242.80		38*	6	56		
6	1244.19		7	10	82		
	1245.30			5	95		
	1245.96			1	92	7	
	1246.93			6	94		
	1247.70		1		98	1	
5	1248.10			2	96	2*	
	1248.47			18	72	10*	
	1249.15		5*	12	66	17*	
	1249.55		4*	10	77	9*	
	1250.32		1*	6	89	4*	
	1250.80		3*	9	59	28*	
	1251.61		13*	64	18	5*	
	1252.10		13*	13	62	2*	
	1253.50		2*	7	87	4*	
	1253.84		23*	1	75	1*	
	1254.35		7*	10	82	1*	
	1254.58		1*	10	88	1*	
	1255.25		2*	19	73	6*	
	1255.60			32	44	24*	
	1256.10			20	78	2*	
	1256.18		1	45	53	1*	
	1256.67			83	15	2*	
	4	1257.54			86	14	
		1258.23				100	
1258.46				33	67		
1259.00				20	79		
1259.55				1	99		
1261.07			5	2	93		
3	1263.85	1	2*	2	95		
	1264.29			10	90		
	1264.85		1*	1	98		
	1265.72			5	95		
	1265.94		29*	10	57	4*	
	1266.72				100		
	1268.03		3*	13	72	12*	
	1268.38				100		
1269.00			86	12	2*		
2c	1269.25			60	40		
	1269.27			4	42	54	
	1270.06			19	75	6*	
	1270.90			22	78		
	1271.22			8	75	17*	
	1272.08		4	50	38	8*	
	1272.78				100		
	1272.95			35	65		
	1273.23			27	73		
	1273.50			7	86	7*	
	1273.80			17	77	6*	
	1274.18				100		
	1274.64		4	15	81		
1275.53				100			
2b	1276.39			16	79	5*	
2a	1277.04			25	75		
	1277.84		6*	68	24	2*	
	1278.55		4*	58	38		
	1278.89			69	31		
	1279.42		25*	68	7		
	1279.90		10*	88	2		
	1280.32		21*	76	3		
	1280.60		12*	81	5	2	
	1280.65		40*	59	1		
	1280.75		26*	72	2		
	1281.00		38*	60		2	
1	1283.14		2	97	1		



1985, Bless et al. 1987, Felder & Bless 1989). The present results and interpretation complement these studies in an area where no data were yet available. A detailed diagenetic study which completes the sediment petrography of the interval investigated will be presented separately (Swennen et al. 1993).

Methodology

The present investigations rely on a detailed macroscopical description of the cores which allowed to define different characteristic lithology types. These were also studied in about 50 thin sections using classical sediment-petrographical techniques.

The stratigraphical interpretation is based on bio-/ecostratigraphical criteria (forams, ostracodes,

belemnites, ...) and eco-/lithostratigraphical criteria (bioclast assemblages, lithofacies). Microfauna determinations were carried out by point counting analysis under the binocular after slightly crushing (desaggregating) >100 gr of the friable limestone. Notice that only bioclasts of the 1.0–2.4 mm sieve fraction have been considered (Table 1).

Classical porosimetry measurements were carried out on plugs. The reported mean values correspond well with the porosity values inferred from density logs and from the application of computerized tomography analysis (Swennen et al. 1993).

Lithological succession

Within the interval 1232.19–1283.17 m seven different lithological units are distinguished (Fig. 3).

←

Plate 1

A. Matrix-supported conglomerate with:

- dark grey to black flat shale fragments (sh)
- brown weathered laminated shale fragments (sw)
- glauconitic sandy shale fragments (gs)
- shell and coralline algae debris (b)
- pyrite clasts (py)

in a glauconitic calcarenite matrix

Sample: 1283.07–1283.00 m (unit 1: lowermost part) RS/B/9-OA

B. Clast-supported conglomerate with well rounded

- iron-oxide fragments (ff)
- phosphate fragments (c)
- quartz bearing iron-oxide fragments (qf)
- polycrystalline quartz fragments (pq)

in glauconite-rich sandy matrix.

Note the presence of compactional fractures (arrows) as well as pressure solution.

Sample: 1281.00 m, Transmitted light. Scale: 2 mm. (unit 2: lowermost part) RS/B/8-24

C. Contact between fine-grained clay/organic-rich calcarenite with bioclasts (lower part) and coarse-grained bioclastic calcarenitic stormlayer (upper part). The contact is sharp and erosive (arrows); a clear fining-upward trend occurs within the storm layer. Most of the bioclasts are oriented parallel to the stratification (crinoids: cr; shell fragment: sh; sea-urchin fragments: u).

Sample: 1263.65–1263.55 m (unit 3: top); RS/B/9-10A

D. Bioclastic packstone/grainstone with well-rounded bioclasts with varying degrees of micritization. Notice the development of biomoldic porosity (arrows: dissolution of gastropods, pelecypods, etc ...) and the creation of enlarged biomoldic porosity prior to equant calcite cementation (see Swennen et al. 1993).

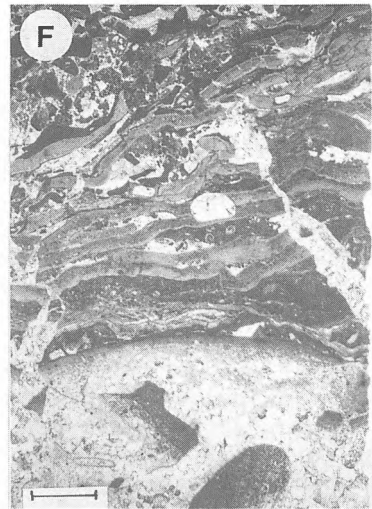
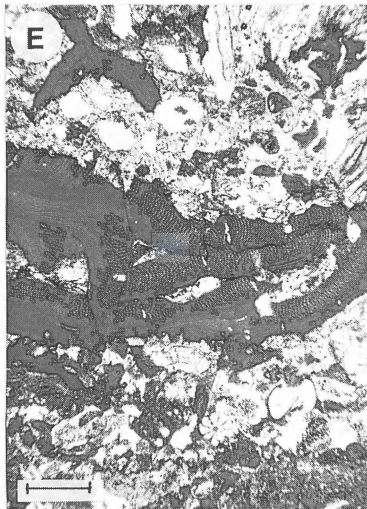
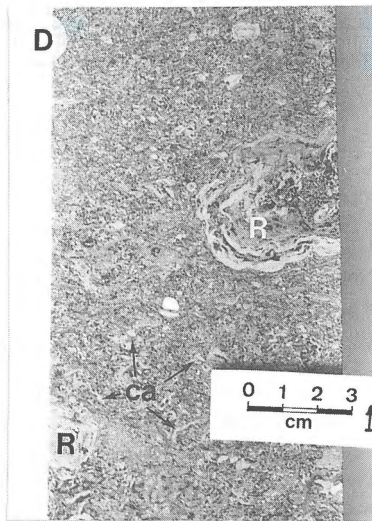
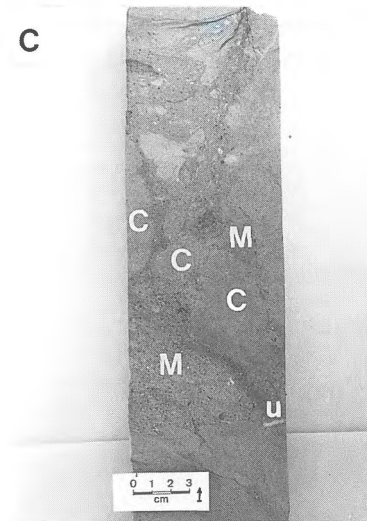
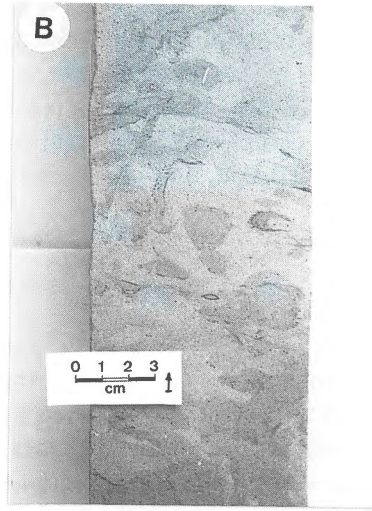
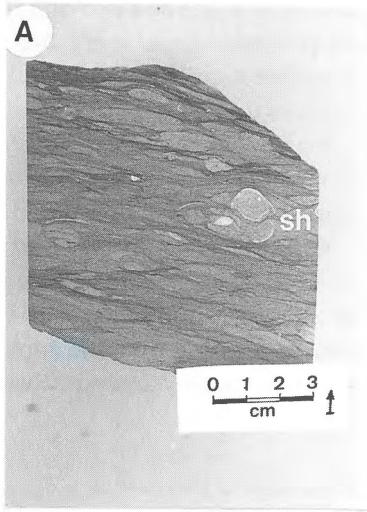
Sample: 1266.86 m, Transmitted light. Scale: 2 mm, (unit 3); RS/B/8-15

E. Contact at 1256.67 m.

Below the contact (arrow) massive white fine-grained calcarenites occur (unit 4) in which stylolites (st) associated by the development of secondary porosity, are present. Vertically oriented vugs occur next to the contact. These vugs are partly cemented by blocky calcite (b). The uppermost 1.5 cm below the contact has a high secondary porosity (P).

Above the contact a conglomeratic horizon occurs with reworked host-rock fragments (F), a shark tooth, belemnite guards (be), sea-urchin fragments (u) etc. within a calcarenitic matrix. The uppermost strata already display a lamination (unit 5).

Sample: 1256.90–1256.51 m (contact units 4–5) RS/B/9-13A-14A-15A



Each unit consists predominantly or exclusively of carbonates. Above unit 2, these carbonates are mainly grain-supported.

Unit 1 (1283.17–1281.00m)

This starts with a thin (about 9cm) basal matrix-supported conglomerate, overlain by a fine-grained, intensively bioturbated, glauconitic, quartz and feldspar bearing calcarenite with some clay pebbles. The conglomerate matrix consists of calcarenite with up to 25% quartz, feldspar and glauconite grains. In this matrix large (<2 cm) clasts of shale (reworked Jurassic), glauconitic sandy shale and pyrite occur along with abundant fragments of belemnite guards and algal (rhodophycan) debris (Plate 1A).

In thin sections, the sandy calcarenite appears to be a porous (mean porosity = 20.9% of bulk volume) bioclastic grainstone, rich in glauconite, quartz and K-feldspar grains. Their mean grain size varies between 50–100µm. Bioclasts (bryozoans, sponge spicules, forams, molluscs, brachiopods and subordinate echinoderms) are intensively micritized.

Unit 2 (1281.00–1269.00m)

This unit starts with a thin, clast-supported conglomerate which evolves upwards into a mud-supported conglomerate with a clayey matrix. Granules are small (ca 3mm), well rounded and rather well sorted. They consist of lithoclasts (sandstone, shale, micrite, iron-oxide and some phosphate:

Plate 1B) and bioclasts (mainly belemnite, bivalve and bryozoan fragments). Immediately above this conglomerate two thin bioclast/coquina layers occur (at 1280.75 and 1280.50m) in a sandy lime-mudstone. They mainly consist of rather well preserved, locally micritized bivalve fragments and brachiopods (about 70%) and up to 20% bryozoan fragments.

Above 1280.45m, a regular alternation of massive (bioturbated, sometimes vaguely laminated) glauconitic calcisiltites, fine calcarenites and clay/organic-rich, glauconitic, laminated marls with some shell debris occurs. Three semi-continuous flint horizons are present between 1277.40 and 1275.60m. The degree of bioturbation and the glauconite contents are higher below these flints than above. The clay/organic-rich marls become more frequent and more sandy upwards.

These lithological variations are also apparent in thin sections. The lower part consists mainly of rather porous (about 15.2% bulk volume) bioturbated bioclastic wackestone to packstone with a relatively high glauconite, lithoclast and detrital quartz content; locally some phosphate granules occur. Above the flints a less porous (about 11.3% bulk volume) biopeloidal packstone with rounded micritized bioclasts is observed. Glauconite, lithoclasts and detrital quartz become less common.

Because of these differences, albeit minor, the regularly bedded unit 2 is subdivided into three smaller intervals: 2a consisting of a basal conglomerate and of a clayey bioclastic wackestone/pack-

←

Plate 2

- A. Parallel, scaly, clay/organic-rich streaks of aggregates surrounding calcarenite (flaser structure) and shell debris (sh).
Sample: 1258.90–1258.78m (unit 4); RS/B/9-11A
- B. Intensively bioturbated calcarenite.
Sample: 1249.30–1249.15m (unit 5); RS/B/10-15A
- C. Karstic horizon. Leached, partly reworked clasts (C) of the underlying host rock occur within a micro-conglomeratic, glauconitic calcarenite matrix (M). Locally sea-urchin fragments (u), shell-debris, etc. are present.
Sample: 1251.48–1251.20m (unit 5); RS/B/10-OA
- D. Detail of a bioclast-rich calcarenite with rhodoliths (R) and crustose coralline algae (ca).
Sample: 1234.95–1234.86m (unit 7: top); RS/B/10-16A
- E. Bioclastic grainstone to rudstone with in the middle part intensively compacted coralline red algae.
Sample: 1242.70m, unit 7. Transmitted light. Scale: 180µm; RS/B/6-5
- F. Continuous overlapping encrustation of coralline red algae below bioclastic rudstone. Notice the presence of fracturing and vug development before blocky calcite cementation.
Sample: 1235.43m, unit 7. Transmitted light. Scale: 180µm; RS/B/7-12A

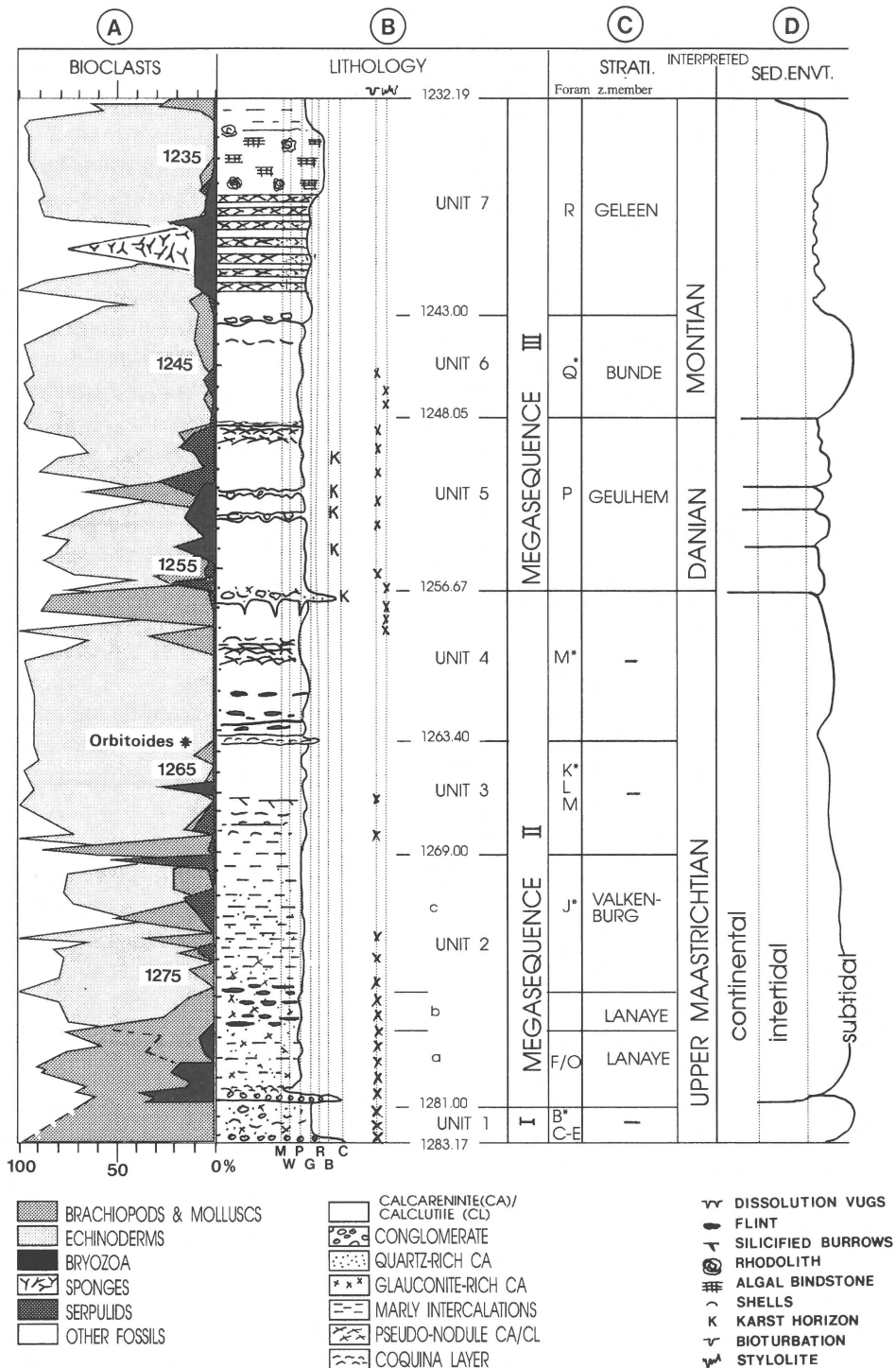


Fig. 3. Upper Cretaceous and Paleocene in the Molenbeersel borehole between 1283.17–1232.19m. (A) Percentage distribution of major bioclast groups (1–2.4 mm sieve fraction, see Table 1) which were used for regional correlations. (B) General lithological overview of the cored interval: M= mudstone; W= wackestone; P= packstone; G= grainstone; R= rudstone; B= bindstone, C= conglomerate. (C) Interpreted stratigraphy: the foram zones refer to Hofker (1966). Inferred foram zones are marked by an asterisk. (D) Interpreted sedimentary environment.

stone with a relatively high glauconite and sand content (1281.00–1277.40m), 2b composed of wackestone/packstone with flints (1277.40–1275.60m), and 2c characterized by a biopeloidal packstone with upwards decreasing glauconite and sand content (1275.60–1269.00m). Just below the top of sub-unit 2c (1269.27 m) a serpulid layer is present.

Unit 3 (1269.00–1263.40m)

Massive, well-cemented fine calcarenites with only a few clay/organic-rich streaks and locally some bioclastic (serpulid) layers or rare laminations build up this unit 3. Silicified burrows occur at 1266.70m. The top layer (1263.60–1263.40m) consists of a coarse-grained bioclastic calcarenite. An increase of clay/organic-rich lamination is apparent from 1264.20m upwards. Whereas dip direction remains due north in unit 3, dip angles which were subhorizontal in unit 2, increase within several intervals to about 25°. The changes are gradual and are especially visible in so-called mixed sutured-glide solution seams (for definition see Wanless 1979). The steeper dips could reflect crossbedding; however, a diagenetic origin cannot be excluded.

In thin sections the sequence is made up of bioclastic packstone/grainstone (Plate 1D) with well-rounded, partly to entirely micritized bioclasts and with practically no lithoclasts or detrital quartz (<1%). Some of the bioclasts (mainly gastropods) have been dissolved and are presently cemented by blocky calcite. These packstones/grainstones are porous (about 19.8% bulk volume). The uppermost layer, which is only 20cm thick, is composed of a fining-upward sequence grading from a bioclastic rudstone with orbitoid forams and rhodophycean fragments into a bioclastic grainstone to packstone (Plate 1C). Most of these bioclasts are oriented parallel to stratification. The layer's lower contact is erosive. This layer thus possesses many features in common with a storm deposit.

Unit 4 (1263.40–1256.67m)

Massive white calcarenites. Flint nodules or platy flint with shrinkage vugs are intercalated in the lower portion of this unit between 1263.30–1261.10m. Thin, irregular clay/organic-rich laminae in the upper part produce non-sutured discontinuous solu-

tion seams which locally give rise to a fitted nodule to pseudo-nodule structure (for definition see Wanless 1979) between 1260–1258m (Plate 2A). The top of the sequence is characterized by an erosive contact with pronounced secondary porosity in vugs and along stylolites (Plate 1E).

This succession is composed in thin section of bioclastic grainstone/packstone (average porosity about 14.0%) often with intensively micritized bioclasts. The porosity is slightly reduced to about 12.6% bulk volume in the clay/organic-rich laminated interval.

Unit 5 (1256.67–1248.05m)

A basal conglomerate with clasts reworked from the underlying unit forms the base of unit 5 (Plate 1E). Besides these reworked clasts, abundant bryozoans and bivalve fragments and subordinate fish remains (teeth and bones) can be observed macroscopically. Above this conglomerate the sequence consists of a white-grey, locally intensively bioturbated calcarenite (Plate 2B) with two important karst horizons (Plate 2C) at 1252.45 and 1251.30m. The karst cavities are filled up by a porous, glauconitic microconglomerate with clasts derived from the host rock and with abundant fossil debris (serpulids, bivalves, bryozoans, echinoids). The dips start to show an erratic behaviour from these karst horizons upwards. Less important erosive contacts and karstic levels occur between 1255–1254m and between 1250–1249m. The top layer is formed by an intensively bioturbated bed overlain by a pseudo-nodular level with coarse bioclasts (mainly echinoid fragments).

Thin sections reveal an alternation of massive bioclastic packstone/grainstone with porous bioclastic wackestone (average porosity of about 14 and 28% respectively). Both lithologies contain abundant micritized bioclasts (peloids) and up to 3% detrital quartz and glauconite grains. The basal conglomerate is intensively stylolitized and contains large fragments of bioclastic mudstone, shell debris, rhodophycean algae, crinoid ossicles, glauconite lumps, phosphate grains and coarse detrital quartz grains, which occur in a porous bioclastic grainstone matrix (average porosity 20.3%).

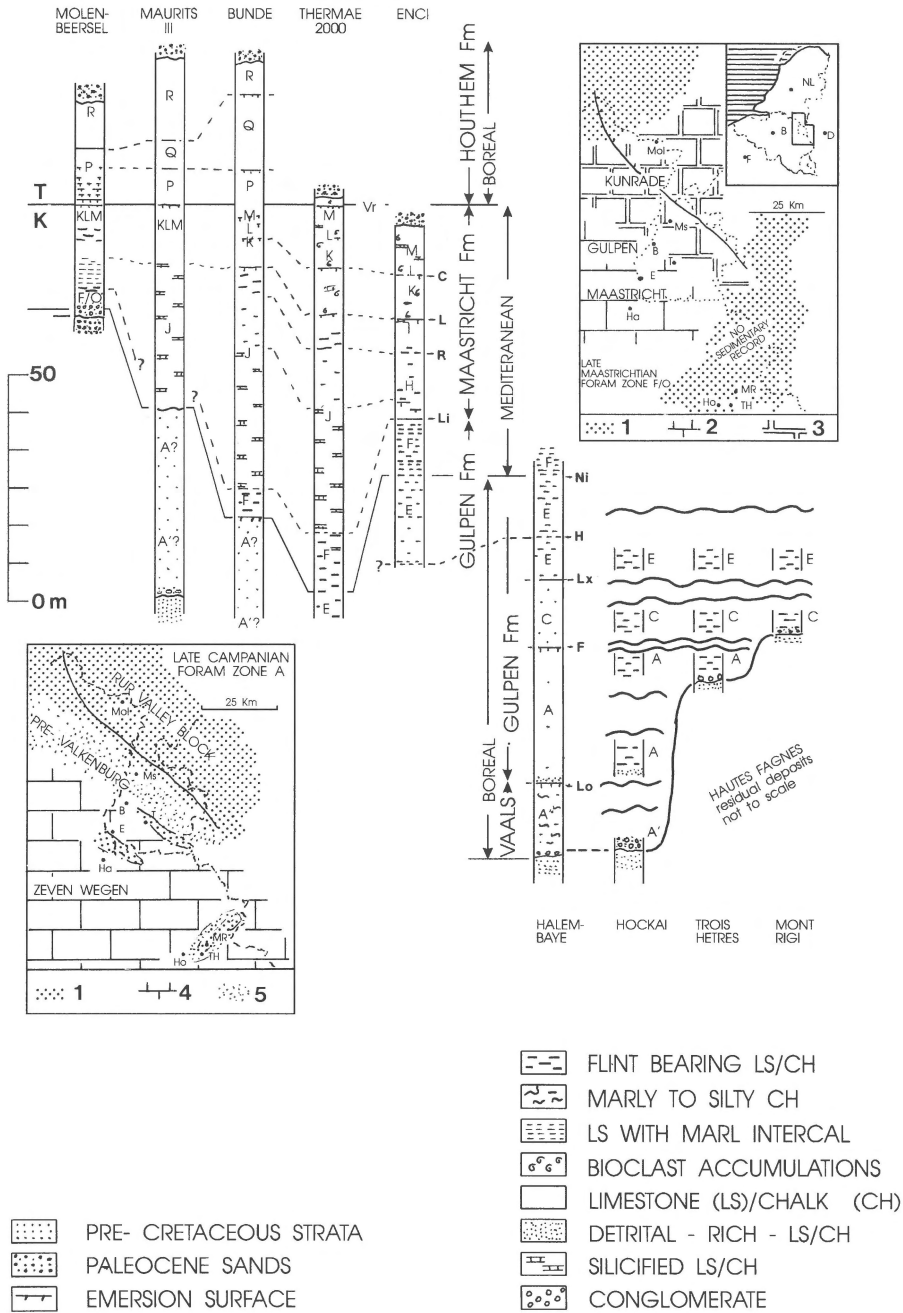


Fig. 4. Time-stratigraphical correlation of Late Cretaceous and Paleocene strata at Molenbeersel with sections in S-Limburg and eastern Belgium. Interpreted age is expressed in terms of foram zones (A', A-R in or alongside lithostratigraphical columns) and lithostratigraphical marker horizons (Lo= Loën, F= Froidmont, Lx= Lixhe, H= Halembaye, Ni= Nivelles, Li= Lichtenberg, R= Romontbos, L= Lauumont, C= Caster and Vr= Vroenhoven). The Vroenhoven horizon forms the Cretaceous/Tertiary boundary and is taken as datum line. Part of the foram zones correlate with each other laterally as shown. Paleogeographical reconstructions are for Late Campanian foraminiferal zone A and Late Maastrichtian foraminiferal zone F/O times (Mol= Molenbeersel; Ms= Maurits III; B= Bunde; T= Thermae 2000; E= ENCI; Ha= Halembaye; Ho= Hockai; TH= Trois Hêtres; MR= Mont Rigi). Legend: 1. No sedimentary record; 2. Gulpen/Maastricht facies deposits; 3. Kunrade facies deposits; 4. Zeven Wegen chalk; 5. Pre-Valkenburg facies deposits.

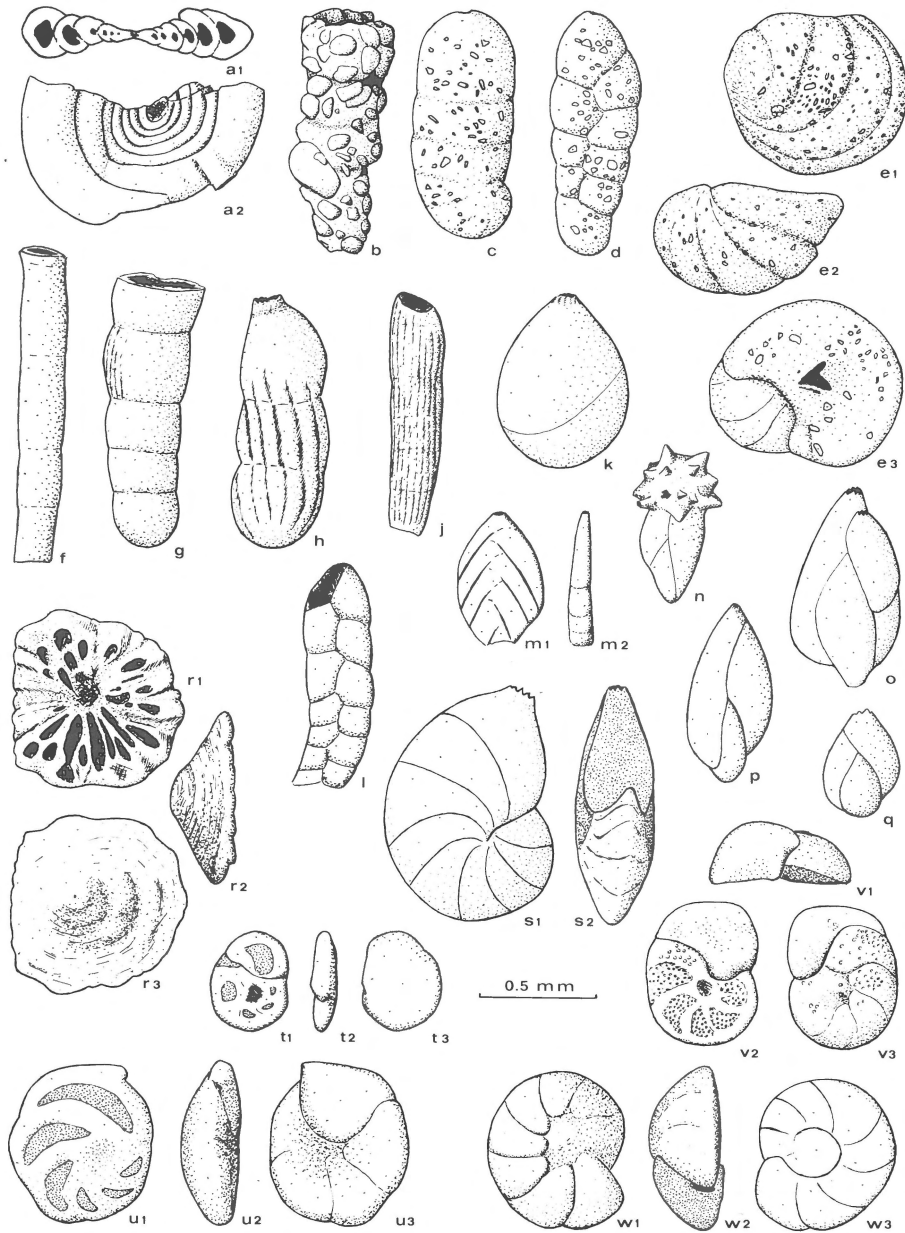


Fig. 5. Late Maastrichtian benthic forams from Molenbeersel borehole (Unit 2: 1278.05–1281.00m).

- a – *Ammodiscus* sp., 1280.45–1280.60 m
- b – *Reophax constrictus* (REUSS), 1280.45–1280.60 m
- c – *Orbignyna rimosa* (MARSSON), 1280.75–1281.00 m
- d – *Orbignyna frankei* (BROTZEN), 1280.75–1281.00 m
- e – *Ataxophragmium crassum* (ORBIGNY), 1280.75–1281.00 m
- f – *Nodosaria* sp., 1278.05–1278.55 m
- g–j – *Dentalina* gr. *proteus* (REUSS), respectively from 1278.05–1278.55 m, 1280.75–1281.00 m and 1280.75–1281.00 m
- k – *Globulina* cf. *globosa* (MUNSTER), 1280.75–1281.00 m
- l – *Bolivina firma* (HOFKER), 1278.05–1278.55 m
- m – *Polymorphina frondea* (KLINE), 1280.75–1281.00 m
- n – *Guttulina* sp., 1280.45–1280.60 m
- o – *Sigmorphina kunradensis* (HOFKER), 1280.75–1281.00 m
- p – *Sigmorphina soluta* (BROTZEN), 1278.05–1278.55 m
- q – *Sigmorphina* sp., 1278.05–1278.55 m
- r – *Cymbalopora radiata* (HAGENOW), 1278.05–1278.55 m
- s – *Lenticulina* sp., 1280.65–1280.75 m
- t – *Mississippina binkhorsti* (REUSS), small form, 1280.75–1281.00 m
- u – *Mississippina binkhorsti* (REUSS), small to medium form, 1278.05–1278.55 m
- v – *Cibicides* gr. *bosqueti* (REUSS), 1280.45–1280.50 m
- w – *Gavelinopsis involuta* (REUSS), 1280.45–1280.60 m.

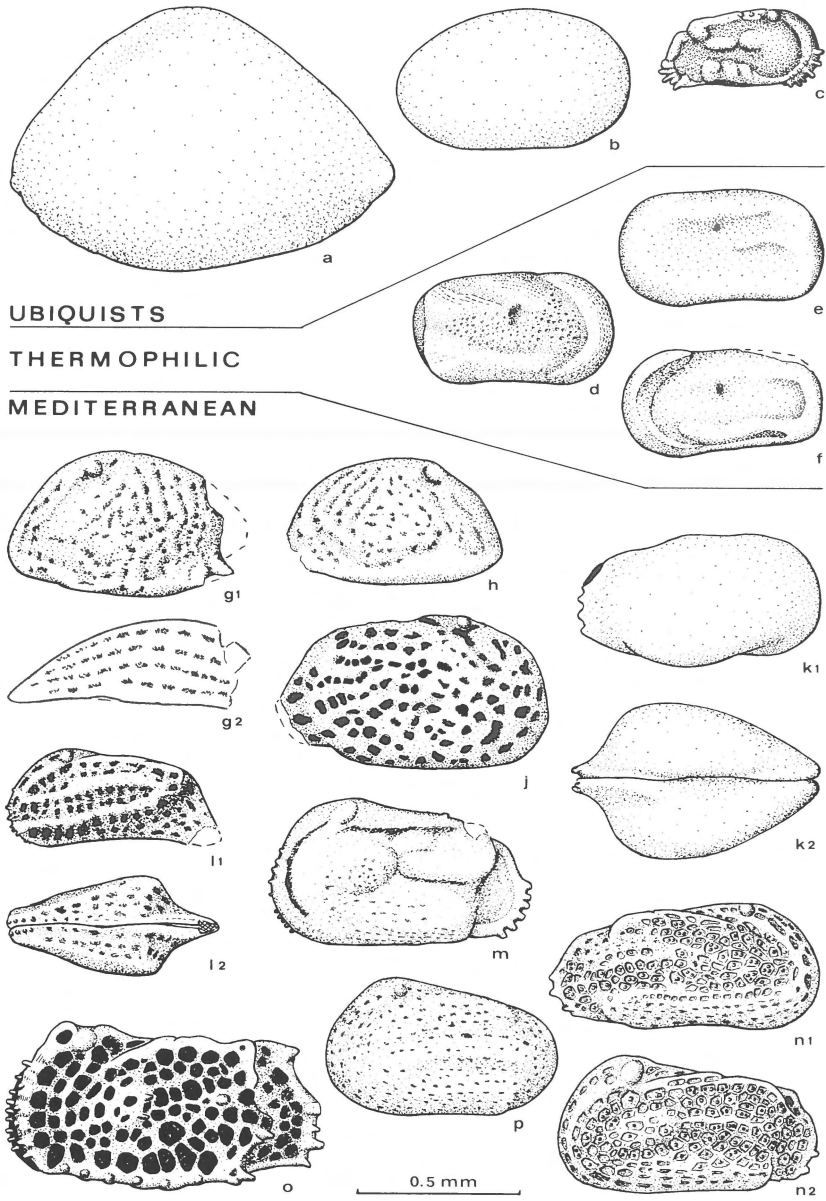


Fig. 6. Late Maastrichtian ostracodes from Molenbeersel borehole (Unit 2: 1278.05–1281.00 m). All specimens are from 1278.05–1278.55 m, except for specimens d (1280.75–1281.00 m) and k (1280.45–1280.60 m).

- a – *Bairdia* cf. *cingulata* (VAN VEEN)
- b – *Cytherella* gr. *ovata* (ROEMER)
- c – '*Curfsina*' *quadriscopinata* (DEROO)
- d – *Cytherelloidea* sp.
- e – *Cytherelloidea* cf. *binkhorsti* (VAN VEEN)
- f – *Cytherelloidea* gr. *levigata* (HERRIG)
- g–h–i – '*Brachycythere*' *emmae* (DEROO)
- j – *Spongicythere koninckiana* (BOSQUET)
- k – '*Semicytheretta*' *furcifera* (BOSQUET)
- l – '*Orinonina*' *sagittata* (BOSQUET)
- m – *Mauritsina* gr. *macrophthalmoidea* (VAN VEEN)
- n – *Imhotepia interruptoidea* (VAN VEEN)
- o – *Limburgina* gr. *ornata* (BOSQUET)
- p – *Mosaeleberis interrupta* (BOSQUET).

Unit 6 (1248.05–1243.00 m)

White calcarenite, consisting of an alternation between compact and more friable decimetre-thick beds, which is vaguely laminated in the upper part. The top is marked by an erosive contact. In the compact bands the porosity is reduced to 9.8% which is the lowest value measured in the cored section. The porosity in the friable beds is >21%. Rare bioclast accumulations (e.g. at 1243.95 m) yield macroscopically recognizable clasts of coralline algae.

In thin sections, the sediment consists of peloidal/bioclastic packstone/grainstone with a micritized hash of bioclasts (including algae, echinoids, forams, bryozoans and some unidentified solitary corals. The latter have been completely dissolved and replaced by blocky calcite).

Unit 7 (1243.00–1232.19 m in cored section; most likely continuing to 1230 m)

The unit starts with a thin, discontinuous layer of reworked clasts, overlain by a succession of sometimes slightly bituminous, massive bioclastic calcarenites to bioclastic calcilutites with abundant fragments of echinoderms, bryozoans, sponges and rhodophycean algae, rhodoliths (fairly concentric laminations of algal thalli; Plate 2D), and pseudo-

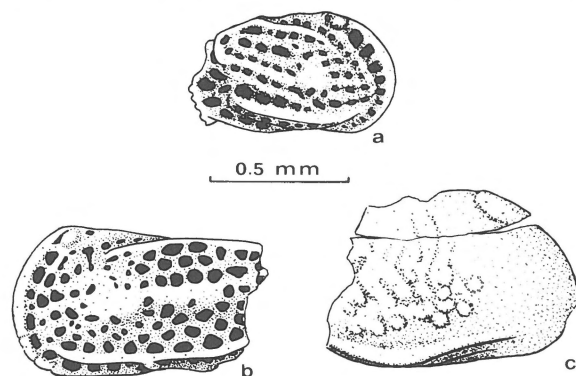


Fig. 7. Paleocene ostracodes from Molenbeersel borehole.

- a – *Limburgina mauritsi* (MARLIÈRE), 1237.72–1237.83 m, Montian, unit 7
- b – *Limburgina ornatoidela fissurata* (DEROO) ('forme géante' sensu Deroo, 1966, pl. 24, Fig. 734–736), 1252.93–1253.50 m; Danian, unit 5
- c – *Ruggieria pustulosa* (MARLIÈRE), 1252.93–1253.50 m; Danian, unit 5.

nodular chalk with bituminous interlayers. Locally, algal bindstones start to develop (e.g. 1236.65–1232.85 m). The bitumen present in this unit is thought to be primary. Solvent extracts are negligible in amount (TSE <0.003%). They are marginally mature and possess a relatively high wax content and low amounts of saturates (<26%) (pers. comm. B.P. Petroleum BV).

The coarse, rather friable, bioclastic calcarenites, near the top of the cored section show a remarkable porosity variation between 12.0% and 21.7%.

Microscopic examination showed that the massive calcarenites consist mainly of bioclastic grainstone to rudstone with rounded and abraded, micritized bioclasts (Plate 2D). The pseudonodular layers have a similar composition as the calcarenites. However, they are finer grained and have a pseudonodular aspect due to the bituminous interlayers. The algal bindstone intercalations are characterized by continuous, overlapping encrustations of coralline red algae (Plates 2E, 2F) with a complex morphology of chambers, pillars, ledges, lips and mushroom-shaped structures. Up to 4 cm-large concentric rhodoliths with irregularly oriented crusts of algal thalli and numerous constructional voids occur between 1236.75–1233.00 m. Cavities within the algal bindstones were partly filled with bioclastic gravel and partly cemented by rhombohedral fringing calcite and botryoidal cement (Swennen et al. 1993).

Cuttings from the non-cored overlying interval (1230–1223 m) present a similar overall lithology.

Stratigraphical interpretation

The stratigraphical interpretation of the 1283.17–1232.19 m interval is based on bio-/ecostratigraphical and eco-/lithostratigraphical criteria. In Table 1 the quantitative distribution of selected bioclasts (1–2.4 mm sieve fraction) is given. The various lithological units are characterized by distinct bioclast assemblages which reflect variations within the depositional environment. In spite of the shortcomings of this method, a best-fit correlation is proposed in Figs 3 and 4 between the lithological units

of the Molenbeersel borehole and the standard sequence for the Upper Cretaceous and Paleocene in S-Limburg (Felder et al. 1985).

Unit 1 (1283.17–1281.00 m)

Four samples of this unit have yielded rich dinoflagellate assemblages indicating a Late Maastrichtian age. Characteristic Campanian or Lower Maastrichtian dinoflagellates are absent. However, reworked palynomorphs from the Jurassic subsurface abound (H. Slimani, Gent, pers. comm.). The stratigraphical position of this unit (below unit 2 with fossils indicating the Upper Maastrichtian foram zone F/O) and the lithofacies (glauconitic quartz and feldspar-bearing calcarenite overlying a basal conglomerate) suggest a correlation with the upper part of the glauconitic deposits of the Pre-Valkenburg facies (clays, sands, marls and subordinate gravel beds) which border the southwestern flank of the Rur Valley Graben (Felder et al. 1985). The base of the Pre-Valkenburg facies is, however, of Campanian age (Fig. 2: foram zones A' and A). At least in the eastern part of the Belgian Campine Basin, which can be considered as the graben shoulder (Rossa 1987) (e.g. boreholes KS17, KS18; Felder et al. 1985), these deposits also include Lower Maastrichtian (foram zone B) and lower to middle Upper Maastrichtian (foram zones B-top, C–E) strata. The foregoing suggests that unit 1 has an age between Early to middle Late Maastrichtian. The absence of Lower/Upper Campanian and Lower Maastrichtian dinoflagellates indicates that the Rur Valley Block either was not flooded by the sea before the Early Maastrichtian or that strata of this age have been deposited and subsequently eroded.

Unit 2 (1281.00–1269.00 m)

As mentioned above, this unit can be split into three lithological subunits. Subunit 2a (1281.00–1277.40 m) yielded several rich and diverse assemblages of benthic forams and ostracodes. The forams (Fig. 5) characterize Hofker's (1966) foram zone F/O. Foram zone F marks the 'Craie grossière' or Lanaye Chalk in the Maastricht-Halembaye area (so-called Gulpen-Maastricht facies; cf. Bless et al. 1987), whereas foram zone O is typical of the Kun-

rade facies in the area bordering the Rur Valley Graben to the southwest. The correlation of foram zone O, as defined in the Kunrade type area, with foram zone F and the lower portion of foram zone H has recently been established by Felder & Bless (1989).

The ostracode fauna (Fig. 6) in this subunit is also characteristic of the Kunrade facies because of the predominance of *Mosaeleberis interrupta*, *Imhotepia interruptoidea* and '*Semicytheretta*' *furcifera*. The bioclast assemblages (Fig. 3) display a pronounced change from a bryozoan and mollusc/bryachiopod to an echinoderm-dominated fauna. This faunal turnover can be traced throughout S-Limburg and the Belgian Campine Basin and takes place halfway through the 'Craie grossière' or Lanaye Chalk (foram zone F, Felder et al. 1985, Bless et al. 1987).

Furthermore, the bryozoan peak (locally >25% of the studied bioclast-fraction) between 1281.00–1279.30 m can be correlated with the bryozoan peak near the base of the Kunrade facies (lower part of foram zone O) in the Kunrade area of S-Limburg (Felder & Bless 1989).

The flints of subunit 2b (1277.40–1275.60 m) are tentatively correlated with the major flint beds in the upper portion of the 'Craie grossière' or Lanaye Chalk in the Maastricht-Halembaye area whereas subunit 2a is assumed to be coeval with the lower portion of the Lanaye Chalk.

The alternation of calcisiltites, calcarenites and marls in subunit 2c (1275.60–1269.00 m) may represent a more nearshore equivalent of the alternation of hard and soft chalk of the 'Valkenburg facies' as observed in the Thermae 2002 borehole (60–90 m interval) at Valkenburg a/d Geul (Krings et al. 1987). This correlation is corroborated by the pronounced minimum in the fraction of bioclasts in the interval 1275.60–1269.00 m (<100 bioclasts/kg friable sediment) which is also apparent in thin sections. The distinct peak of serpulid (*Sclerostyla mosae*) clasts (54%) at 1269.27 m can be correlated with similar peaks in the upper part of foram zone J (= foram zone I in ENCI reference profile; Fig. 4) or with foram zone K (cf. Jäger 1987, Felder & Bless 1989). Because the 'Valkenburg facies' is elsewhere

restricted to foram zone J, a correlation of this serpulid peak with the upper part of foram zone J seems the most likely interpretation.

Unit 3 (1269.00–1263.40 m)

Fossil content in this unit is low. However, the presence of large (>1 mm) specimens of *Orbitoides* in the storm layer between 1263.60–1263.40 m indicates that this unit is either of the same age or younger than the latest Maastrichtian foram zones K-L-M. The serpulid layer around 1268 m fits in this correlation.

Unit 4 (1263.40–1256.67 m)

The fauna present in these calcarenites does not allow an age dating. However, reworked fragments of belemnite guards occur in the basal conglomerate of unit 5. Higher upwards in the sequence they are missing. As will be discussed below the unit 5 calcarenites are undoubtedly Paleocene in age. The reworked fragments at the base of this Paleocene succession are interpreted as an erosion product of Maastrichtian strata. Since a karst horizon marks the top of unit 4, just below the basal conglomerate of unit 5, it seems very likely that the underlying unit 4 calcarenites are of Late Maastrichtian age. The pronounced abundance of bivalve clasts (50% to 85%) between 1257.54–1256.67 m may be comparable to a similar abundance near the top of foram zone M described by Dusar et al. (1987) from a well situated 13.5 km S of Molenbeersel.

Unit 5 (1256.67–1248.05 m)

A poor nannoplankton assemblage at 1252.80 m contains, in addition to reworked Cretaceous coccoliths, *Cruciplacolithus* sp. which indicates an early Paleocene (Danian) age (E. Steurbaut, KBIN Brussel, pers. comm.). A small ostracode assemblage at 1253.50–1252.93 m includes fragments of *Ruggieria pustulosa* and the 'forme géante' of *Limburgina ornatoïdella fissurata* (Fig. 7b, c). These unmistakable species characterize the Danian 'Couches à *Cytherelloïdea*' of Marlière (1958; = Tuffeau de Ciply) in the Mons area (S-Belgium) and the Geulhem Chalk of the Curfs Quarry in S-Limburg (= foram zone P; cf. Deroo 1966, Bless 1988). The frequent occur-

rence of glauconite lumps and grains in this unit matches the lithology of the Geulhem Chalk (Felder 1988). Presumably, the various bryozoan, bivalve and serpulid peaks in this unit represent local variations in the depositional environment. Such peaks also occur elsewhere in the sediments of foram zone P (Dusar et al. 1987, Felder 1988), but their detailed correlation is still uncertain.

Unit 6 (1248.05–1243.00 m)

This unit has not yielded any information concerning its time-stratigraphical position. However, by inference it is provisionally correlated with foram zone Q of the Bunde Chalk, because it occurs between deposits interpreted as equivalent to foram zones P (unit 5) and R (unit 7).

Unit 7 (1243.00–1232.19 m in cored section; most likely continuing to 1230 m)

This unit is characterized by the frequent presence of the foraminifera *Valvulammina* and *Rotalia* (relatively large specimens), indicating foram zone R (Geleen Chalk). This correlation is confirmed by the presence of the ostracode *Limburgina mauritsi* at 1237.83–1237.72 m (Fig. 7a), which is typical of the 'Calcaire de Mons' ('Couches à *Triginglymus*') according to Marlière (1958), who also recognized this species in foram zone R in the –99 m to –120 m interval of the Maurits III shaft in S-Limburg. Notice that the algal/bryozoan/sponge bindstones in this interval are petrographically comparable to the 15 m-thick algal bindstones of the Montian in the Paris Basin (Marie 1964, Guillevin 1977). This seems to indicate that favourable conditions for the development of these coralline algal bindstones occurred on a regional scale during the Montian. The nannoplankton sample at 1239.12 m contains *Prinsius bisuleus*, appearing from nannozone NP4 onwards and thus confirming the Late Danian to Montian age (E. Steurbaut, KBIN Brussel, pers. comm.).

Depositional environment and regional correlations

The cored Upper Cretaceous-Paleocene carbonates of Molenbeersel presumably represent three megasequences, which can be distinguished also in the area along the southwestern border of the Rur Valley Graben in S-Limburg and the Belgian Campine Basin (Fig. 4). Each of these starts with a basal conglomerate (at 1283.17, 1281.00 and 1256.67 m) which is overlain by more or less glauconite-rich deposits passing into pure mostly grain-supported limestones in the Megasequences II and III (Fig. 3).

Presumably, the conglomerates represent intertidal strand deposits, from which other bioclasts were abraded and/or washed away. This suggestion is corroborated by the presence of fish bones, teeth and scales in and just above the basal conglomerates of Megasequences II and III.

Megasequence I (1283.17–1281.00 m)

This megasequence corresponds to unit 1 which probably has an age between Early to middle Late Maastrichtian (foram zones B, C–E) and which is lithologically comparable to the Pre-Valkenburg facies.

To the south and west (Antwerp Campine, Brabant Massif, Maastricht-Halembaye area and Hautes Fagnes) the Pre-Valkenburg facies is replaced by Lower Campanian clays and marls, by Upper Campanian, sometimes flint-bearing, calcilitites to calcisiltites of the Zeven Wegen facies (Bless et al. 1987) and by Lower and lower Upper Maastrichtian relatively pure (flint-bearing) chalk. The geographical distribution pattern of the siliciclastics suggests that the Rur Valley Block served as a major source area (cf. Fig. 4; Bless et al. 1987). This suggestion is further supported by the presence of spores and pollen which have been reworked from Jurassic to earlier Cretaceous deposits and which presently occur in unit 1 and in the Vaals Formation at Halembaye (Robaszynski et al. 1985).

The repeated presence of pebble and storm layers in the deposits of the Pre-Valkenburg facies of the Belgian Campine Basin and S-Limburg, as well

as the usually intensively micritized bioclasts point to a shallow subtidal environment, frequently above storm wave base. Storm wave base in modern seas like the 'Pre-Valkenburg' sea which are beyond the direct reach of the ocean, occurs at a mean depth of 30 m (Liebau 1980, 1984). The relatively frequent occurrence of fish remains which are common in deposits of the Pre-Valkenburg facies (with teeth fragments also occurring in unit 1), indicates a nearshore environment.

Megasequence II (1281.00–1256.67 m)

This comprises the lithological units 2 to 4. It correlates with foram zones F–J/O (deposits of the middle Upper Maastrichtian Kunrade facies) and K–L–M (uppermost Maastrichtian; sometimes also considered as foram zone O, but here consistently indicated as K–L–M). This megasequence thus correlates with the Maastricht Formation. The Kunrade facies (foram zone O) sensu stricto is distinguished from the typical Gulpen/Maastricht facies (foram zone F and lower H or J) by the alternation of soft chalk with hard intensively cemented chalk layers, and by the occasional occurrence of flints. The latter are common in the Maastricht-Halembaye area.

Moreover, typical 'mediterranean' microfossils (forams, ostracodes) are more common in the Kunrade facies, possibly because of a shallower and therefore warmer environment (Bless et al. 1987, Bless 1989). The ostracode faunas of subunit 2a contain several species of the thermophilic genus *Cytherelloidea* as well as a number of 'mediterranean' immigrants which presumably preferred relatively warm water (Fig. 6). Many of these 'mediterranean' species possess well-developed eye tubercles ('*Brachycythere*', *Spongicythere*, '*Cythereis*', '*Orionina*', *Limburgina*, *Imhotepia*, *Mosaeleberis*, *Mauritsina*), just as some of the ubiquitous ('*Curfsina*'). This suggests a well lighted sea floor (cf. Kontrovitz & Myers 1988, Puckett 1990). Finally it is noted that genera like *Alatacythere* and *Pterygocythereis* are absent. In addition, the presence of many micritized bioclasts indicates deposition in a subtidal environment above storm wave base for subunit 2a.

The base of Megasequence II thus coincides with the onset of an important immigration of thermophilic organisms from the Tethys (Bless et al. 1987). This coincidence has been explained by the assumption that the Rur Valley Block (inverted since the Early Campanian) acted as a physical barrier to warm-water currents from the Tethys until the beginning of foram zone F/O, when tectonic relaxation allowed these currents to flow freely northward over the Rur Valley Block (Bless 1989) and thus across the Molenbeersel area. Because of the inversion of the Rur Valley Block, the SE Netherlands and NE Belgium remained under the influence of the Boreal realm during the Campanian to early Late Maastrichtian.

The composition of the ostracode and benthic foram assemblages of subunit 2a and the frequent presence of fish remains (teeth and bones) and phosphate grains closely resemble those of other Late Cretaceous glauconitic clays and marls, such as the Santonian Ems Greensand in the German Münsterland or the Early Campanian Vaals Greensand in S-Limburg (Bless & Robaszynski 1988). The only difference is the presence of 'mediterranean' immigrants in subunit 2a while the foram-ostracode assemblage of the Ems and Vaals greensands is exclusively 'boreal' or cosmopolitan. In the Molenbeersel, Vaals and Ems cases, the glauconitic clays and marls occur in a transgressive succession between a basal conglomerate and more or less pure carbonates. This succession matches the Holocene succession of glauconitic siliciclastics and coccolith-rich carbonates in the Belize Lagoon (eastern coast of Central America; Simien 1987). By comparison, the glauconitic calcisiltites and marls of subunit 2a suggest deposition on a shallow nearshore shelf (perhaps less than 40 m deep according to the example of the Belize Lagoon).

From subunit 2c onwards the presence of higher amounts of micritized bioclasts could reflect a slightly shallowing water depth. This hypothesis is also supported by the occurrence of large orbitoid foraminifera at the top of unit 3, suggesting epineritic (infralittoral to mediolittoral) conditions (Liebau 1984). The karstified hardground at the top of Megasequence II points to a temporary emergence

of the area at the Cretaceous/Tertiary boundary (Fig. 3).

Megasequence III (1256.67–1232.19 m; most likely continuing to 1230 m, possibly to 1223 m)

This megasequence comprises the lithological units 5 to 7, is of Dano-Montian age (foram zones P to R) and corresponds to the Houthem Formation. It starts with a basal conglomerate with frequent clasts of belemnites, fish remains (teeth, bones) and phosphate grains suggesting deposition in a near-shore environment.

Unit 5 reflects a repeated change from shallow subtidal to intertidal conditions and temporary emergence. This is indicated by the relative abundance of micritized bioclasts or peloids and several karstified erosion levels. The more massive calcarenites of unit 6 testify to uniform subtidal conditions. Finally, the algal/bryozoan/sponge-rich bindstones of unit 7 point to a shallow subtidal environment with rather calm marine conditions at a water depth of 10–40 m (Guillemin 1977, Bosence 1985). The existence of such a depositional setting is also supported by the presence of rhodoliths which according to Toomey (1985) develop in relatively shallow waters well within the photic zone. The intercalated layers with algal debris indicate periods of high energy (subtidal conditions above storm wave base, or perhaps intertidal facies). Also the frequent occurrence of large (>1 mm) foraminifera, including *Valvulamina* and *Rotalia* in unit 7 points to a shallow environment (lagoonal, upper sublittoral; cf. Liebau 1984, Luterbacher 1984). Based on similar lithological aspects of the cuttings, the uppermost non-cored carbonate unit (1230–1223 m) probably represents a similar depositional environment. This unit is covered by lagoonal deposits of Paleocene age.

Thus, Megasequence III reflects a slightly deepening and subsequently shallowing cycle. The fossils reflect a boreal influence.

Conclusions

The Upper Cretaceous to Paleocene carbonate suc-

cession of the Molenbeersel borehole testifies to the repeated flooding of the Rur Valley Block during the period of tectonic inversion. Three megasequences, which correlated with much thicker successions in the area along the southwestern border of the Rur Valley Graben, are distinguished.

The lower, Megasequence I in Molenbeersel is interpreted as Early to middle Late Maastrichtian in age. The abundance of reworked lithoclasts and detrital quartz, as well as the usually intensively micritized bioclasts in this glauconitic calcarenite interval point to a shallow nearshore, subtidal environment above the storm wave base. This megasequence is interpreted to correlate with the upper part of the Pre-Valkenburg facies of the adjoining Belgian Campine Basin.

Megasequence II is of (middle to late) Late Maastrichtian age. Deposition occurred in a shallow subtidal, sometimes high-energy environment within the photic zone and in relatively warmer water. The gradual upward decrease in the glauconite and detrital quartz content and in the number of clay/organic-rich intercalations in this predominantly grain-supported sequence is here interpreted as characteristic for the transition from nearshore (submerged littoral) to more open marine conditions, which also occurs in Late Cretaceous successions in adjacent areas and in the Holocene Belize lagoon. The karstified erosive top of this megasequence (at 1256.67m) marks a temporary emergence of the area, possibly caused by active inversion after a period of tectonic relaxation. This relaxation period coincided with an immigration of 'mediterranean' organisms.

Megasequence III is of Paleocene (Dano-Montian) age. Initially, the area was repeatedly emerged, as is confirmed by various karstified horizons. Subsequently, a slight deepening of the environment is indicated by massive, homogeneous bioclastic grainstones. Finally, crustose coralline algal limestones (bindstones), intercalated by pseudonodular chalk with bituminous interlayers, testify to renewed shallow subtidal (perhaps sometimes even intertidal) conditions. Its fauna again is boreal.

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